INFORMATION PROCESSING
AND
TIME-SHARING

A thesis submitted for the degree of
Doctor of Philosophy

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July 1975

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To my late father-in-law, Doron Ariely

SUMMARY

A model of human information processing is put forward and then tested in time-sharing situations.

The proposed model has a hierarchical structure of specializing functions. The low level functions specialize in quick and simple processing of a relatively large number of signals, with few degrees of freedom. Along the hierarchical scale, the nature of the operation is gradually changed from physical based to meaningful based. The high level functions specialize in complex, slow processing of a limited number of signals, and also in the control and co-ordination of lower level functions. Their operations are flexible with many degrees of freedom.

The characteristics and dynamics of the model are listed and discussed. The topics covered include selection and filtering of signals; inter-dependency of functions; flexibility of pathways; learning and practice; the influence of load, and time-shared performance.

The model identifies two extreme time-sharing situations: successive and simultaneous, and two main features of tasks: sense modality (the sense they stimulate) and transformation (the set of operations demanded for making a decision).

In successive time-sharing, the main dependent variable is the time consumed by the sharing process.

In the first experiment 18 subjects performed alternately two tasks with varying lengths of task series. It was found that reaction time (RT) to the first stimulus was significantly longer than RT to the rest of the stimuli in that series. The longer the series the bigger was the difference between RT to the first stimulus and the mean RT to the rest of that series.

In the second experiment 12 subjects performed alternately two either compatible or incompatible tasks. The RTs to the first stimuli in the series in the incompatible condition were significantly longer than the RTs to the first stimuli in the compatible condition. However, the estimation of magnitude of experimental effect ($\hat{\omega}^2$), was very small.

In the third experiment four groups of 6 subjects performed alternately two tasks in each of the four combinations of same and different transformations and sense modalities. It was found that it takes longer to time-share between different, rather than same transformations, as well as sense modalities. Time-sharing is more influenced by the type of transformation than by the type of sense modality.

In the fourth experiment 5 subjects performed five RT tasks either individually or simultaneously with a shadowing task. There is a significant deterioration between shared and individual performances, when both tasks stimulate the same, but not different sense modalities.

The type of stimuli has no impact on this deterioration, but the type of transformation has.

The deterioration due to simultaneous stimulation of the same sense modality is the same regardless of the types of stimuli and transformation.

Successive time-sharing does not cause more human errors, whilst simultaneous does.

The findings of these experiments support the assumptions of the model. These and other experiments, as well as other theories were explained and classified in terms of the hierarchical model.

ACKNOWLEDGEMENTS

I would like to express my grateful thanks to Professor W T Singleton, Head of the Department of Applied Psychology, and to Mr D Whitfield, Head of the Ergonomics Development Group in the same department, for their valuable advice, encouragement and constructive criticism.

I have drawn confidence from my discussion with Professor N Moray of the University of Stirling and from the comments of Dr R Davies of The University of Aston in Birmingham.

My thanks also go to Mr L Bagnall for his technical ingenuity in setting the apparatus for the experiments and to Mrs C Maddison for having been such a skilled and efficient typist. Also many thanks to the students who participated as subjects in the experiments.

Last, but by no means least, my grateful thanks to my wife for her unlimited assistance, faith and encouragement.

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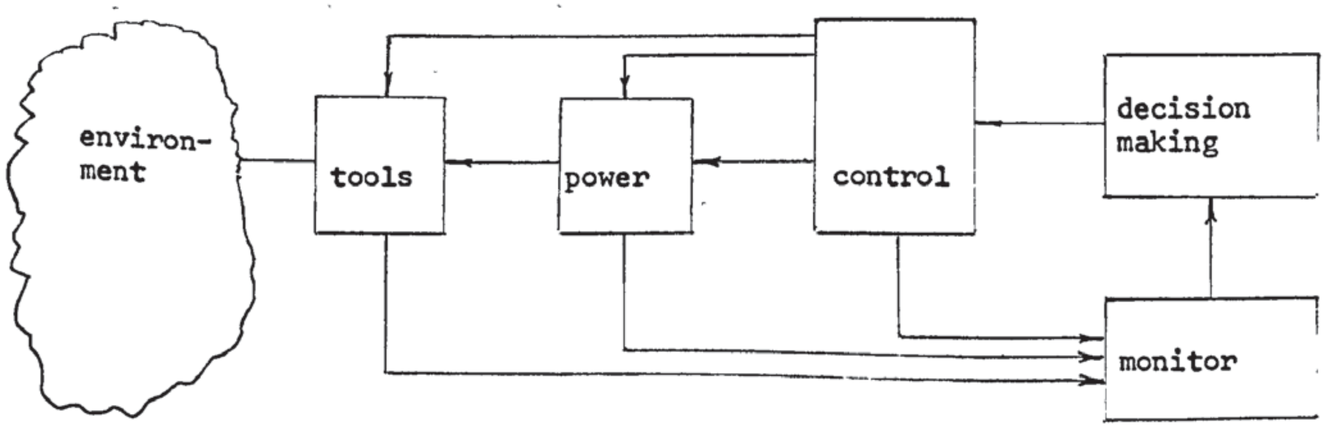
1.0 INTRODUCTION

1.1 Human time-sharing - its theoretical importance

Through the evolution of technology, the role of man, as a component in any productive system has undergone great changes. He has transferred most of the overt activity functions to the hardware components of the system and has retained the covert aspects. Figure 1.1.1 represents the various aspects of the system contributed by the man and the machine. Many years ago man started to employ tools rather than his bare hands, then he began to use external power to activate the system, rather than his own physical force, and eventually transferred to the machine most of the control functions. With increasing automation he even gave up most of the decision making functions and was left mainly with a monitor task. At the same time, the system as a whole became more and more complex and man's task as a monitor and as a decision maker, became more difficult and more crucial. As a result, man has an increasingly great variety of tasks to perform and an increasing number of monitoring activities to cope with. Whitfield (1967) suggested to take a broader view of human performance in systems.

Figure 1.1.1 Aspects of the working system



1.1 (Continued)

Since there is a variety of monitoring and controlling tasks to be performed, the operator spends a great deal of his time, not only in performing these tasks, but also in switching from one task to another.

Operational researchers have long recognized that the time which is consumed on performing any task, is composed of two main factors:

1) 'set-up time', the time needed to prepare all the necessary equipment, tools, devices and personnel needed for a successful execution of the task.

2) 'performance time', the time needed to actually perform the task.

This categorization ignores various pauses in performance, such as rest periods and maintenance time. There is not always a correlation between the two times: a relatively short 'set-up time' does not necessarily indicate a short 'performance time', and a long set-up time could very well be followed by a short performance time. Therefore, there is a justification in studying set-up activities as such, independently from the much studied performance activities.

The operator's switching activity is associated with the set-up activity, because each time he switches to monitoring and controlling a new task, he has to set-up all the equipment, tools, etc. necessary to perform the new task. Since he is more and more engaged in switching between tasks he is also more and more engaged in setting up activities.

The set up activity can be divided into two main components:

a) a physical set-up

b) a mental set-up

1.1 (Continued)

The physical set-up includes all the gathering of equipment, tools, etc. needed to perform the task. It also includes the operator's own physical movements, so that he will be stationed in the right position, and his eyes, limbs, etc. will be appropriately co-ordinated.

The time consumed on the physical set-up activities depends on the spatial arrangement of the environment and on the amount of training the operator had in performing all the necessary movements. However, it has already been stated that the operator has less and less overt activities to perform. In other words there are less and less physical set-up activities. There are almost always minor physical adjustments to be done, such as switching knobs, pushing buttons or eye movements, but the bulk of physical activity is diminuating.

This account by no means undermines the importance and the time consumed on such activities. For example, Gabriel and Burrows (1968) argue that aircraft pilots are so busy monitoring instruments, reading maps or charts, changing their radio frequencies, etc., that they have less and less time to devote to extra cockpit cues. These cues are said to be extremely important in preventing mid-air collisions between aircrafts. They stress the physical operations such as: accommodating the eyes from distant to near vision, dark or light adaption, moving the eyes to the appropriate area, reading instruments, moving the eyes to return to the outside environment, re-accommodation and re-adapt to light conditions. Re-training pilots to minimize the frequency of eyes transition will minimize the time spent in eye movements, limb movements etc., and thus maximize the amount of time that visual information could

1.1 (Continued)

be acquired. A comparison of such a trained group with a control group in a highly specific and complex simulated flying task, showed that hazard detection (such as collision) was improved significantly without compromising other flying tasks.

The decrease in the time consumed on the physical set-up is accompanied by an increase in the time consumed on the mental set-up. Broadly speaking, the mental set-up includes all the necessary 'mental preparations' to bring the operator to a 'state of mind' where he is able to start performing the new task.

Mental preparations, shifting the mental gears, and the right 'state of mind', mainly indicate the shifting of attention from one task to another, the allocation of capacity in the central information processor to process the new type of signals, and the various types of load imposed on the operator in such situations. Since this thesis looks into the various aspects of mental set-up and examines its influence on performance, the rather vague statements made here will hopefully become less vague later on.

The operator's need to switch from one type of activity to another type is sometimes defined as time-sharing. For example Gabriel and Burrows (1968) define time-sharing as 'the method or requirement of alternating attention between two or more sources of information'. On the other hand Singleton (1974 p.166) defines time-sharing as a 'situation in which an operator is simultaneously engaged in more than one task'. It may seem at first that the two definitions are incompatible in so far as the first definition speaks about <u>alternating</u> attention (the writer

1.1 (Continued)

thinks that a different word which indicates task performance rather than mere attention would give this definition a more complete meaning) while the second definition speaks about simultaneous engagement. In fact they are not incompatible but complementary: one speaks about serial engagement and the other about parallel engagement. Indeed both types of engagements exist, as different aspects of time-sharing.

Singleton (personal communication) argues that his definition of 'simultaneous' includes serial as well as parallel engagements. According to his concepts the term 'simultaneous' used in this thesis has the connotation of 'instantaneous'.

The writer prefers to define time-sharing as: 'the sharing of a given period of time between two or more types of activities'. Although this thesis is mainly concerned with overt time-sharing, this definition also provides for covert activities such as the need to time-share between encoding of signals and decoding of responses. According to this definition of sharing, time is of great importance in determining whether sharing activities did or did not take place. Indeed a long period of time, for example twenty four hours, might be shared between many different activities, while a relatively short period of time, for instance one minute, might be spent on one type of activity only.

According to the above definition, time is shared between performances and thus the need to time-share means also a need to switch the attention from one task to another, or a need to divide the attention simultaneously between two or more sources of information. It also means either pro-

1.1 (Continued)

cessing two different sets of signals simultaneously, or processing them in alternation. Finally, time-sharing also includes the ability to perform two responses in parallel, or the ability to perform them in serial order, one after the other.

All this indicates that a systematic investigation of time-shared performance, has not only an applied value, but also a very important theoretical value. Theoretical findings concerning time-sharing, can not only throw new light on attention or information processing, but can also have a further general implication to various applied situations.

1.2 The aim of the study

This study aims to gain further understanding of how the human information processing system operates in time-sharing situations.

There are two main aspects to the study:

1) The development of a comprehensive theory concerning the human information processing system.

2) The estimation of the influence of various factors, derived from the theory, on the human ability to perform:

   a) successive time-sharing

   b) simultaneous time-sharing

The theory which is formulated in the first part of the study is then tested for its ability to predict a) 'backwards' - (i.e. by explaining the finding of other experiments) and b) 'forwards' - by the ability to predict the outcome of the experiments carried out as part of this study. Some aspects of the theory are based on other investigators' experiments and some of its aspects are left for future investigations.

Since the proposed theory is a theory of attention, the literature survey contains theories and experimentations from this area. All the experiments carried out in this study are choice reaction time (CRT) experiments, and therefore part of the literature survey covers this area. As successive time-sharing indicates a serial presentation of stimuli, some room is also allocated to the analysis of the psychological refractory period. The theoretical model developed here advocates that various 'mental loads' are imposed on the operator while he is time-sharing, and therefore the literature survey also

1.2 (Continued)

includes theories and findings from this area of research. Finally, some of the findings are presented alongside the development of the theory. In some cases the writer took upon himself the liberty to reinterpret the findings or to label them with the terms developed here.

1.3 Literature survey

1.3.1 Attention

1.3.1.1 A general outline of theories of attention

At the end of the nineteenth century and the beginning of the twentieth century there were many debates with respect to attention. The arguments then were not only about the importance of the study of attention (Pillsbury (1910)) through introspection, but also about the question whether attention is unitary or divisible. To-day, in the last quarter of the twentieth century, the research techniques have changed and developed, but the question still remains unanswered.

Broadly speaking, there are two schools of thought with regard to attention:

1) Attention can be paid only to one object or event at a time.
2) Attention can be paid to several objects or events at the same time.

1) The first approach has its roots in the theory that the human perceptual processing system is composed of a single channel mechanism. At any given moment there is only one signal which passes through the system. Since we have the possibility to direct our attention to a vast number of objects and events, there ought to be a many-to-one conversion somewhere along the processing system. Each object or event is perceived through a particular channel. All the channels are converged in a selection switch which converts the

1.3.1.1 (Continued)

parallel incoming signals into a single queue of outgoing signals.

Most debates among the theorists of this school are about:

a) the location of the selection switch

b) the nature of its operation.

Currently there are three major theories advocating strict serial processing of information: Broadbent's 'Filter' theory (Broadbent (1958, 1970, 1971)), Treisman's 'Filter Attenuation' theory (Treisman (1960, 1964d)), and the theory of Deutsch and Deutsch (1963).

According to Broadbent the filter is located in the periphery of the system and the selection of relevant from irrelevant stimuli is based on clear physical distinctions between the stimuli. The filter performs one simple operation, similar to an electric selection switch.

According to Treisman the operation of the filter is not all-or-nothing, but rather an attenuation of the irrelevant message. In a later development of her theory (Treisman (1969)) concluded that divided attention and parallel processing are possible for two simultaneous inputs, but only if they do not reach the same analyser. She placed the filter much higher along the processing system than Broadbent did.

Deutsch and Deutsch's theory locates the transition from parallel to serial processing (i.e. the filter) closer to the ultimate response than to the two previous theories. The selection of stimuli is mainly based on their importance, at any given moment the most important

1.3.1.1 (Continued)

stimulus is attended to.

Only a short account of the models is given here. A more detailed description and evaluating comments of these and other theories are given at a later stage in the thesis.

2) The second approach to attention is based on the theory that the human perceptual processing system is composed of a multi-channel mechanism. The term 'channel' is used mainly to indicate the arrival of stimulation in parallel and not to indicate limitations. The signals arrive in parallel and are processed simultaneously. The limitation of attention lies in the limited capacity of the central processor, because a limited amount of processing ability has to be shared among all the incoming messages. The process of conducting the sharing policy also consumes some of the information processing capacity. Taylor et al. (1967) have demonstrated that in simultaneous discrimination tasks, the time-sharing requirement used about 15% of the available capacity. They suggested that the capacity could be measured by determining the detectability, d's of a signal when presented alone, and its detectability, d'm when another task is being performed at the same time. "The processor capacity devoted to the task in the shared environment is $d'm^2/d's^2$ times the capacity used for the single task alone". In their experiments they found that the sharing index, the sum of the sharing ratios $d'm^2/d's^2$, was 0.85 in all cases. It was suggested that the remaining 15% of the capacity was employed in the programming required to monitor the sharing procedure.

1.3.1.1 (Continued)

Most investigators in this area (Miller, Galanter and Pribran (1960); Posner and Rossman (1965); Baddeley (1966); Moray (1967); Egeth (1967); Triggs (1969); Hunt (1971); Kahneman (1973) and others) derive their approach from the computing systems. Sometimes the computing system serves as a direct simulation of the human information processing (Hunt (1971)). Sometimes it only serves as a general analogy (Moray (1967)) and sometimes it is only a vague frame of reference.

Other types of theories have also been put forward. For example, Allport et al. (1972) suggests that a more appropriate model would be that of a number of independent, special purpose computers operating in parallel and capable of accepting only one message for processing at a time. They refer to their model as a multi-channel hypothesis.

The type of theories of attention and the way in which they were developed was criticized by many authors, including those who have contributed to the development of these theories. They have been said to be either vague, verbal, comprehensive and almost untestable (e.g. Hebb (1949)), or precise, mathematical, testable and so restricted in their application that they are almost trivial (e.g. Howarth and Bloomfield (1969)).

Moray (1969b) considered that the terminology relating to attention is "at best confused and at worst a mess". Howarth and Bloomfield (1971) claimed that "there has been little cross-referencing between the literatures of selective attention, visual search and information

1.3.1.1 (Continued)

processing, in spite of their theoretical and experimental similarities". They argued that no-one has managed to devise an adequate experimental test to distinguish between the 'traditional' models proposed by Broadbent, Treisman, Deutsch and Deutsch, Moray and so on. Even theories of memory, (e.g. Sperling (1967); Norman and Rummelhart (1970)) or of language (Morton (1969a)) which should be capable of explaining some attentional phenomena, do not propose a clear way to distinguish between themselves experimentally. In spite of their seeming precision, it is difficult to reduce the model to analytical equations.

The standing of the theories of information processing is similar. For example, Egeth (1966) has pointed out that the comparisons of items may be exhaustive (i.e. requiring all dimensions to be analysed before a response is made) or self-determinating (i.e. a response being made as soon as a difference or similarity is noticed). In serial models, the comparison may be made in a fixed or in a varied order. In both serial and parallel models, the time required to make a single comparison may be constant or may fluctuate.

Neisser (1967) proposed a hierarchical theory which involves parallel processes at a first 'pre-attentive' stage and serial processes at a second 'focal attention' stage. Although Neisser's approach may increase the theoretical complexity still further, it points at least in a way to synthesize the two apparently conflicting approaches.

To summarize, until quite recently the two main schools of thought with regard to attention seemed unbridgeable. The one advocates strictly serial processing of information while the other claims that such

1.3.1.1 (Continued)

processing takes the form of parallel and in some cases even independent operations. Lately, broader and more integrated approaches have arisen and the two conflicting ways of thinking seem to merge.

1.3.1.2 Experimental findings on attention

The diversity and multitude of experiments in the area of divided attention are too large to be contained in this study alone. Some of the findings are directly related to the theory and model developed in this thesis, and therefore are discussed in their appropriate context later on. Others, which throw light on the general experimental approaches in this field of research, are discussed here, as connected with the theories and models which were described earlier in this chapter.

1.3.1.2.1 Auditory selection

Speech shadowing - the technique of asking a listener to repeat aloud a continuous message while hearing it, was first used in attentional experiments in 1953. Two papers, one by Cherry, and one by Poulton, mark the beginning of this technique.

Cherry's subjects had to repeat a message heard through one ear and ignore a distracting message played to the other ear. He found that his listeners could report the semantic content of the shadowed message, but knew very little about the other message. They were able to say whether it had been speech or some other kind of signal, whether in a

1.3.1.2.1 (Continued)

man's or woman's voice, sometimes even whether it was a list of words or continuous speech, but they could not report the content. The language of the message could change from English to French to German to Latin, even to reversed English, and still they would not notice. This seemed to be a powerful way to block the listeners' attention and make them aware to what then was called the 'general physical characteristics' of the message. Poulton's results were not as dramatic. His subjects only managed to shadow approximations to the real message and they tended to use spoken jargon instead of the proper words.

Cherry (1953); Cherry and Taylor (1954) established that the presence of a distracting message barely impairs shadowing performance when the rejected and attended messages are distinguished by an obvious physical characteristic, such as spatial origin. Spatial position is the most effective attribute for identifying the selected message. It is relatively easy to attend to a position, whether with auditory stimuli (e.g. Poulton (1953); Spieth, Curtis and Webster (1954); Treisman (1964b)) either real or apparent (Broadbent (1954)), in frequency range (Spieth and Webster (1955)), in intensity (Egan, Carterette and Thwing (1954)) and in tachistoscopic visual presentation (Sperling (1960)).

In a different type of experiment, subjects were asked to listen to two messages at once. It appears that most investigators agreed that increase in the amount of information presented caused a relative decline in efficiency. Thus Webster and Thompson (1954) found that the greater the amount of overlap between two messages the lower was the relative efficiency. Their results also seemed to imply that messages conveying

1.3.1.2.1 (Continued)

little information may be dealt with simultaneously, while those containing much information may not.

Poulton (1956) also found a drop in relative efficiency when two relevant messages arrived simultaneously, as compared with isolated messages or with the simultaneous arrival of relevant and irrelevant messages. The chief source of error was mixing up of digits from one message with those from the other, which is different to errors due to sensory masking. Poulton varied the spatial arrangement of the loudspeakers which delivered his messages, but he could find no differences in performance due to the different conditions. Webster and Thompson similarly found little effect of the spatial arrangement. They did, however, find that the louder of two unequal messages was more likely to be heard correctly. This effect was confirmed by Tolhurst and Peters (1956), for the case in which one message is on one ear and the other on the second ear.

Broadbent (1954) presented pairs of messages simultaneously, only one of each pair requiring an answer. Spatial separation of loudspeakers was a help and so also was stereophonic separation. Stereophonic reproduction through headphones was superior to a conventional mixture of voices. A split headphone with one ear on each channel was inferior to a pair of loudspeakers. Webster and Solomon (1955) presented groups of up to four simultaneous messages, with instructions to some subjects only to answer one of them, while other subjects had to answer two. A split headphone was superior to the conventional type even when filtering was introduced.

1.3.1.2.1 (Continued)

Spatial position is not the only physical variable which has been shown to affect the central process of picking out one set of sounds for response. Egan, Carterette and Thwing (1954) examined the effect of band-pass filtering when listening to one voice in the presence of another. A high-pass filter put in the channel which was to be ignored, improved the performance. Lower cut-off frequencies, which allowed more of the natural components of the voice to pass, seemed less advantageous. The authors interpreted the different results by saying that the listener, in order to separate wanted and unwanted speech, may use the differences in loudness and pitch as well as the spatial position.

Spieth, Curtis and Webster (1954) found that if one of the competing channels was passed through a high or low-pass filter, and it made no difference which filter was used, there was an improvement in performance. A condition of high-pass filter in one channel together with a low-pass in the other gave the best results. They also noted that the correct message of a pair had a better chance of producing a response if the pair of messages was not exactly synchronous. Two of the above authors, Spieth and Webster (1955) carried out further research on the effect of various degrees of messages filtering on perception.

Welford (1968) reports studies done by Peters in 1954 which showed that unwanted speech which is similar in content to the wanted message produces greater difficulty than does a dissimilar background. He also found that if an unwanted message is followed by a wanted message, the latter one is not very likely to be correctly heard. A few years later

1.3.1.2.1 (Continued)

(1959) Moray demonstrated another effect: a listener is more likely to follow instructions in the irrelevant message, if it follows after a message which contains his name, than if it follows after a message which does not contain his name. The finding can be interpreted as complementing each other: a message - even an irrelevant one which appears in an irrelevant channel - is likely to be attended to if attention has recently been paid to that channel (due to calling ones own name); however, a message - even a relevant one - is not likely to be attended to if attention has not recently been paid to that channel.

All the experiments mentioned up till now involved only listening or shadowing. In the same period of time, Mowbray carried out a group of experiments (1952, 1953, 1954) which dealt with the question of listening while also receiving visual information. In his first set of results, Mowbray required subjects to detect missing items either from the alphabet or from the series of the first twenty numbers. There was an increase in the number of errors when both sequences were presented simultaneously, one visually and one auditorily. The numerals were easier than the alphabet, but they were more affected when both sequences were presented simultaneously. This applied to whichever sense received the particular type of material.

In his second experiment, Mowbray used prose passages of various levels of difficulty as assessed by a 'Flesch count' (Flesch (1948)). He found that the easier passages were the most affected when given with more difficult ones. It seems that the less well comprehended passage was ignored, (the mean of the scores was only at the chance level, while

1.3.1.2.1 (Continued)

some information was gathered from the other). He also found that the performance of two tasks at once is to some extent possible if the rate of arrival of information for each is low.

In the last experiment, Mowbray concluded that successful division of attention did not occur. Once again, the material on one channel was assimilated while that on the other channel was discarded. He delivered the items always in pairs, one to each sense. This technique makes the alternation of attention even more difficult than in the previous experiment.

The content of messages was also studied in the condition of two auditory stimulations. Already in 1953, Cherry showed that subjects can use the contextual probabilities of words to pick out one of two messages in the absence of any other cue. However, this type of selection is much less efficient than that based on general physical features, for Cherry's subjects needed many trials to separate the two messages completely.

Moray (1959) confirmed Cherry's finding with regard to the efficiency of the block for the content of the rejected message. However, there were certain defects in the design of his experiment, and also a thirty second delay between the end of shadowing and the start of a recognition test. Moray (1958) demonstrated that making the rejected message louder did not have any striking effect on its reception. His findings were compatible with the data on dichotic interference reported by Egan et al. (1954).

1.3.1.2.1 (Continued)

Treisman (1964d) reports that in her thesis for D. Phil. degree (1961), she employed bilingual subjects and presented them with two messages in different languages. They were hardly more efficient in translating one of the two than when both were in the same language. In another of her experiments she had subjects shadow a message which was coming over one headphone while ignoring another message coming over the other headphone. They also had to react upon hearing a digit in either ear. In fact, they responded only to digits from the selected message, even though digits appeared equally often in the two messages.

On the basis of the studies by Cherry, Moray and Treisman cited above, Egeth (1967) concluded that the semantic content of rejected messages has little, if any, behavioural effect. However, when a word in the rejected message was very probable in the context of the relevant message, the subjects often reported it (Treisman (1960)). Subjects' brain waves also showed large potentials, when a subject's name was played over a tape-recorder while he was in deep sleep. These potentials were smaller when the name of other subjects were played back. Moray's subjects (1959) sometimes noticed their own name if these occurred in the irrelevant message. Howarth and Ellis (1961), based on Moray's (1959) findings, measured the detectability of a listener's own name and other names when masked by white noise, and found a lower threshold for a listener's own name. After analysing quantitatively their results and those obtained by Oswald et al. (1960) and Moray, they concluded that probably the same mechanism was activated in all the three cases. This is a very important conclusion since some of the data were obtained from dichotic listening and some

1.3.1.2.1 (Continued)

during sleep.

Cherry (1953) showed that if identical messages were presented to the two ears a few seconds out of step, subjects became aware that the two were the same. Gray and Wedderburn (1960) found that when speech was delivered to subjects in both ears simultaneously, such that a meaningful sequence could be formed by choosing syllables or words alternately from each ear, the subjects reported back the meaningful sequence rather than the series of words or syllables presented to one ear or the other.

All these examples of recognition of the verbal content of irrelevant messages led Deutsch and Deutsch (1963) to their proposed theory. They argued that selection is made only after full analysis of all inputs. As further support for this idea they quoted studies of habituation by Sharpless and Jasper (1956) and by Sokolov (1960). Habituation as such will be dealt with later on in this thesis.

In later years additional support was found for their conclusion. Lewis (1970) recorded latencies for shadowing unrelated words and found that the shadowing latency for a word is significantly increased by simultaneously presenting its synonym to the other ear. Evidently both words must be recognized for this effect to occur. Corteen and Wood (1972) associated an electric shock to the presentation of city names in a word list. Later, city names which were included in the rejected message in a dichotic shadowing task often elicited a galvanic skin response, although they were never consciously identified and did not interfere with the shadowing performance. These findings demonstrate

1.3.1.2.1 (Continued)

the occurrence of some verbal analysis of rejected messages.

Mackay (1973) showed that a single word or pair of words on the unattended ear could bias the recognition of an ambiguous sentence on the attended ear. This is again another demonstration of verbal analysis of an unattended ear. However, the effect of these two last experiments was quite small (i.e. increases of 14% and 26% due to association with electric shock and 4% to 14% of the cases in Mackay's experiment). In fact the size of the effect in these two experiments is similar to, or smaller than the proportion giving an overt response in Treisman and Riley's (1969) monitoring task. The latter found a very large increase in the efficiency of detecting unattended target words when these differed in voice quality as well as in semantic class. A similar effect was reported by Lawson (1966). She used tone bursts as targets, requiring a tapping response. She found that there was no difference between the detection of pips in the primary and secondary message.

Broadbent and Gregory (1963) were the first to use the signal detection theory in a selective situation. In 1967 there were already quite a number of investigators employing this theory (Treisman and Geffen; Moray and O'Brien; Taylor; Kahneman, Beatty and Pollack). The contribution of signal detection theory to selective attention will be discussed at a later stage in this thesis.

Recent studies of auditory attention have also used tasks other than shadowing. In monitoring tasks, for example, the subject is exposed

1.3.1.2.1 (Continued)

to a continuous message, but unlike shadowing, he is expected to respond only to occasional target items. In other types of experiments, he is expected to recognize items presented to him, at an earlier stage, in parallel with a shadowing task.

Monitoring a list of letters for occasional digits is not seriously impaired by the presentation of an irrelevant message to the other ear (Moray and O'Brien (1967); Underwood and Moray (1972)). Similarly, a subject instructed to press a key as soon as he hears an animal name in a message, responds as fast in the presence of an irrelevant message as when that message is absent (Kahneman (1973)).

In an experiment involving delayed auditory feedback (DAF) and shadowing, Zelnicker (1971) presented subjects with three groups of four auditory digits. In an easy experimental condition the subject repeated the first group of four digits twice, synchronizing his responses with the second and third group heard on the tape. In the hard experimental condition he repeated the first group while hearing the second and repeated the second whilst hearing the third. In both conditions the subjects own voice was played back to him but at a delay of 0.2 seconds. Such a DAF is one of the most disturbing and unpleasant time based feedbacks (Fairbanks (1955); Black (1951); Ram (1971)). The subjects in DAF experiments are doing their best to ignore or overcome the playback. Zelnicker's subjects were more successful in the hard condition than in the easy one. These results are consistent with a notion of limited capacity according to which subjects are more successful when engaged in a demanding task (Kahneman (1973)).

1.3.1.2.1 (Continued)

Gopher and Kahneman (1971) found differences in performance between reorientation and maintenance of attention in auditory monitoring. Their subjects first monitored one of two dichotic lists of words and digits for several seconds, reporting the digits heard in the relevant ear, then they heard a cue which defined the relevant ear for the second part of the task. Shortly after that cue, short lists of digits were presented to both ears. The reorientation of attention after a period of selective listening was found to be difficult.

Underwood and Moray (1971) argued that shadowing is not as powerful a technique as might have been supposed (e.g. Hochberg (1970)). Instead they suggested an 'alternative, simpler technique' of monitoring. Kahneman (1970) maintained that selectivity fails in the absence of a continuous response, which is the case in monitoring. Underwood and Moray (op.cit.) compared shadowing and monitoring tasks when attentional selectivity was required, and when it was not required. The experiments indicated that similar attentional strategies operate during the monitoring and shadowing of brief messages. They demonstrated that greater interference was apparent when the shadower's voice and the stimuli to be shadowed were similar than when they were distinct. Carey (1971) pointed at shadowing as possibly consuming too much capacity to allow analysis of the second linguistic channel. As an alternative method of controlling attention, subjects were instructed to memorize the primary message (Broadbent and Gregory (1963); Underwood (1972)) while performance on a secondary task was measured.

In the remembering condition of the experiment reported by Underwood (1972) the report of a target word was influenced by the position of

1.3.1.2.1 (Continued)

the word in the list and by the delay in reporting the word. The well known phenomenon of remembering the beginning and the end of lists better than their middles was demonstrated once again with the target words. The delay of subjects' reports had a slightly depressing effect on detection of targets presented towards the beginning of the list. In a similar experiment, Underwood (1973) varied the temporal delay of reporting the target words. This variable was found to have only slight effects upon the success of report. However, the detection of target words presented in both channels varied according to their serial position in the list, and this relationship was interpreted as support for the hypothesis that perceptual factors may influence performance when sequential presentations are involved.

Underwood (op.cit.) presented target words on both auditory channels. Mewhort, Thio and Birkenmayer (1971) demonstrated that the switching operation between the channels also consumes capacity, and that switching strategies are determined by the capacity residual after the completion of primary tasks.

Treisman and Fearnley (1971) measured RTs to a single item or pair of items in a classification task. They found that advance knowledge of the identity of a target digit reduced the response latency equally when two simultaneous items were presented and when a single item was presented, suggesting parallel processing of the two items. However, responses to the pair were considerably slower than responses to the single items, suggesting a limit to the capacity. In another experiment (Treisman and Davies (1973)) subjects were unable to detect more

1.3.1.2.1 (Continued)

than half the targets.

In an attempt to replicate and clarify an earlier finding by Lewis (1970) Treisman, Squire and Green (1974) explored the semantic processing of one message while another was attended to and shadowed. Like Lewis, they found that mean shadowing latency was increased when a synonym of the shadowed word coincided with it on the unattended channel. However, their results also show that the semantic interference arises only with pairs occurring early in the list. By the seventh pair (or earlier), the meaning of the secondary words stop having any effect on shadowing latencies. The authors argued that it is very difficult to find conclusive evidence for or against consistent and unimpaired semantic analysis of irrelevant messages.

An original experiment was carried out by Herman (1965) whose subjects performed simultaneously an auditory tracking and an auditory discrimination task. He found that subjects were able to process information effectively from the two simultaneous tasks. However, performance in the dual case was not as good as performance on a single task. Herman claimed that these results support the single channel hypothesis. The writer thinks that there is no apparent connection between this claim and the experimental results.

The role of practice and compatibility in dichotic memory span tasks was studied by Moray and Jordan (1966). They found that with practice recording becomes much more fluent. Even when giving a vocal alternating response, subjects were performing at a much higher level than in any

1.3.1.2.1 (Continued)

previous experiments such as Broadbent (1954), or Moray and Barnett (1965). Moray and Jordan also found that in a compatible situation no parallel to serial recoding was required, and the signal transmission rate could be very greatly increased.

Many of the studies carried out with auditory messages have applied the signal detection theory (e.g. Broadbent and Gregory (1963); Kahneman, Beatty and Pollack (1967); Moray and O'Brien (1967); Norman and Lindsay (1967); Taylor (1967); Treisman and Geffen (1967)). In most studies it was found that when a subject was attending one message and failed to respond to another, there was a change in sensitivity (d') rather than a change in criterion (β - Beta).

These findings are compatible with Treisman's filter attenuation theory (Treisman (1969)). Deutsch and Deutsch (1963); Deutsch, Deutsch and Lindsay (1967) argue that the change is in the criterion, not in d'. In most cases where some changes in β were detected they were found to be unsystematic. Taylor (1967) showed that changes in β are hard to interpret unless the form of the ROC curve is known, estimates of β may be misleading. In many cases the form of the ROC curves has not been obtained (Moray (1969b)).

This research is not designed to study this problem. However, it seems to the writer that a system which only causes changes in d' by attenuating the irrelevant signals, must be a very uneconomical system. A change in β or in both d' and β seems far more suitable. Moray, Fitter, Ostry, Favreu and Nagy* in a very detailed and meticulous study

* Private communication with regard to 'attention to pure tones'paper in preparation.

1.3.1.2.1 (Continued)

found that d' and β are strongly correlated and changes can be found in both.

To summarize, there is a fairly impressive body of qualitative generalizations. Messages are selected on the basis of their pitch voice quality, loudness, semantic continuity, time of onset and spatial localizations (ear dominance as such is discussed in a later section). The more similar the messages, the more likely they are to be confused by the listener and the less effective is attentional selection.

The efficiency of the selection is also influenced by practice (detailed account is given in section 3).

1.3.1.2.2 Visual selection

Most of the experiments employing division of attention were carried out with auditory stimulation. Very few experiments in this area employed simultaneous visual stimulation, because of the reorientation of the eyes needed in such experimentation. However, some experiments were carried out with dual visual stimulation.

Bahrick, Fitts and Rankin (1952) engaged subjects in two tasks: continuous tracking of a target, and monitoring of the occurrence of occasional signals in the visual periphery. When the incentive pay for both tasks was increased, performance of the control task improved, and performance of the peripheral task deteriorated. Similar findings were also described by Bursill (1958), who manipulated arousal through the

1.3.1.2.2 (Continued)

use of environmental conditions. The balance of attention to central and peripheral tasks was altered in conditions of high arousal.

Related results have been reported by Callaway (1959); Callaway and Stone (1960); Callaway and Thompson (1953), who manipulated arousal by means of drugs. Drugs which decrease arousal tended to improve the registration of peripheral cues, whereas increase in arousal level had the opposite effect.

Cornsweet (1969) found that peripheral vision was unimpaired when the competition between peripheral and central tasks was removed. Bursill (op.cit.) also noted that the decrement of peripheral detection did not occur when the peripheral task was emphasized. Hockey (1970c) - in a dual task situation similar to Bursill's - observed that the relative performance for central targets is reduced under low arousal and enhanced under noise stress - high arousal (Hockey (1970a)). He showed (1970b) that the neglect of peripheral targets under stress is due to the low probability of detecting such targets, which reduces their importance.

Senders, Webb and Baker (1955) observed that when people view a series of dials, they appear to be able to take in more information than may be expected by means of peripheral vision - once they have formed a hypothesis of what is likely to happen there.

Payne (1967) studied reaction times to stimuli presented at various points on a circle about the fovea and 15° out. He found that these were faster average reaction times when the light was presented in the

1.3.1.2.2 (Continued)

region corresponding to the blind spot of the opposite eye.

Garner (1962) reviewed and commented on the extent to which various dimensions of a visual signal are handled independently of one another. In the earlier years of attention research, there was extensive literature on the interaction of different aspects of visual stimuli. Thus Meads (1915), Curtis and Foster (1917), Bowman (1920) and Friedline and Dallenbach (1929) examined such factors as the size, intensity and position of stimuli as determiners of attention.

Visual experiments on the division of attention, in a way analogous to the methods used in hearing, were carried out by Sampson (Sampson and Spong (1961a, 1961b); Sampson (1964); Sampson and Horrocks (1967)). Sampson and his team applied the 'split span' method of Broadbent (1954) to vision, by using a slide projector to back-project stimuli on a screen down the middle of which there is an opaque division. The left eye could not see the right side of the field, and the right eye could not see the left side of the field. In one of their experiments they presented one series of digits to one eye and another to the other eye simultaneously. This idea was originated by Broadbent in auditory experiments. Broadbent's subjects tended to recall all the stimuli from one ear followed by all those from the other ear (Broadbent (1954), (1958)). Sampson and his co-workers found that viewers tended to recall them as simultaneous pairs of digits, not eye by eye. These results are not very surprising since it is a human natural tendency to read two digits appearing side by side, as a single two-digit number. Subjects were also presented with digits to one eye

1.3.1.2.2 (Continued)

and coloured patches to the other. Some of the subjects tended to report first all digits together and then all colours together, rather than alternating them. Stimuli presented to the left eye were less well recalled and the recall was slower than stimuli presented to the right eye. This is compatible to the well-known fact that subjects usually show right ear dominance in shadowing. Kahneman (1973) reports that in 1971 Colavita showed that the dominance rule is applied to 'break the tie' when two stimuli require a simultaneous response. His research, however, was carried out in a two sense modality stimulation and it seceded in demonstration that in man visual stimulation is more dominant than auditory stimulation. Within the auditory sense modality, the pattern of ear dominance can be altered by requiring subjects to fixate 20° to the right or to the left of the frontal plane (Kahneman (1973 p.151).

In a more recent paper Sampson and Horrocks (op.cit.) employed the same method of presentation as in the earlier experiments, but they also varied the level at which the digits were presented. They found that subjects first reported the upper digit of a pair, before the lower one. The only exception for which the relation was strongly reversed, was when the upper stimulus appeared on the right-hand side. In this condition subjects reported in pairs, from left to right, as was found before.

The tendency to report items by channel (i.e. by ear, location, voice, modality) demonstrated by Broadbent (1954); Broadbent and Gregory (1961, 1965) can be overcome by other grouping factors. Gray and Wedderburn

1.3.1.2.2 (Continued)

(1960) found that subjects' reports followed content rather than ear of arrival. Similar results have been obtained in many other experiments (e.g. Bartz, Satz and Fennell (1967); Broadbent and Gregory (1964); Yntema and Trask (1963)). This effect of content is limited to dichotic presentation; when the series are presented on different modalities, report by content almost never occurs (Madsen, Rollins and Sene (1970)).

Bryden (1971) studied the question of how attention affects storage in an auditory split span design experiment. He found that attended and unattended messages are treated differently. Although Massard (1972) has argued that this difference was due entirely to rehearsal of the attended message, a similar recency effect can be obtained with visually presented words (Corballis and Luthe (1971)). Perhaps subjects 'attend' to a message by a form of inactive encoding, or rehearsal (Murray and Hitchcock (1969); Neisser (1967)) which alters the nature of the memory trace, and also strengthens it, and hence the 'different treatments' for attended and unattended messages.

Many studies of divided attention have used verbal material. For example, Mowbray (1953) found that subjects could not listen to one story while reading another. Subjects were apparently focusing on only one of the messages, despite their intention to divide attention. If different aspects of a complex task were presented simultaneously to both visual and auditory senses, the subjects were unable to use the simultaneous messages. Furthermore, they usually denied noticing the simultaneity (Mowbray (1954)).

1.3.1.2.2 (Continued)

Treisman and Davies (1973) found that it is possible to monitor two messages simultaneously. It is, however, easier to monitor them if the two messages are on different sense modalities, than if the two messages stimulate only one sense modality, vision or audition. They also showed what most investigators indicate: that the performance in a simultaneous situation is not as good as the performance in a solitary situation.

Allport (1971); Allport, Antonis and Reynolds (1972) reported on studies of attention divided among channels. In one of his experiments, the subjects were instructed to report the values of three items on one or two dimensions. Interference occurred between shapes and numerals, but not between colour and another dimension. Allport and his co-workers found that people can attend and shadow one message and at the same time 'take in' complex unrelated visual scenes, or even sight reading piano music. The tasks employed in these experiments, stimulated two different sense modalities, in parallel, and the results of the experiments were compatible with those of Treisman and Davies (op.cit.).

Dividing attention within a sense modality often involves a conflict of orientation tendencies (Kahneman (1970)), or is difficult whenever a task involves storage (Kroll et al. (1970)). The latter found that a single target word presented during shadowing is retained better if it is visual than if it is included within the auditory message. Interference is more likely to occur between items presented to the same modality than between items on different modalities (Parkinson (1972)). Related results were reported by Treisman and Davies (1973, exp. 1) in

1.3.1.2.2 (Continued)

a bisensory split span experiment, and some were already found by Mowbray in 1952.

Dividing attention within the visual sense depends, among the rest, on grouping of stimuli. Beck's work (1966, 1967, 1972); Beck and Ambler (1972), suggests that the grouping process is controlled primarily by the detection of similarities and differences among the elements simultaneously present in the field. He proposed that this detection of differences takes place in the periphery prior to the focusing of attention. Beck suggested that pre-attentive and attentive discriminations follow different rules, which is a support for Neisser's (1967) suggestion that pre-attentive mechanisms carry out the task of sorting and organizing the field prior to the operation of focal attention. Obvious physical features are discriminated pre-attentively. However, it is inappropriate to assume, as some authors have done, that discriminations of physical features are always pre-attentive, and that only higher order properties are analysed attentively (Ellis and Chase (1971)). Beck's work and also that of Olson and Attneave (1970), indicate that discriminations of physical features occur at both the pre-attentive and attentive levels, but follow different rules at the two levels. Some factors of grouping, such as proximity and similarity, are common to the formation of spatial units in vision and of temporal units in audition. Sounds, for example, tend to be grouped if they originate from the same location, or if they share certain physical characteristics (Broadbent (1971 Chap. 4)).

The selection of relevant cues often involves a discrimination between these cues and others. Such discrimination tends to be impaired by a

1.3.1.2.2 (Continued)

state of high arousal. High arousal, for example, causes an increased tendency to focus on a few relevant cues, in other words, it reduces the ability to focus on all the relevant cues. Subjects became spontaneously more selective when highly aroused. However, the effectiveness of their selections is likely to deteriorate especially if the selection requires a fine discrimination (Bahrick, Fitts and Rankin (1952); Broadbent (1971); Bursill (1958); Easterbrook (1959); Hockey (1970a, b, c); Kahneman (1973)).

Broadbent (1971 p.430), for example, suggested that the ability to select relevant stimuli is impaired by arousal. Noise did slightly improve the performance when subjects were told to write as many digits as possible, but when they were shown an array of red and white digits and were asked to report as many digits of one specified colour as they could, noise caused a deterioration of the performance. It was also found that the identification of a faint word presented together with a heavy printed word was significantly impaired by the presence of noise. In these experiments noise was employed in order to increase the level of arousal.

Not only 'white noise' impairs the ability to discriminate and identify relevant stimuli, Greenwald (1970a, b) simultaneously presented a visual and an auditory digit and measured the RTs for reading the visual digit. The subjects were unable to reject the irrelevant auditory digit and the RT for the visual digit was slower when both digits were different. The interference from the auditory item was more severe when the subject had to say the visual digit than when he wrote it (Greenwald (1970a, c)).

1.3.1.2.2 (Continued)

Greenwald's experiments point to a certain degree of confusion which occurs between the two different sense modalities stimulation. Other investigators (Sperling (1960); Conrad (1964); Keele and Chase (1967); Laughery and Harris (1970); Kroll, Parks, Parkinson, Bieber and Johnson (1970); Rollins and Thibadeau (1973)) have found similar effects. For example Rollins and Thibadeau (op. cit.) tested the recognition of information presented to subjects while shadowing or while listening. The information was presented in four different forms:

1) a list of concrete nouns presented to the other ear.
2) printed words
3) pictures of objects easily labelled
4) pictures of objects difficult to label.

They found that 'attending to an auditory message (shadowing) interferes with the processing and storage of any information whether visually or auditorily presented when that information can be verbally labelled' (i.e. groups 1, 2 and 3). The shadowing task interfered more with information received auditorily than with any form of visual information. Under the condition of 'listening only' the auditory words and the visual words were equally recognized. Rollins and Thibadeau interpret the results in terms of models proposed by Atwood (1971) and Bower (1970). Later on in this thesis a simpler explanation will be given to these results.

Atwood (1971) suggested a very uneconomical model, in which verbal information may be stored in two independent but interacting memory systems. One system stores visual information and the other auditory information. The two systems operate in parallel, but they may also interact. Under normal conditions a particular word or phrase can be

1.3.1.2.2 (Continued)

stored in both systems regardless of its origin modality. If the auditory system is blocked, for example, then the word will only be stored in the visual system. Since it is only stored in one of the systems, recall would be reduced.

The 'auditory confusions' (subjects generate intrusions which sound like actually presented stimuli) have led some investigators (Sperling (1960); Atkinson and Shiffrin (1968)) to suppose that:

- visually presented letters must pass through a stage of auditory encoding.
- letters must be transferred directly to this stage from a rapidly fading icon or be lost.

The visual confusions obtained in different experiments have often been interpreted as demonstrating the existence of a separate visual code lasting beyond the duration if iconic storage and separate from the auditory store (Murdock and Walker (1969); Henderson (1972)).

Briggs (1974) argues that such simple modality encoding hypothesis may be premature. What is taken to be 'encoding into memory' might be 'retrieval for a response'. He suggests that auditory and visual confusions reflect strategy-contingent <u>recoding</u> rather than modality-specific <u>encoding</u>.

There are experiments in which the irrelevant signals, even when stimulating the same sense modality, do not cause any confusion. For example Neisser (1969) developed a visual analogue to the auditory

1.3.1.2.2 (Continued)

shadowing situation. His subjects read a coherent text aloud and at the same time had to ignore words printed in red under each line of the selected text. Subjects can do this very well and the situation is very similar to ordinary reading where the reader pays attention to each line at a time and ignores the others.

Finally, there are situations in which the need to divide the attention causes an improvement in the simultaneous performance. Adams and Chambers (1962) used a bisensory discrete tracking task where a probabilistic series of simultaneous auditory and visual stimuli were presented, each stimulus series for response with a separate hand. There were control groups - auditory and visual - each practised in a unisensory version of the task. The results revealed a net superiority of bisensory over unisensory responding when stimulus events were certain. The anticipation of certain events resulted in an increase in speed of the visual response time to that of the faster audio response time, because subjects in the bisensory task usually made the two response movements together. When events were uncertain, the faster audio response time was slowed down to synchronize with the slower visual response time.

To summarize; at the beginning of the century the students of attention were involved in studying its visual aspects. They mainly concentrated on factors such as size, intensity and position of stimuli and their influence on attention.

Until recent years the study of visual attention was completely abandoned, chiefly because the main stream of research moved away from

1.3.1.2.2 (Continued)

attention. Later on when investigators renewed their interest in the subject they used mainly the auditory sense, because it does not involve accommodatory movements.

In recent years considerable progress has been made in the study of visual attention. Nowadays, the study covers central and peripheral attention, as determined by arousal. It also looks at discrimination or identification of cues and their impairment by arousal. The investigation includes the order in which subjects tend to report stimuli (from the upper parts downwards and from left to right).

Many of the studies are designed in the same format as the auditory investigations, and outcomes such as right side dominance, and dependence of the division of attention on grouping of stimuli are very similar. However, unlike audition, in vision the subjects tend to recall digits side by side (like numbers) rather than eye by eye, even if each eye can only see half of the visual field.

In recent years, more and more research has been carried out in the field of divided attention between the senses. It has been found that simultaneous performance is not as good as individual performance. It is, however, better than divided attention within the same sense modality.

The current trend is to investigate the difference between the visual and the auditory attention in order to find out to what extent they really differ.

1.3.2 Measurement of mental load

Rolfe (1971b) claims that "the demands of work have changed from being primarily physical to being predominantly mental, requiring more covert than overt activity on the part of the operator". This change in the nature of human activities raises the question of how busy an operator is, since his activities can no longer be directly observed. Poulton (1958) emphasized that "the absence of overt action does not necessarily indicate that a man's capacities are not being fully employed."

The question which remains is how to measure the extent to which these capacities are employed. This question is important because of the possibility that the operator's capacities can be overloaded with the result that performance deteriorates. Indeed Fitts (1961) lists such overloading as one of the factors which can have an adverse effect upon skilled performance.

There are several methods employed by the various investigators in measuring the so-called 'mental load' (sometimes also referred to as 'perceptual load' or 'perceptual motor load', Michon (1966)). Some of these methods are directly related to the activities in question but some are only indirectly related to them. The various physiological and neuropsychological methods used in measuring mental activities are not related to the type of investigation developed in this thesis and therefore there is no attempt to evaluate or relate to them. The only methods which are applicable here are those which measure task performance.

1.3.2 (Continued)

Conrad (1951, 1954, 1955) in a series of experiments on perceptual load had his subjects watch a number of dials and press a button whenever one or more of the pointers, either coincided with the target marked around the dials (1951, 1954), or were about to come to a standstill (1955). Conrad simply defined perceptual load as the number of dials, and found that the performance level deteriorated with an increase in the number of dials, when the total number of actions to be taken was kept constant.

Michon (1966) claimed that Conrad's method is too restricted for general use. Yet, it may be of interest to mention Regan's (1959) experiment which can be regarded as making use of it.

Rolfe (1971b) reports that Regan compared the performance of subjects when using separate displays or a combined display to perform two-dimensional tracking. He showed that the combined display produced a lower number of errors than the separate displays. The same experiment examined the effect of using individual controls for each axis of tracking compared with that of a two-dimensional joystick. Again it was found that the joystick control gave improved performance over the individual controls. However, it it possible that the first findings are due to central load while the second are due to peripheral load.

The so-called secondary task method is the most common way of estimating the mental load through task performance. The rationale behind the idea of a secondary task is well-known (Bahrick et al. (1954); Brown and Poulton (1961); Brown (1962); Schouten et al. (1962)). The extent

1.3.2 (Continued)

to which a second task can be performed adequately indicates how much 'spare mental capacity' is left over from the primary task. This idea of measuring how much additional work the operator can undertake while still performing the primary task, is fulfilled by applying secondary tasks. Another way (Knowles (1963)) is to compensate for any deficiency in the loading of the primary task and to simulate aspects of the total job that may be missing. This idea to 'put pressure' on a primary task in order to improve the simulation, is very arbitrary since it is not at all certain that the difference between the simulated task and the real one lies within the aspects of loading. Furthermore, if there is a loading difference between the two tasks it is not clear to what extent a secondary task is able to fill the gap.

Knowles (1963) was right in saying that by giving an additional task, the operator becomes more heavily stressed and his performance on difficult tasks deteriorates more than his performance on easy tasks.

Rolfe (1971a) noted that not all experimenters find it necessary to employ one or other of the above rationales. So, in some instances, the subjects have been instructed to do as well as possible on both tasks. To complicate the matter even further, many experimenters have not found it necessary to record what were the instructions given to their subjects. This, of course, adds to the general confusion and disagreement which is found in this area (Michon (1966)).

Secondary tasks techniques have also been utilized in investigations of learning effects. The argument put forward is that if a secondary task is introduced in a learning experiment, it should be possible to

1.3.2 (Continued)

demonstrate the reduction in the primary tasks demand by showing an accompanying increase in the level of performance on the secondary task.

Bahrick and Shelly (1958) studied the value of a secondary task to provide an index of automization in a time-sharing situation. The results supported the hypothesis that the redundancy of stimulus sequences permitted a change from exteroceptive control of responses to proprioceptive control and the performance in time-sharing situations provided a useful index of this process of automization. This experiment followed another experiment by Bahrick et al. (1954) which investigated the value of a second task as a measure of learning a primary task. Concurrent performance on a secondary task in the form of an auditory arithmetical subtraction task was required either early or late in practice on two versions of a primary motor task. Scores on the two forms of the motor task remained similar whether the secondary task was added early or late. However, arithmetic scores were superior for a repetitive primary task, than for a random primary task, when the secondary task was added late in practice. When it was added early in practice, the arithmetic performance was comparable for both primary tasks.

Baker, Wylie and Gagné (1951) examined the interference of one task with another after varying degrees of practice on the first task. They studied a complex co-ordination task which involved learning a motor skill. The results showed that the interfering task caused an increase in the time taken for control movements on the primary task. At each degree of practice there was an initial sharp increase in

1.3.2 (Continued)

performance time when the interfering task was first introduced. Although performance on the primary task improved, as practice with both tasks present continued, it never reached the level of the performance of those subjects who were not given the interfering task.

Garvey (1960) took a previously developed analogue computer model describing human operator behaviour in the learning situation (Garvey and Mitnick (1957)) and attempted to extend its application to a situation in which the operator was forced to perform various secondary tasks. No differentiation between the effects of the various secondary tasks was reported, but all three brought about a deterioration in the quality of tracking task performance.

According to the above experiments it appears that in simultaneous performance, some deterioration in performance occurs in either both tasks or in one of them. This deterioration is related to:

1) The level of learning achieved on the tasks.
2) The complexity of the tasks.

Many investigators introduced a secondary task in order to measure the relative merits of a number of differing methods of performing the same task. Secondary tasks were also used in order to look into the differences in workload at various stages of an operation.

For example Rolfe (1971a) reported several series of experiments carried out by him (1963) and by others (Walker et al. (1963); Dougherty et al. (1964)) in which secondary tasks, such as auditory shadowing, tracking,

1.3.2 (Continued)

or reading out digits, caused some deterioration in the performance of primary tasks.

Poulton (1958) used a secondary task in an experiment to measure the order of difficulty of two dial watching situations. One task involved watching two dials and the other six dials. The results showed that watching six dials gave significantly more errors on the secondary task than watching two dials.

Benson et al. (1965) used a secondary light-acknowledging task to compare the effectiveness of two display configurations in a tracking task. Tracking performance was unaffected by the display used while the secondary task performance was affected. Primary task performance was degraded by the presence of the secondary task.

Rolfe (1971a) reported that in 1966 he used the same experimental situation as that described above to examine performance on a task requiring the subject to change the indicated value on the display to another value demanded by the experimenter. The presence of the secondary task increased setting times and the number of errors made on the displays, although these differences were not significant, but the type of error was significant. Rolfe went on reporting that in a later experiment in 1969 he examined the pattern of secondary task response which occurs during individual setting operations. The results showed that increases in response time on the secondary task could be related to covert decision making as well as motor response in relation to performance of the setting task. In 1963 Rolfe used a second task to

1.3.2 (Continued)

load subjects while comparing various displays for the speed and accuracy with which they could be read. This method proved to be an effective loader and forced the subjects to keep their reading times as short as possible.

Garvey and Knowles (1954) loaded subjects' performance through the use of mental arithmetic. They studied different methods of presenting one hundred discrete visual stimuli and their associated response buttons. A few years later Garvey and Taylor (1959) employed similar secondary tasks while studying various orders of compensatory tracking. Their method proved to be successful as it did cause deterioration in performance on the complex tracking tasks while the less complex ones were relatively unaffected.

Day (1953) adopted a different approach to studying tracking performance. He examined the effect of changes in the size of the target area on the performance of a tracking test through the introduction of a two choice light cancelling subsidiary task. The manipulations in the primary task difficulty did not cause any meaningful variations in the secondary task response times. Unfortunately, the experimenter did not consider the possibility that the secondary task might influence the performance of the primary tasks.

Olson (1963) studied the effect of different arrangements of eighteen instrument displays, on the performance of an instrument monitoring task, and also on the performance of a secondary simulated driving task being done at the same time. The different display arrangements

1.3.2 (Continued)

affected not only performance on the monitoring task, but also the performance on the secondary driving task.

There are a number of experiments, mainly carried out by Brown, sometimes with the colaboration of others (1961, 1962, 1965, 1966, 1967, 1969) on the subject of mental load imposed by car driving. Brown and Poulton (1961) estimated the spare capacity of car drivers while driving in light traffic areas and in heavy traffic areas. The spare capacity was estimated by giving the car drivers an auditory secondary task. They concluded that when driving in heavy traffic areas the spare capacity was smaller than when driving in light traffic areas. This smaller spare capacity caused a greater decrement in the performance of the secondary task. The authors pointed out that the validity of the technique depended upon there being no effect of the secondary task on driving. They only checked on this in their first experiment by not finding a significant change in the average speed of driving.

Brown (1962a) carried out an experiment using the same procedure as in the previous experiment. The aim of the experiment was to test the value of a secondary task as an indicator of fatigue. The drivers were tested at the beginning and end of a spell of duty. Performance on the auditory task while driving was worse for the subjects who were about to commence their duty, than it was for the drivers who had just finished. Brown suggested several explanations for these unexpected results. One of these was that the experiment was always carried out in the afternoon when one group of drivers were about to finish their duty and the other group were about to start theirs. He claims that

1.3.2 (Continued)

both groups got up at about the same time in the morning, but those drivers who were starting duty in the afternoon filled their day with activities such as gardening or decorating. The author suggested the possibility that the members of this group were more tired than the other subjects who were driving all day.

Brown (1965) also compared two alternative forms of secondary tasks for their effectiveness as indicators of driver fatigue. He found that both influenced the time needed to complete the driving route.

Brown (1966) found that the spare capacity of the ultimately successful trainee of public service vehicle drivers - measured in terms of secondary task performance - was significantly higher early in training than that of those who later failed the course.

Brown et al. (1967) applied a method developed by Michon (1966) of measuring irregularity in task performance as an indication of perceptual load. They found that the presence of an interval task increased steering wheel activity.

Brown et al. (1969) used gaps of varying width as tests of driving skill. They concluded that using a radiotelephone as a secondary task while driving produced a relaxation of criteria. They concluded that central rather than peripheral mechanisms were being interfered with.

Pilots' workload was also studied. For example, Rolfe (1971a) reports that Ekstrom in 1962 let pilots perform an additional self-paced light cancelling task while 'flying' an aircraft simulator. The results

1.3.2 (Continued)

showed that the pilot could complete all the various phases of the flight profile. However, some of these phases were more mentally loading than the others, and the more automatic systems demanded less of the pilot's attention.

Most experiments employing the secondary task technique were strictly applied studies. However, some investigators were also concerned with the theoretical aspects of using such a technique. Michon (1966) argued that some secondary tasks interfere with the performance level of the main task, especially when they employ the same 'sensory motor pathways'. He further pointed out at the possibility that all particular secondary tasks interfere <u>functionally</u> with the main task, without necessarily making use of the same peripheral pathways. He does not elaborate this particular point of functional interference. However, he gives an example of the experiment carried out by Brown and Poulton (op. cit.) in which drivers had to select the changing element in a series of eight digit numbers. Michon claims that such a secondary task would not have been ideal if the main task consisted of deciphering numerical codes, even if one task was presented auditorily and the other visually. The writer agrees with this hypothetical example, but claims that it does not provide an explanation, it merely points at possible occurrences. At a later stage in this study a model is put forward which proposes to account for these and other similar phenomena.

There have been many attempts to assess the value of different types of secondary tasks or different experimental procedures.

1.3.2 (Continued)

Schouten et al. (1962) found that the performances of alternative secondary tasks decremented differently when carried out simultaneously with a standard primary task.

Kalsbeek (1964) found that when the secondary task required only movement, or movement and positioning, the effect on the primary task was mainly one of slower performance. When choice was also part of the secondary task, errors tended to occur on the primary task.

Glucksberg (1963) carried out an experiment, in which the secondary task could be presented via the same sense modality as the primary task or via one of two different sense modalities. The secondary task could be varied for its content, and for its mode of presentation: visual, auditory or cutaneous. The results pointed out that the performance on the primary tasks was impaired when the secondary task was presented via the same sense modality as the primary task.

Murdock (1965) found that as the secondary card sorting task became more demanding, so the number of words recalled, in a short term memory task, decreased.

Michon (1966) employed a tapping task as a secondary task. The irregularity of the tapping indicated the 'perceptual motor load' imposed by the primary task. He found that the secondary task performance discriminated between various primary tasks and indicated an order of difficulty which agreed with both subjects' and experts' judgments.

1.3.2 (Continued)

Trumbo et al. (1967) found that the presence of two forms of a secondary number anticipation task resulted in marked interference with the primary visual tracking task, particularly in relation to the timing of responses to the primary task. The interference was due to the response requirement of the secondary task and not to its number anticipation requirement.

Noble et al. (1967) investigated the effect of secondary task on the learning of a primary task. The results did show a deterioration in the performance when the secondary task was present. However, this did not prevent an improvement in the performance from taking place. Unlike the interpretation of Trumbo and his colleagues, Noble et al. interpreted their results as indicating that the source of the interference between the two tasks was due to the selection and implementation of responses and not to the competition between peripheral responses.

There is a great variation in the techniques of conducting mental load experiments. Rolfe (1971a) reports on many experiments carried out by various investigators in which serious methodical errors, such as failing to employ the proper 'control condition', were committed. However, the main difficulty in the field of mental load does not lie in the technical ability to carry out proper and well designed experiments. For example, Brown's (1968) criticism on the various techniques is an empirical criticism, while the difficulty in the area is a theoretical one.

While most investigators carry out ad hoc experiments with limited and specific applied purposes, some authors are concerned with the

1.3.2 (Continued)

theoretical implications of such manipulations. Some base their approach on the so-called 'single channel hypothesis', others are less rigid in their approach and rely upon a concept of the human as a limited capacity system in relation to tasks performance. The theories developed in this field are very limited in their scope and can only have predicting value in single straightforward cases. The results which are successfully predicted are in most cases so self-explanatory, that almost any naïve person would reach the same conclusion, without carrying out an experiment. The more sophisticated predictions are usually shown to be in full agreement with the operators, or experts opinion. This may lead the reader to wonder why should we go through such a lengthy and complicated procedure, if the operator can easily tell us the results.

The various methods of manipulating the two task range from instructing the subjects to ignore the secondary task, through giving them priorities as to which task should be concentrated on, to giving no priorities at all.

The limited theories developed in the field cannot always give an account for the particular results. For example, Rolfe (1971a) argues that from a theoretical point of view - if the subject is asked to perform a primary task and to attend to a secondary task only when the primary allows - there should be no deterioration in the performance of the primary task. This is not the case, neither from a theoretical point of view, nor from a practical one. Later in this thesis it will be shown that such situations call for 'successive time-sharing', and

1.3.2 (Continued)

that the inevitable deterioration in the tasks performance has nothing to do with load of any kind.

The estimation of the load imposed on operators becomes increasingly important, as the operators are more and more involved in decision making and other covert activities. However, the secondary task as a measure of mental load caused by a primary task, will always remain indirect and limited in its scope. Perhaps a more direct approach of estimating the load imposed by the primary task itself, instead of using intervening variables, would yield better results.

1.3.3 Choice reaction time

1.3.3.1 Historical background

Woodworth and Schlosberg (1954 p.8) suggest that the speed at which work can be carried out is a useful measure in two ways: as an index of achievement - the quicker one performs a task the more he masters it; and also as an index of the complexity of the inner process by which a result is accomplished. To them, the time required to get the overt response started is of great importance. The time interval between the stimulus and the response is the 'reaction time' (RT). Fitts and Posner (1967 p.93) define reaction time as 'the delay between the occurrence of a stimulus event and the initiation of a response'.

Experiments with reaction times (RTs) were initiated in 1850 by the famous physiologist Herman von Helmholtz who succeeded in demonstrating that the nerve impulse was relatively slow, although not nearly as slow as RT itself. Personal differences in timing stars trajectories among astronomers were recorded even before Helmholtz made his discoveries (Fitts and Posner (1967)). Later on in 1879 Wundt opened his psychological laboratory in Leipzig and experimented in RT to visual and auditory events.

The employment of RT experiments in psychology started with 'simple reactions'. They were 'simple' in so far as the subject had only one fixed and uniform stimulus to attend to and he was asked to perform only one uniform response.

1.3.3.1 (Continued)

Even such simple experiments produce great variation in RTs. The astronomers already knew that RT decreases as the intensity of the stimulus increases. The RT also depends on how certain the subject is about when the stimulus is about to occur. It is necessary to introduce some temporal uncertainty as to when the signal will occur, otherwise the subject's RT will be reduced to close to zero. Klemmer (1957) found a positive correlation between temporal uncertainty and RT. Various other experimenters found different RTs due to stimulations of different sense modalities, motivational factors, age factors, or individual differences between subjects.

The more complex work with RT began when subjects had to choose between various possible reactions (choice reaction time - CRT) according to the particular stimulus presented to him. The earliest attempt to deal with CRT was that of Donders in the late sixties of the last century. He compared RT under three conditions:

a) - reaction, simple RT.

b) - reaction, where five different responses were each made to a different one of five possible stimuli.

c) - reaction, where five stimuli were presented but only one of them required a reaction, the rest were ignored.

His theory was that each component function increased the RT by a fixed amount. Thus, b-reaction required both discrimination and choice, c-reaction required discrimination but not choice, whilst a-reaction required neither. He thought that by computing RTc - RTa he could obtain discrimination time, and by computing RTb - RTc, he could obtain the choice time. Although intuitively his idea seems attractive and logical,

1.3.3.1 (Continued)

it was rejected (Fitts and Posner (1967); Neisser (1963); Pollack (1963b); Rabbitt (1959, 1964, 1967, 1971)).

Markel in 1885 (from Boring (1950)) extended Donders' data to include a choice from among ten stimuli and responses. He found a logarithmic increase in the RT as the number of stimuli and responses increased. Hick (1952) and later on Hyman (1953) derived equations based on this property, relating it to postulates of communication theory developed by Shannon and Weaver (1949). They suggested that the rate of gain of information in experiments similar to Markel's, is constant and the relation between information and RT is linear.

The fact that RT rises with the number of alternatives gained support from many investigators who employed various methods for calculating this connection (e.g. Crossman (1956); Edwards (1964); Fitts, Peterson and Wolfe (1963); Fitts (1966); Taylor, Lindsay and Forbes (1967); Morikiyo and Iida (1967)).

The influence of other factors, such as age (e.g. Griew (1958a, b, 1964); Suci, Davidoff and Surwillo (1960); Szafran (1963, 1966)), or type of stimuli (e.g. Brainerd, Irby, Fitts and Alluis (1962); Fitts and Switzer (1962); Pollack (1963 a, b, c); Stone and Callaway (1964); Morin, Konick, Troxell and McPherson (1965); Oldfield and Wingfield (1965); Oldfield (1966)), on the above connection were also studied. Excellent reviews concerning this area of investigation were carried out by Welford (1960, 1968).

1.3.3.1 (Continued)

Donders' principle of the addition of RTs was recently accepted by Sternberg (1969, 1975) based on his experimental paradigm (1966). Sternberg's basic experiment was to present subjects with a variable list of positive stimuli to remember, followed by a single 'probe' stimulus which might or might not be a member of the positive set. Sternberg (1966) found a linear increase in RT with the increase in the positive set. He also found an increase for negative set items with the increase of the size of the positive set. He concluded that his subjects searched serially and exhaustively through the positive set for a match to the probe item. Lindsay and Lindsay (1966) suggested that subjects do not emit negative responses in default of positive matches, but rather re-check stimulus comparisons before committing themselves to a negative response. Similarly Nickerson (1969) argued that positive and negative comparison processes are separate and independent. Briggs and Blaha (1969) agree with Sternberg's acceptance of Donders' principle, but they also employ independence and addition of sub-processing within the stages of stimulus identification, matching and response execution. Briggs and Swanson (1970) extended the previous study to derive numerical values for stimulus encoding and decoding rates, retrieval time from memory, the time required for each individual comparison, and the interaction of all these with uncertainty. Hoving, Morin and Knoick (1970) studied the influence of age on RT in an experiment based on Sternberg's (1967) technique.

The hypothesis (Sternberg (1966); Briggs and Blaha (1969)) of exhaustive (requiring all dimensions to be analysed before a response is made) rather than self-terminating serial search (a response being made

1.3.3.1 (Continued)

as soon as a difference or similarity is noticed) was not confirmed by Morin, DeRosa and Stultz (1967). Clifton and Birenbaum (1970) argued that a substantial proportion of their subjects made use of self-terminating rather than exhaustive serial search. Rabbitt (1971) reports that in 1970 Baddeley and Ecob found clear evidence of list - position effects in Sterenberg - type paradigms interpreting these with earlier similar data by Corballis (1967), in terms of a trace strength decay - interference model for the availability of items from the positive set in immediate memory.

1.3.3.2 Stimulus response compatibility and the influence of practice

All reviewers of RT literature (e.g. Welford (1960, 1968); Laming (1968); Smith (1968); Sternberg (1969); Rabbitt (1971)) agree that the nature of the display control relations determine the simplicity or the complexity with which signals are encoded, transformed and decoded. The basic principle is that some sets of stimulus response relations produce shorter RTs than others.

The notion of stimulus response compatibility introduced by Fitts and Seeger (1953) was further developed by Fitts and Deininger (1954) and Deininger and Fitts (1955).

They argued that the maximum S-R compatibility, which produces minimum RT, is approached when the following two conditions are met:

1) The stimulus set corresponds in a direct physical sense to the response set.

1.3.3.2 (Continued)

2) The pairing of stimulus and response elements agrees with strong population stereotypes.

Such display control relations were least complicated in a situation used by Leonard (1959), in which the subject held his fingers on the armatures of a set of relays, the signals were vibrated to one of his fingers and he reacted by pressing that armature. Welford (1968) reports that Baker found in 1960 that tracking was much better with a stylus that could be used to trace the target directly on a cathode ray tube than with a joystick which moved a spot on the tube. Morin and Grant (1955) found that when the key for a given light was directly under it, the CRT obtained was better than when the spatial relations were reversed (left key assigned to right light and vice versa). The worst performance was for a random assignment of responses to lights.

Singleton (1953) described a task in which the subjects had to move a lever in one of four directions, depending on which one of four lights was lit. The relation between the position of the light and the direction in which the control had to be moved was varied, being either the same, the opposite, or inclined at 90°. Except for the first trail, there was an increase in the time required to make a decision and to begin to move the lever. There was very little change in movement time, indicating that the slowing of response was due to a decision process. The increase in response time was proportional to the difficulty of the decision due to varying degrees of compatibility.

Maximum S-R compatibility yields a shorter RT, but practice also has a similar effect. Mowbray and Rhoades (1959), and Mowbray (1960) argued that with sufficient practice or familiarity, RTs for degrees

1.3.3.2 (Continued)

of choice, at least up to ten, can be brought to the same level as two-choice, even though the relationship between signal and response are not entirely direct.

The next 'natural' step was to combine compatibility and practice. Davis, Moray and Treisman (1961) found that relatively little practice was necessary to abolish the difference between 2, 4 and 8 choices with a compatible task. The two-choice time remained about the same, whilst the times for 4 and 8 choices became markedly shorter.

Brainard, Irby, Fitts and Alluisi (1962) gave their subjects 2, 4 and 8 choice tasks with poor and good compatibilities. In the poor compatible conditions they found similar results to those found by Hick (1952) and Hyman (1953) and in the good compatible conditions the RTs were similar to those obtained by Davis, Moray and Treisman (1961).

Frequency of signal appearance also affects RT. For example Lamb and Kaufman (1965) and Kaufman and Levy (1966) found that with unequally likely alternatives, the less frequent response was substantially slower, and the more frequent quicker than would be expected from the equal frequency results.

S-R compatibility and practice certainly interact (Welford (1968)), and the compatible S-R combinations are probably just those that receive most practice in daily life (Crossman (1964)). However, it is now more firmly agrued that S-R compatibility and extended practice are not alternative concepts but rather tend to overlap (Rabbitt (1971)).

1.3.3.3 Reaction time in the study of attention

The technique of RT has been widely used in experimental paradigms of attention studies. The type of hypothesis and the type of designs employed in these experiments derived directly from the more basic question: can we do two things at the same time? The question usually takes the more specific form of whether we can pay attention to more than one thing at the same time, rather than whether we can do more than one thing at the same time. 'Doing' implies much more than 'paying attention', and while almost all investigators believe that response grouping and the ability to respond simultaneously are important aspects of simultaneous performance, most of them still argue that the bottle-neck is in the attentional phase and not in the executional phase.

The answer to the question whether we can pay attention to more than one thing at the same time, depends on the adaption of a single or multi-channel information processing model.

The types of RTs experiments are further complicated by the kind of situation in which the single or multi-channel models are used, to test other hypotheses. Broadly speaking the two types of situations include either successive presentation of stimuli, or simultaneous presentation of stimuli.

The RTs experiments used in studying attention will be reviewed under the following sub-headings:

1.3.3.3 (Continued)

1) Single channel models
   a) successive presentation of stimuli
   b) simultaneous presentation of stimuli
2) Multi-channel models
   a) successive presentation of stimuli
   b) simultaneous presentation of stimuli.

1.3.3.3.1 (1a) Single channel model and successive presentation of stimuli

From a chronological point of view the 'single channel' model, originated by Broadbent (1958), was developed prior to the 'multi-channel' model, and therefore more experiments were carried out under this hypothesis than under the other.

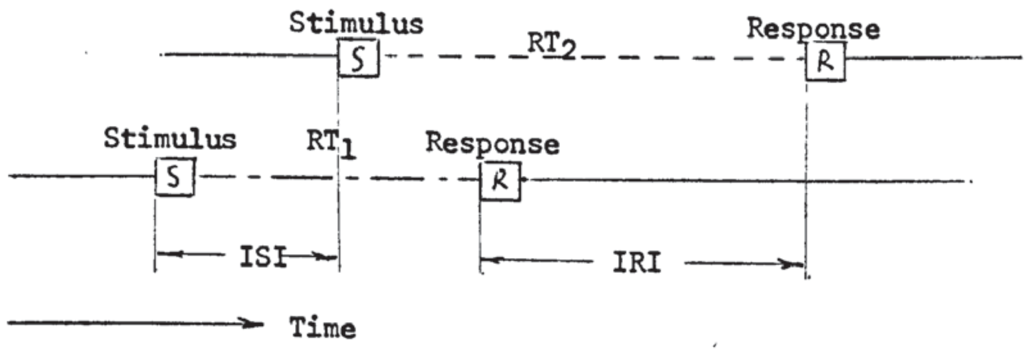
The phenomenon discussed in this paragraph is one which follows from the nearly simultaneous, or immediately successive, presentation of two stimuli to the subject. Craik (1947, 1948) is usually credited with the main discoveries and the first theoretical formulation in this area. The basic finding was that whenever two signals followed one another within 0.5 seconds, the reaction to the second signal was markedly delayed. In most cases the two stimuli were not identical, but a similar effect could be found even when the second stimulus closely resembles the first (Reynolds (1964)). The magnitude of the second signal did not seem to matter (Craik (1947, 1948)). Craik described his results in terms of 'psychological refractory period' (PRP) introduced earlier by Telford (1931). Reynolds (1964) labelled it as

1.3.3.3.1 (Continued)

'temporary inhibition of response' (TIR).

The sequence of events in a typical trial of such experiments is shown in Figure 1.3.1. The usual question is whether the subject can prepare the response to the second stimulus while still engaged in responding to the first stimulus.

Figure 1.3.1 A typical trial of a refractoriness study



The data of a RT experiment are usually presented in terms of RT_2 as a function of the interval (ISI) between the two stimuli.

Explanations of delay in responding have been advanced along traditional lines of stimulus centred, organism centred, or response centred responses:

1) The stimulus centred approach explains the results in terms of variation in signals input.

2) The organism centred approach prefers explanations such as, anticipation, set and expectancy.

3) The response centred approach discusses the results in terms of competing response tendencies elicited by each of the stimuli.

1.3.3.3.1 (Continued)

An application of Craik's original view to the RT situation derived from the single channel model was formulated by Welford (1952, 1959, 1967, 1968) and by Davis (1957). The main assumption of the single channel theory is that the response selection stage of information processing is a bottle-neck, or single channel, which can respond to only one stimulus at a time. Therefore if the second stimulus is presented before the completion of the first response it is held in storage, and its processing will begin only with the occurrence of the first response. According to such a theory if the second stimulus is presented after the execution of the first response, RT_2 should be normal. However, many experiments have shown that this is not the case, in fact RT_2 still remains longer. Davis (1957) explains the additional delay by postulating an additional central refractory state, while Welford (1952, 1959, 1967) argued that the system may be occupied for some time by the feedback from the first response. This allowance for feedback, according to Welford, is optional and will mainly occur in the early stages of practice or in complicated responses.

The role of 'preparatory set' is RT using the rapid succession technique was studied by Elithorn and Lawrence (1955). They varied the inter-stimulus interval (ISI) finding that the greatest delay to the second stimulus was at 100 m.sec. ISI. Davis (1956) used two visual stimuli and a visual auditory pair (Davis (1957)) while varying ISIs. The pattern of his results is the same in unisensory and bisensory presentation. The response to the second stimulus was always delayed in the shortest ISIs. Davis (1959) hypothesized that it is the paying of attention to a signal, rather than making an overt response to it, that

1.3.3.3.1 (Continued)

leads to a delay in RT_2. His results, although complex and not accompanied by statistics, were taken to support his hypothesis, especially in the bisensory condition. Klemmer (1956) studied the effects of 'time uncertainty' on simple RT tasks using five different ISIs. He found that RT tends to increase with an increase in preparatory interval variability. Borger (1963) presented two stimuli to the subject (auditory and visual or vice versa) and varied the ISI. The second response was found to be slower when the subject had also to make a first response, but not so when he only had to respond to the second stimulus.

Adams (1962) varied ISI and found that at less than a 200 m.sec. ISI, the bisensory condition led to a delay in response to the second stimulus. At 400 m.sec. or more, there is little evidence of the PRP. Adams and Chambers (1962) found that the bisensory group was superior to the unisensory group when the stimulus events were certain, but when the events were not certain the auditory RT tended to synchronize with the usually slower visual RT.

Welford (1968) pointed at the fact that if the two stimuli are nearly simultaneous some response grouping may occur. This tends to speed up rather than slow down the second RT. Gottsdankr, Broadbent and Van Sant (1963) found that some grouping of responses did occur and the speed of the second response was facilitated or at least not retarded. The second response seemed to be shorter than the first by about 25 m.secs. Halliday, Kerr and Elithorn (1960) presented paired stimuli with very short ISIs, or a single stimulus after a warning signal. The general finding was that a large number of second responses were not delayed

1.3.3.3.1 (Continued)

but were as fast as the first responses.

Helson and Steger (1962) reported that the first response was found to be delayed when a second signal followed the first by 10-170 m.secs. The interesting fact about this report is that the second signal was not considered a stimulus, and no response to it was required of the subject. In a second study, Helson (1964) found that at very short ISI (0-15 m.sec.) the second signal speeded up the reaction to the first stimulus. At medium ISI (25-35 m.sec.) the second signal appeared to have no effect on RT_1. At more than 50 m.secs. the second signal slowed down the first response. Reynolds (1964) interpreted Helson's results in terms of the competing response theory. In short ISI, both stimuli are perceived as one enhanced stimulus. It is a well-known fact (Woodworth and Schlosberg (1954)) that RTs tend to decrease as the intensity of the stimulus increases. Hence, the quickening of RT for very short ISI. In the long ISI there are competing responses, which slow down the first response. In the medium ISI there is the combined effect of grouping stimuli and competing responses, and since both effects are opposite, there is a mutual cancellation and no effect on RT_1.

Nickerson (1970) asked his subjects to respond as quickly as possible to a visual stimulus that either preceded or followed an auditory stimulus by a variable interval. He measured the RT to the visual stimulus as a function of ISI. The effect of the occurrence of the tone was considered to be facilitated, the degree of facilitation increased, to a point, with the duration of the tone light interval. He also found some facilitation even when the light which preceded the tone providing

1.3.3.3.1 (Continued)

the interval was sufficiently brief.

Single channel theory argues that division of attention between response processes is impossible. This is not tenable in view of the vast amount of evidence indicating that attention is often divisible. Nevertheless, single channel theory has often been viewed as the dominant theory in this area (Bertelson (1966); Smith (1967)).

1.3.3.3.2 (1b) Single channel model and simultaneous presentation of stimuli

Most of the experiments reviewed here are derived from the basic single channel theory. The experiments employing simultaneous presentation of stimuli have mainly tried to break away from shadowing as the means of analysing what heppens in selection.

Treisman and Geffen (1967) required listeners to shadow one of a pair of dichotic messages. In addition they had to make a tapping response if they heard a crucial target word, either in the accepted or in the rejected message. They found that the number of tapping responses to target words in the rejected message was very much lower than to those in the accepted message.

Moray and O'Brien (1967) asked their subjects to tap a right-hand key when they heard a target in the right ear, a left-hand key when they heard a target in the left ear, and both keys when they heard targets in both ears. These studies and other similar ones (for example, Lawson (1966); Moray (1970a, b)) although they cannot be accounted

1.3.3.3.2 (Continued)

as RT experiments in the traditional manner, help in further understanding other RT experiments. In several experiments (Morrel (1968); Bernstein, Clark and Edelstein (1969a, b)) the intersensory affect is defined by more rapid RT to a combination of auditory and visual stimulation than to visual stimulation alone. The theoretical question is how the auditory event, which in many studies is the irrelevant signal, can affect RT within a single channel theory. Bernstein (1970) points out several possible solutions: either it is assumed that the irrelevant event can pass at the same time as the relevant event, thereby dropping the single channel assumption, or it is assumed that non-attended and unprocessed events can affect performance. It is also possible that highly correlated inputs from different modalities may proceed along a single channel. Bernstein himself assumed that stimulus intensities may add across modalities, causing the joint event to be effectively stronger, and he further assumed that response preparation may proceed in parallel and may be initiated by non-attended stimuli. His basic model remains that of a single channel.

Lehtiö (1970) reported on an RT experiment in which the subject looked for a target defined by a combination of values of several attributes. He concluded from the research that processing is serial, which is compatible with a single channel model, but in a fixed order which could be manipulated by differential training. The model also advocates a self-terminating search.

Rabbitt (1971) argued that almost any conceivable empirical results that suggest a serial, fixed order, self-terminating process can also

1.3.3.3.2 (Continued)

be interpreted in terms of a parallel, distributed, self-terminated one. The theoretical issues and the evidence have been much reviewed by Nickerson (1967, 1969), Donderi and Zelnicker (1969); Hawkins (1969); Cohen (1970); Donderi and Case (1970); Downing and Gossman (1970); Marcel (1970) and Rabbitt (1971).

1.3.3.3.3 (2a) Multi-channel model and successive presentation of stimuli

Theories advocating a multi-channel processing system, or the ability to process signals in parallel, differ in many ways as to what is the nature of operation of these parallel channels. The experiments reviewed here have in most cases the same paradigms and the same design as those reviewed under the single channel models, only their hypotheses and conclusions are different. Finally this paradigm of successive presentation of stimuli used under a multi-channel hypothesis is quite rare, since usually the investigators tend to use a simultaneous rather than a successive presentation of stimuli.

Posner (1969); Posner, Boies, Eichelman and Taylor (1969) employed a 'same - different' technique, in which the subject sees a single letter for a brief period of time, followed after a variable interval by a second letter. The task is to respond as rapidly as possible 'same' if the two letters have the same name or otherwise - 'different'. Posner argues that the first letter has two functions: it serves as a warning signal and also tells the subject what letter he is looking for. What happens during the interval between the two letters depends

1.3.3.3.3 (Continued)

greatly, according to Posner (1969); Posner and Boies (1971), on how the attention of the subject is directed. If the subject knows that all the matches are to be physically identical, he maintains his speed much better than if some matches are to be based on the name. It is also important whether the first letter disappears or remains present during the interval. Posner and Boies (1971) found that a stimulus may be used to increase alertness for processing all external information, to improve selection of particular stimuli, or to do both simultaneously. They argue that encoding a stimulus may proceed without producing interference with other signals. In fact Posner advocated at least some parallel processing, based on his experiments of successive presentation of stimuli.

Karlin and Kestenbaum (1968) carried out a similar experiment to that of Smith (1969), in which they studied five different combinations of RT tasks. Their data shows very small variation in the inter-response interval (IRI) for all conditions. The complexity of R_2 had very little effect on the IRI functions.

Keele (1973) has further developed the findings of Karlin and Kestebaum. He separated the stages of information processing into two sets:

1) perceptual analysis and response selection
2) initiation and execution of responses.

He argued that the first set does not require attention while the second does. Therefore, the earlier operations occur in parallel and without interference, while the second, the response-related operations, are mutually interfering. Kahneman (1973) argues that Keele's position that the processes of perceptual and retrieval do not depend on attention is similar to the views of Deutsch and Deutsch (1963) and Norman (1968)

1.3.3.3.3 (Continued)

which, according to Kahneman, are inadequate. However, he himself reinterpreted some of the findings previously advocating a single channel model, and showed that they could very well demonstrate the opposite (i.e. multi-channel model).

He argues (1973 p.165) that the survival of single channel theory in the face of massive contradictory evidence, can be at least partially traced due to the tradition of plotting experimental results of RT_2 as a function of ISI. He claims that plotting the interval between the first and second responses (IRI) as a function of the interval between the two stimuli, yields a better understanding of information processing. In re-presenting and re-interpreting the results found by Smith (1969), Kahneman demonstrates that the data violate drastically the predictions of single channel theory and that some of the processing must be parallel. This implies that as soon as the second stimulus is presented some attention is allocated to the processing of this stimulus even though the first response has not yet been executed. Furthermore, the amount of attention devoted to the second stimulus increases steadily during the latency of the first response. Kahneman argues that these results are typical of a large number of studies (e.g. Bertelson (1967a, b); Broadbent and Gregory (1967, exp.1); Nickerson (1967); Sanders and Keuss (1969)). Similarly, Ninio (1975) re-analyses the findings of others. She concludes that for the same inter-stimulus interval, the more complex the first reaction, the more the second response is delayed.

1.3.3.3.4 (2b) Multi-channel model and simultaneous presentation of stimuli

Most of the experiments reviewed here employ a similar paradigm, the simultaneous presentation of two stimuli and the request to respond to both. For example, Kahneman (1973) reports an experiment done by Colavita. He asked his subjects to press one key when they heard a tone and another key when a light was flashed. The unexpected simultaneous presentation of light and tone led in most cases to only one response - that of the light. However, the subjects could very easily learn to respond simultaneously to both stimuli.

Lawson (1966) played two prose messages to listeners and required them to shadow one. They also had to tap whenever a target - tone burst - was heard in either of the messages. She found that all the targets were responded to. Her results are not compatible with those of Moray (1970a, b) who argued that time-sharing lowers performance. Moray and Fee (in Moray (1969a)) repeated Lawson's experiment and found that while about half of their subjects behaved like Lawson's, the others showed very markedly inferior performance in detecting pure tones in the non-shadowed ear.

Moray and Jordan (1966) presented three pairs of digits in the same way as Broadbent (1954). However, they provided subjects with a 'Palantype' (stereotype) in which two keys can be pressed simultaneously, so that they could also output in parallel. The results show that subjects could perform with a high degree of efficiency. They also found that after practice subjects could recall the digits vocally by alternating between the ears while Broadbent's subjects, if not

1.3.3.3.4 (Continued)

practised, could not do so.

Flaherty and Coren (1974) measured the RT to target words in both ears in a shadowing and in a non-shadowing condition. Although their hypothesis was about attenuating signals in the non-attended channel, their findings could be interpreted as demonstrating that processing takes place in both channels simultaneously. In fact subjects perform better in divided attention, without shadowing, than they perform on the shadowed channel.

Schvaneveldt (1969) faced his subjects with four display units and four response buttons. On a trial, a single numeral was shown in one of the units and the subject responded by pressing the corresponding button and by saying a letter corresponding to that numeral. Schvaneveldt compared the observed latencies of the manual and of the verbal responses to two theoretical models: the multi-channel and the single channel. According to the former model, both responses ought to be independent and therefore any of the RT should be the same, regardless of whether it is performed in solitary or in conjunction with another response. The latter model advocates that the two responses can only be executed in strict succession. Therefore the slower RT should be equal to the sum of the latencies of both responses in the corresponding single task conditions. The results do not fit any of these models. The RTs were too long to be considered as fully independent from each other and were too short to be considered as being processed in succession. At a later stage in this thesis a model will be developed which proposes to explain the fallacy of the independent channel and

1.3.3.3.4 (Continued)

of the single channel. This last point is true for most of the RT experiments carried out in order to study human attention. Those investigators who held the single channel view cannot give an adequate account for the experiments which demonstrate parallel processing. On the other hand, those who hold the view that each channel can be processed independently of the others, cannot give an adequate account for the situation in which the parallel processing was either deteriorated or broken down into serial or succession performance.

It is quite clear that if a model is to give full account of these and other studies, it must give allowances for some parallel processing, but at the same time also account for purely serial processing on some occasions. It must also predict (or explain) what types of processing will take place in various situations.

1.4 Functional Hierarchical Model of Human Information Processing

1.4.1 Performance is a function of the sensory, central and motor systems. Its future ultimate explanation will be physiological. Meanwhile, according to Crossman (1964), the psychologist aims at three things:

1) To enumerate the functional elements required to produce observed performance.

2) To state their properties.

3) To analyse the complex interaction between the operator, with specific internal functions, and the task with known dynamic properties.

The model which is set up in this thesis has relevance to all these aims. It proposes to look into attention and the internal processing of information. After the seminal work of Newel, Shaw and Simon (1958) on the construction of computer programs to solve symbolic logic problems, followed a very large literature which developed the "information processing" approach, using computer programs to model specific tasks. Its central theme is that there is a valid analogy between a human being and a computing system. System, in this context, is the key word. According to Hunt (1971) the analogy is drawn between the interrelationships among components in a large computing system and the interplay of human capabilities. The analogy refers to the system functional architecture, not to the physical system components.

According to Hunt's approach and following the pattern laid down by Singleton (1974) the description of the model will be described in

1.4.1 (Continued)

three stages:

a) Structural analysis of the system.

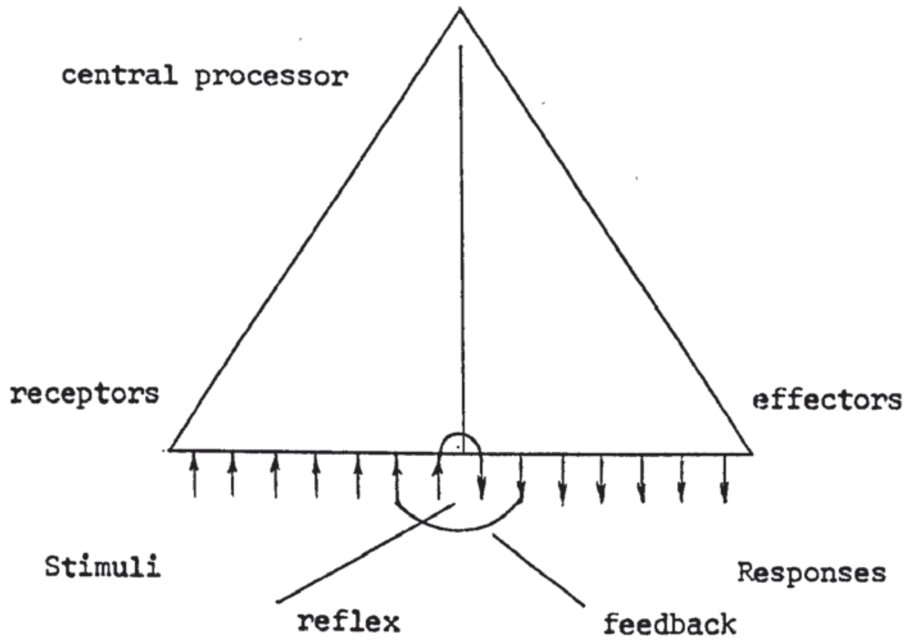
b) Functional analysis of the system.

c) Characteristics and dynamics of the system.

1.4.2 Structural analysis of the human information processing functions

Figure 1.4.1 shows the principal architecture of the information processing functions in the human.

Figure 1.4.1 - Principal architecture of information processing functions in the human



The diagram represents two dimensions:

1) The horizontal dimension: Stimuli responses. This dimension includes all the stimuli detected by the human and the whole range of human responses.

2) The vertical dimension: A functional hierarchy. The 'stimulus functional hierarchy' is composed of three main stages: the receptors which detect the external and internal stimulation; the encoders which translate the external signals into an inner language; the central processor, which for the time being, represents all the necessary components which process the information and make the decision.

1.4.2 (Continued)

The 'response functional hierarchy' is composed of similar stages in reverse order: the first stage takes place in the central processor where the taken decision is interpreted and is transferred to the following components. The following main stage is the decoding of the inner command and the final stage takes place when the relevant effectors respond.

The model suggested here can be considered as an information flow model, and has its roots in similar flow models developed earlier, e.g. Broadbent (1958), Crossman (1964), Singleton (Singleton, Easterby and Whitfield (1967)) and Welford (1968).

1.4.3 Functional analysis of the human information processing model

1.4.3.1 The main feature of the model is its hierarchy of functions. This hierarchy appears as a symmetry, in which incoming signals have to be processed through several stages until a decision is made regarding the response. This decision must also undergo several stages of interpretation until the appropriate response takes place.

The model developed in this thesis is concerned only with the first half of this through-put, namely from the stage in which signals are received by the human, to the stage where a decision about the response takes place.

1.4.3.2 The hierarchy of functions in this model - in analogy to hierarchies of social organizations - is characterized by several aspects:

1) Functions at the top of the scale control the functions which are at the bottom of the scale.

2) At different levels of the hierarchy, different levels of functions take place. The higher the function the more central, (from the point of view of the system as a whole), will its activity be.

3) Different levels of the hierarchy have different processing capacities. The higher the level the more limited the information processing capacity.

These last two points imply that lower functions have the capacity to make a simple process on a vast amount of signals. Higher functions however, are limited in the amount of data which they can

1.4.3.2 (Continued)

handle, but they possess the ability to carry out very complicated processes. Important discussions have to be taken at high levels in the hierarchy. The complexity of such a decision is high, and therefore it can be provided only by the higher levels.

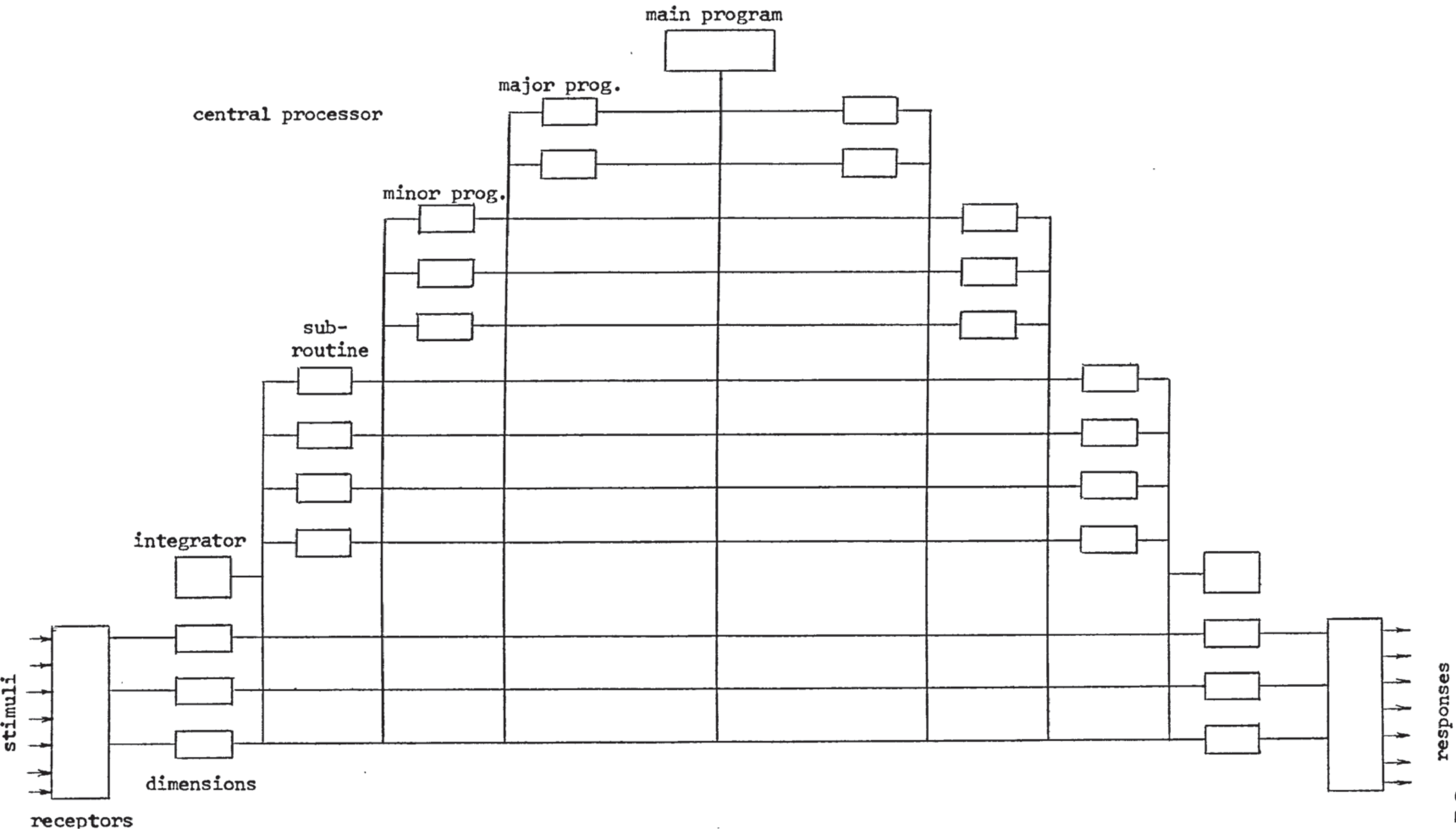
Information theorists often make the mistake of calculating the amount of information transmitted by a system without attempting to assess its importance to the system. This may prove to be a valid method when dealing with mechanical-communication systems, but not always applicable in systems where man is one of their components. The question whether to have a cup of tea or not to have a cup of tea, bears the same amount of information as Hamlet's question "to be or not to be ...", only the levels differ.

4) At each level in the hierarchy different functions specialize in processing different types of information. In other words the proposed model is of specialized functions - a particular process is carried out by the specialized function at the level which corresponds to its importance and complexity.

1.4.3.3 Figure 1.4.2 is a more detailed account of Figure 1.4.1 and represents the interrelations and interactions among the components of the information processing system.

1) The lowest level of the system is composed of the receptors. Their function is to sense the inner or outer world and to provide the central mechanisms with the necessary data for immediate course of effector action, and for the build up of a store of data for future use.

Figure 1.4.2 The human information processing system



1.4.3.3 (Continued)

The sense organs produce a continuous output with high information rates. For instance, it is reported by Crossman (1964) that a speech wave carries some 10,000 bits/sec. The visual system alone can transmit information to the brain at the rate of 4.3 10^6 bits/sec. (Hunt (1971)). Hunt also reported that silent reading proceeds at about 45 bits/sec.

The information which reaches the receptors must be translated to an inner language understood by the system. Crossman (1964) argues that there is an encoder which uses a code book. He also assumes the existence of peripheral "filters" which reject all but a small proportion of the incoming data. The receptor system will then decide between a fairly small number of alternative patterns corresponding to spoken words, physical objects, and so on. Crossman concludes: "The output from the receptor system is a sequence of so called "perceptual responses", giving a summary description of the environment in a prearranged code."

Hunt (1971) has a different approach. His model of the receptor system is computer-like with a transducing mechanism, a memory register, and a feature detection unit. Hunt stresses that the feature detection unit is an essential step in the process.

It is true that feature detectors have been found in the visual system of a number of animals: the frog - Lettvin et al. (1959), the cat - Hubel and Weisl (1968); Weisl and Hubel (1966). On the other hand, generally, complex specific visual detectors located at the periphery are characteristic of animals low in the

1.4.3.3 (Continued)

phylogenetic scale, while the higher vertebrae have more general feature detectors located in the cortex (Weisstein (1969)).

Most animals interpret objects according to their physical features, while the human carries the interpretation on to a meaningful level. The amount and degree of physical differentiation and interpretation needed by the human, in order to later achieve a meaningful integration of the information, is great. Therefore the human central processor and the peripheral systems have different architecture and different functions to those of lower level animals, and hence the different physiological findings.

2) The model proposes that the interpretation of the signals takes place on different dimensions. To be descriminate, objects must differ on at least one sensory dimension, and this limiting condition has been studied by varying the number of alternatives in so-called "absolute judgement" experiments. The capacity to judge each dimension is surprisingly small - about 3 bits per judgement at the most (Miller (1956)). For instance, that for tones identified by pitch alone and presented in random order is 2.3 bits, corresponding to about 5 error-free categories (Pollack (1952, 1953)). As more dimensions of variation, such as loudness and duration are added, the total information rises but the information for each dimension falls off (Pollack and Ficks (1954)). We may therefore conclude that the human extracts a little information from each of many dimensions, in order to recognize objects.

Hick (1952) argues that the reception system probably possesses a large permanent store of patterns, Gestalten, or templates for

1.4.3.3 (Continued)

recognition. Most of them are presumably formed in childhood (Hebb (1949)), but new ones are acquired later in life through learning and experience. Belbin (1958) argues that this perceptual learning amounts to a great deal in the acquisition of skill.

Lawrence and Laberge (1956) experimented with stimulus cards bearing objects that differed in colour, form and numerosity (four values per dimension). The cards were presented tachistoscopically. There were four types of instructions to the subjects, among them: Emphasis - when subjects were asked, before stimulus exposure, to pay primary attention to one dimension only, but to report on all three; Ordered - when subjects were asked to pay equal attention to, and report on, all three dimensions, but the order in which they were to be recorded was specified immediately after the exposure of the stimulus.

The results of the 'Emphasis' condition indicated that an emphasized dimension yielded significantly more accurate reports than the unemphasized dimensions. However, it was also reported that under 'Ordered' instructions, the difference in accuracy between the first recorded dimension and the average of the other two, was as large as the differences between the emphasized and unemphasized dimensions. These results suggest that the effect of emphasis instructions is to determine the order in which dimensions are reported, and this order, in turn, determines the accuracy of reporting. The authors concluded that the effect of an instructional set was on memory, rather than perception. However, Egeth (1967) argues that emphasis may

1.4.3.3 (Continued)

effect the order of reporting, but it has an influence greater than that attributable simply to order of reporting.

Harris and Haber (1963) (this study was replicated by Haber (1964)) argue that the order in which data was reported may not be as important a factor as the order in which data was put into storage. A pilot study indicated that almost all subjects encoded complex visual stimuli verbally and rehearsed them silently until the report was required. Their investigation suggested that adequacy of recall for a particular stimulus dimension may depend upon the state of the image at the time when information concerning this dimension is encoded into memory.

Harris and Haber's stimuli were similar to those used by Lawrence and Laberge. The order in which dimensions were to be reported was specified after the stimulus presentation. The main experimental manipulation was the induction of various "strategies" in subjects. Each group of subjects was instructed in the use of one of two basic verbal codes, which subjects in the pilot study had used spontaneously. These were: Objects code and Dimensions code.

The critical finding was that the code used by a subject, determined whether or not his accuracy of reporting was affected by attention instruction. Objects - coders were less able to adopt to the demand of Emphasis instructions than were Dimensions - coders. Harris and Haber found higher error rates on unemphasized dimensions than on emphasized dimensions, even for those instances when unemphasized dimensions were reported first. This indicates that temporal delay

1.4.3.3 (Continued)

of reporting cannot be the sole cause of the inferiority of unemphasized dimensions. Egeth (1967) suggests that the Dimensions code allows selective attention to occur, since Dimensions coders may give preferential treatment to an emphasized dimension by encoding it first. An Objects coder would have difficulty exhibiting such flexibility.

Harris and Haber (1963) show that in the experimentally naive population there are both Objects coders and Dimensions coders.

To summarize, all these studies indicate the existance of the "dimension - encode" as a distinct stage in the information processing system.

3) The following stage in the present model (Figure 1.4.2) is perceptual integration. Its function is to integrate the outcome of the dimensional functions into a meaningful identification of an object or an event. Relatively little is known about this level. Language studies (Yngve (1962)) drew attention to its importance. However, identification is not a crucial stage in processing information. People are capable of functioning in situations, where they cannot fully identify all the surroundings. Even if the surrounding can be identified, people can react to a particular dimension before the completion of the identification. For example, it is possible to react to red objects, before we even identify what exactly they are. It is also possible to physically identify two letters as being the same before fully recognizing their names (Posner (1969, 1970); Posner and Mitchell (1967); Posner, Lewis and Conrad (1972)).

1.4.3.3 (Continued)

It has been stated earlier that higher levels of processing have an option to intervene with lower levels. In this case higher levels can extract the information produced by the dimensional decoders even prior to the integration of several of them. Furthermore, many studies of the information processing in speeded tasks have demonstrated that subjects are capable of very effective gating of irrelevant dimensional information. Fitts and Biederman (1965), based on Morin, Forrin and Archer (1961), provide a clear example of this technique. Subjects were told to ignore the number of objects and to respond as quickly and accurately as possible on the basis of the shape of the object(s). A control group received only single objects. There were no differences between the two conditions in either information transmission rate, or medium reaction time.

Imai and Garner (1965) using a card sorting task, showed that sorting time depended on the discrimination of the relevant dimension but not on the discrimination of the irrelevant dimensions.

4) The last stage in the information processing model (Figure 1.4.2) is the central processor. The central processor is composed of a network of sub-routines (or programs) organized in a functional hierarchy.

Processing of information takes place at all the levels of the functional hierarchy. In that respect, there is a difference between the way in which the low and the high level sub-routines (or programs) operate.

1.4.3.3 (Continued)

The main characteristics of the low level sub-routines are:
It is a peripheral activity, simple in its operation and single purpose. It is a very specialized and specific operation, limited in its scope and relatively short. The program itself is pre-arranged, extremely rigid with very few 'degrees of freedom', or very little room for modification. Its main operation is carried out as the interpretations and transformations of physical features.

Examples of simple activities and interpretations can be the distinction between a continuous line and a dotted line; a straight line and a curved line; a green card and a yellow card; a moving object and a stationary object.

The characteristics of the sub-routines gradually change as we go up in the functional hierarchy, from the lower to the higher levels.

The high level of the information processing hierarchy is characterized by the fact that:
It is a central activity, complex in its operation and multi-purpose. It is a very generalized and difused operation, extended in its scope and relatively long. The program itself is adaptable, extremely flexible with many 'degrees of freedom', or with a lot of room for interpretation. Its main operation is carried out on the interpretation and transformation of meaningful features.

For example: landing an aircraft, a surgical operation, writing a scientific article.

1.4.3.3 (Continued)

Besides processing of information there are other activities which take place in the central processor:

a) Control: the determination of activity. It is possible to differentiate between two types of control activities:

Inter-program - the decision as to which programs or sub-routines will take part in a particular process.

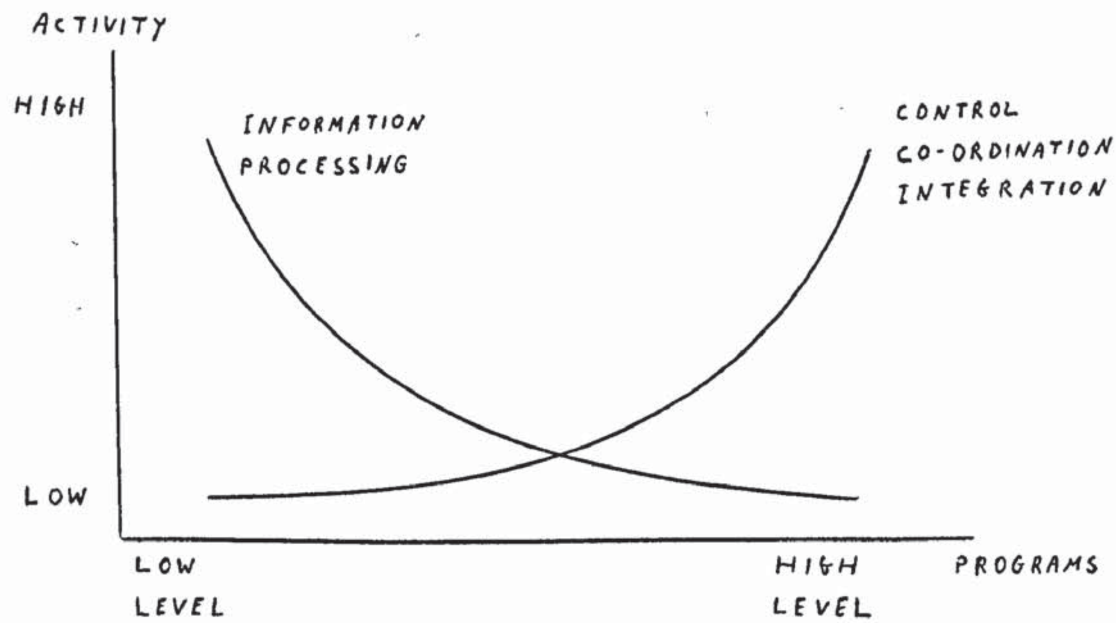
Intra-program - the decision as to what is the function or process which will be carried out by each individual program or sub-routine.

b) Co-ordination: the determination of the order or sequence in which the functions will be organized.

c) Integration: the building up of separate functional outcomers into a connected whole.

These activities of control, co-ordination and integration are characteristic of the higher level programs. There is a gradual increase in these activities as we climb up the functional hierarchy. This increase is accompanied by a gradual decrease in the information processing activity (Figure 1.4.3).

Figure 1.4.3 Hypothetical activities in the central processor



1.4.3.3 (Continued)

The decrease in the amount of information processing in the higher levels refers to the hypothesis that all the incoming information must pass through the low level programs, while only a small part of this information will reach the high levels. In that respect the higher levels process less 'bits of information' than the low levels. However, as it was mentioned earlier, there is a difference in the importance of the information reaching them.

The lowest levels are almost entirely involved in the most elementary stages of information processing, with very little or no control co-ordination or integration activities.

The ascent in the hierarchy brings about a gradual reverse in the amounts and types of activities.

The highest programs are predominantly involved in integration, co-ordination and control activities, leaving very little room for information processing.

The way in which the system operates is analogue to the functioning of the social organization of a factory:
At the lowest level of the organization there are the people who are involved in production activities with little or no management duties. The higher the place in the organizational hierarchy the more managerial functions of control and co-ordination become part of the duties.

1.4.3.3 (Continued)

At the top of the hierarchy a minimum amount of time is devoted to production activities, the major involvement being in important decisions which concern the control and co-ordination of other peoples activities.

1.4.4 Characteristics and dynamics of the human information processing model

This part of the theory deals with the functioning or 'working order' of the proposed model. Several characteristic aspects are put forward:

1.4.4.1 Flexibility scale

It has already been mentioned that the periphery of the system, the lower parts of the pyramid, has a very limited and rigid scope of functioning. In other words sensing, encoding and certain operations on dimensions (size, contours, hue, loudness, pitch etc.) are fairly fixed and pre-programmed. Being sensitive only to specific physical energies and operations which derive from such signals. In the middle of the hierarchical scale, operation changes into processing sets of stimuli, rather than particular physical energies. At the top of the scale processing takes place in accordance to meanings and consequences regardless of the type of stimuli sets. In other words, a complete change takes place from a rigid system to an extremely flexible one, offering a whole range of degrees of flexibility.

The lowest possible level of processing in this model is the 'reflex arc'. In functional terms it is 'the shortest possible pathway between the receptors and the effectors'. It is regarded as a very peripheral activity which does not reach the central processor. This does not mean to say that after such an action takes place the central processor is not aware of what has happened. Nor does it mean that a reflex cannot include vast organism changes such as EEG, GSR or vegetation processes (circulatory, respiratory, electro-cutaneous and pupillary) as many of the U.S.S.R. psychologists

1.4.4.1 (Continued)

have demonstrated (see Razran (1961) and Berlyne (1963)).

A feedback, in terms of this model, is 'the shortest possible way between the effectors and the receptors'. It is required by the higher programs to keep track of the performance and to make necessary adjustments in the performance. Any distortion in the normal manner of the feedback such as spatial or temporal delays, or displacements, causes disturbances and distractions in the normal manner of performance. Lee (1950) was the first psychologist to experiment with time based delayed auditory feedback. Ram (1971) changed the time based delay into a syllable or speech pulse delay of auditory feedback. The new technique utilized a mini-computer and produced a delay which always lagged by one syllable. Smith (1962) delayed various sensory feedbacks, spatial and temporal. They all demonstrated the distractive effect of distorted feedback. Training under delayed feedback conditions (Ram (1971)) had no significant effect in improving the performance.

1.4.4.2 Specializing functions

The specialization of function is two dimensional, and they correspond to the dimensions in Figure 1.4.1. The vertical dimension varies along the axis of meaningfulness orientation. One extreme of this continuum is meaningless while the other is meaningful. The meaningless operations have a physical basis whereby the lower parts of the hierarchy carry out operations based on the conversion of physical energies and other logical

1.4.4.2 (Continued)

operations based on physical features of the information. Further along this vertical dimension, the nature of the operation changes into a less and less physically meaningless process, into a more and more meaningful type of processing.

The horizontal dimension varies along types of processing. One part of this dimension specializes in receiving and interpreting stimuli, while the other part is interpreting and carrying out the responses. There is further specialization within each part. In the receiving stimuli part, there is the allocation of function, where one particular type of information is dealt with by a certain part of the system and another type by another part. A parallel allocation of functions exists in the part which carries out the responses. Particular responses are carried out by certain parts of the system and others by other parts.

The two specializing dimensions interact to create a whole range of possible processing functions.

For example, at the receiving lower part, different receptors specialize in processing certain types of physical energies. Therefore in order to receive visual information we must use our eyes and we cannot use our nose. Only specializing receptors are sensitive to red light, while the others are invariant to its existence. Further along the functional hierarchy, programs are specialized in processing particular meanings. For example all the hand-written 'a' letters, regardless of their physical size or handwriting, will be processed by the same specializing program. Broadbent (1971)

1.4.4.2 (Continued)

spoke of a slow process of categorizing which leads different stimulus configurations which are associated with the same response (such as the example given above) to eventually elicit the same perceptual interpretation.

High along the functional hierarchy, programs are very flexible, but even then, according to the present model, a particular program may process letters and printed materials, another may specialize in interpreting facial expressions in social events, a third may specialize in identifying motor vehicles and so on.

A computing system can be a good analogy to demonstrate specializing functions. At the peripheral level components are specialized in either inputting or outputting information into the system. An inputting device such as a cards-reader is specialized only in reading cards and is useless when it comes to reading paper tapes. A particular multiplication sub-routine is capable to perform its duty regardless of whether the initial information originated from a tape-reader or a card-reader. It is not, however, very useful in extracting square roots.

Calling the central processor an 'all purpose processor', only means that it is capable of accepting a variety of specializing programs. However, the specialized program must be written into the central processor in order to enable it to perform various types of processing.

1.4.4.3 Selection and filtering of signals

No sensory motor perceptual theory claims that there are no limitations to the capacity to process information, and this theory does not differ from the others in this respect. Most of the arguments among the theorists revolve around the question as to where are the limitations. In other words where is the 'bottle-neck', where does the narrowing of the stream of information take place.

Most experiments about the nature of selective attention and the narrowing of the stream of information have centered on tasks that require the subject to select inputs, or to filter information. In general, a person is said to select inputs when he focuses attention exclusively on stimuli that originate from a particular source, or share some other characteristic feature (Kahneman (1973)). Selection in these experiments takes place, usually, while the subject attends one task and ignores the other. Many studies have used shadowing tasks, or designs in which at least one of the simultaneous tasks is a shadowing task. The reason for using shadowing tasks, as put forward by Broadbent (1958), is that auditory attention can be studied without the encumbrance of the orientation movements which dominate visual attention.

More than twenty years ago experiments (Broadbent (1952); Cherry (1953); Mowbray (1953); Poulton (1953); Webster and Thompson (1954)) showed that if a man must deal with competing messages there is a point at which his performance is likely to break down.

1.4.4.3 (Continued)

Broadbent argues that stimuli are analysed according to their physical features and only those which arrive to the designed 'channel' are allowed to penetrate further into the P-system. The relevant stimuli are distinguished by a simple operation of the filter, mainly by discrimination of some physical features, such as location, pitch, type of voice etc. or by any other physical feature. In the absence of a clear physical distinction between a relevant and irrelevant message, selection is extremely difficult if not impossible altogether. Selection by semantic class, or by language, requires that the subject adopts a response set (Broadbent (1970), (1971)), because the relevant items are defined by a common set of responses rather than by common stimulus features. Broadbent, however, also presents evidence (1970) that response-set is generally much less effective than stimulus-set.

According to the filter theory, there is no diversion of attention and no parallel processing of discrete stimuli in the P-system. The apparent division of attention in the performance of concurrent activities is mediated by alternation between channels or between acts. Broadbent (1958) assumes that the minimum dwell-time of the filter is about 250-500 milli. seconds.

In the concepts of the present theory, Broadbent's filter is a peripheral, low level mechanism which selects inputs mainly according to some physical criteria. Filter theory provides a useful approximation of what people are capable of doing, but as Kahneman (1973) puts it, virtually all the predictions of filter theory about what people cannot do have been disproved. The idea

1.4.4.3 (Continued)

of a slow moving filter that selects one stimulus at a time is not viable.

Moray (1969) argues that with minor changes, Broadbent's model is correct. He postulated a filter than can alternate very rapidly between channels. When an important stimulus is recognized, the filter remains locked on that channel until its processing is terminated. Sampling may be continued on one channel indefinitely until the switch is 'called' by another channel. While sampling one message, all the others are totally rejected. These assumptions explain why a single target is easily detected in divided attention, while an either/or pattern of detection is approximated with simultaneous targets. However, it was pointed out (Treisman (1972)) that performance with such targets is actually too good to be explained by a strict application of Moray's theory. His theory assigns an extremely important role to the timing of stimuli from different messages, while synchronization of inputs does not appear to be particularly important in divided attention (Treisman and Davies (1973)). Kahneman (1973, p. 142) argues that one of the students at his department found that the factor of ear dominance is important at such near synchrony situations, rather than the precise temporal relations between the onsets of stimuli.

In terms of the present model Moray's switch is a mechanism placed in medium or low level programs. The switching operation is determined by the incoming signals. Moray's switch is placed at a higher level in the processing hierarchy than Broadbent's filter, because it is capable of switching also according to the meaning of messages, rather than only according to their physical features.

1.4.4.3 (Continued)

Treisman (1960, 1967d) proposed a modification of the filter theory which Broadbent (Broadbent and Gregory (1964)) subsequently accepted. The modification was simply that filtering is not an all or nothing process: the rejected message is merely attenuated, not eradicated. On one hand the messages are analysed for crude physical properties (loudness, pitch, position, hue, brightness etc.). On the other hand, the unattended messages are attenuated - weakened.

The 'dictionary units' have different thresholds, which must be exceeded for perception to occur. The differing thresholds are mainly a function of the significance, probability, or emotionalism of the stimuli. Therefore even an unattended signal can be perceived provided it is above the blocking threshold.

A major deviation in Treisman's model, from the filter theory, is her proposal (1969) that a single input can be processed by several analysers in parallel (this applies also to two different signals). The constraints are that one analyser cannot analyse two signals simultaneously, only one at a time.

Attention, according to Treisman, is in fact a two stage process, since firstly there is filtering on the basis of the channel characteristics, and secondly by the threshold setting of the dictionary units. The major physical change in the characteristics of a rejected message is invariably recognized (Lawson (1966), Treisman and Riley (1969)). It is easily detected because it reaches analysers that are not occupied with the relevant message.

1.4.4.3 (Continued)

In the concepts of our theory, Treisman's filter-attenuation theory is a mechanism, set at a higher level to the one proposed by Broadbent. It operates on either the lower levels or the medium level processing programs. Some of the selections of the incoming signals are based on rigid physical operations, which are characteristic to dimensional operations. Other selections, however, are based on probabilities or further interpretations which take place in sub-routines or in low level programs in the central processor.

Deutsch and Deutsch (1963) criticize Treisman's model by arguing that it is redundant, and that by suitable altering of the properties of the dictionary the lower level filter is made unnecessary. They locate the transition from parallel to serial processing closer to the ultimate response than does the filter theory. Attention does not affect the degree to which the mechanism is activated by sensory stimulation, but rather, among the concurrently active central structures, the one with the highest weighting of importance is selected to control awareness and response. In the terms of signal detection theory, the important parameter is a criterion bias (Beta-β) favouring the relevant items. This contradicts Treisman's argument that the important parameter is a reduction of sensitivity (d') for unattended stimuli.

The placing of the selector mechanism, close to the ultimate response, led others to call their theory 'response selection', although they regard it (Moray (1969b p. 35) as selecting incoming signals.

1.4.4.3 (Continued)

Norman (1968) attempted to reformulate the 'Deutsch's theory'. He proposed central units which accept two types of inputs: sensory and pertinent. The latter are equivalent to the heights-weights proposed by Deutsch and Deutsch. Norman explained the operation of stimulus-set by assuming that the activation of a recognition unit is a gradual and recurring process. His theory, like Treisman's, accounts for the effects of context and word significance in selection by criterion bias. However, Norman also explains filtering as a criterion effect, while Treisman argues a reduction of sensitivity (d').

Reynolds (1964) proposed another response selection theory of temporary inhibition of response. When two stimuli are presented simultaneously there is a genuine perceptual process which involves a temporary inhibition of response. His theory has little explanatory or predictive value, and in many cases it just redescribes or verbalizes the phenomena.

In terms of the theory developed in this thesis, Reynolds is mainly emphasizing the limitation of the system, after the decision making has taken place in a high level program. Although Reynolds is not always consistent in his adoption of a response orientated theory, (also see Moray (1969b p. 35), we may conclude in terms of the present theory, that somewhere between a high level program and the effectors, the parallel processing turns into a successive one.

According to Neisser's theory (1967), perception is an active process of analysis by synthesis. Perception is an act of construction, and the role of attention is to select the percepts

1.4.4.3 (Continued)

that will be constructed or synthesized. Neisser (1967) argues that irrelevant or unattended streams of speech are neither filtered out nor attenuated; they fail to enjoy the benefits of analysis by synthesis. One of his main ideas is that selective attention consists of the allocation of a limited capacity to the processing of chosen stimuli and to the preparation of chosen responses. Although Neisser objects to the image of a filter, Kahneman (1973 p. 126) claims that the selection of messages for synthesis is indistinguishable from the operation of a filter. He claims that there seems to be no prediction to separate Neisser's view from Treisman's attenuation theory. Neisser's theory attributes the effects of significance and context to the role of expectations in the process of synthesis. It also assumes a crude and global analysis of rejected messages.

In terms of the present model, Neisser argues that selection takes place after the different incoming signals have been analysed and processed, at least to a certain degree. Meaning that stimuli will be encoded in parallel and will even be processed according to their different dimensions, until at least a medium level program will try to process a logical construction by rejecting the 'parts which do not fit'.

Hochberg (1970) presented a similar view to Neisser's, but he implied a separation of detailed perceptual analysis from awareness while Neisser did not. Hockberg describes perception as the confirmation of a set of expectations. Stimuli that are not matched to prior expectations are very rapidly forgotten.

1.4.4.3 (Continued)

Irrelevant messages are not expected in detail and are forgotten very soon.

In terms of our model Hochberg implies that a high level program gives instructions to all the necessary lower programs as to what type of signals should be let through, while the others are blocked.

Although it is possible to claim that Neisser's and Hockberg's theories are similar, they place different functions on the 'key program'. According to Neisser this program - and others which are needed in the process - will accept all the incoming information, but block all 'bits and pieces' which do not fit. According to Hockberg, this program expects or anticipates the required stimuli, therefore it will see to it that the irrelevant stimuli are blocked.

Kahneman (1973 pp. 129 - 135) suggests that at the stage of figured emphasis, capacity is allocated in graded fashion to various groups formed by perceptual units. This is done much in the manner of Broadbent's filter. The emphasis on the selected message, however, is a matter of degree, as suggested by Treisman's concepts of attenuation. He argues that the effectiveness of selection depends on the ease with which relevant stimuli can be segregated at the stage of unit formation, and that the effectiveness of rejection of irrelevant stimuli depends on the amount of capacity demanded by the primary task.

The writer believes that the most important questions concerning the limitation of the central processor are:

1.4.4.3 (Continued)

1) in what it is limited and

2) how this limitation is achieved (as opposed to where the limitations are).

The present model adopts a functional viewpoint according to which the limiting function is integrated in the process as a whole. The attempt to answer these questions should be made in the light of the characteristics and dynamics of the system.

The principle of limiting the flow of information means simply the blocking of irrelevant messages by ignoring them. Each level in the system selects at each given moment the most important, or the most relevant signal, and blocks the others. There are different ways in which this is done, according to the level of the particular program.

The filter is surely not a single selection switch, allocated somewhere between the effectors and the decision making mechanism, capable of selecting one set of information and of rejecting the rest.

Moray (1969b p. 180) argues "... there is evidence of selectivity occurring at several different levels of complexity, from loudness to language. It would be naive to expect such different types of classifying necessarily to be controlled by a single mechanism."

There are several stages of signal filtering:

(a) Peripheral systems, such as receptors, have a built in mechanism which enables them to receive only very particular physical energies. Accordingly, it can be argued that the

1.4.4.3 (Continued)

sensitivity to a very limited range of physical energy, means, in fact, filtering out the rest of the physical signals.

(b) The next stage of filtering takes place in the dimensions analysers. Since each object or event is interpreted as a number of dimensions, each unit will only accept the information to the particular dimension to which it is sensitive, and reject the rest of the information. Objects and messages must differ on at least one dimension and in at least one j.n.d., otherwise the system will not be able to select, separate or filter out relevant and irrelevant information. Differences in phase, intensity and frequency range can serve as cues to aid in listening to a message against an irrelevant background (Egan et al. (1954)).

Fitts and Biederman (1965) carried out a study in which one group of subjects were shown either one or two circles, or one or two squares. They were told to ignore the number of objects and respond as quickly and accurately as possible on the basis of the shape of the object(s). Another group was always presented with a single figure, circle or square. There was no difference in either information transmission rate or medium reaction time between the two groups. The experiment by Imai and Garner (1965) which emphasized the importance of discrimination of various dimensions has already been discussed.

These two studies could be interpreted as demonstrating that it is possible to block information on the basis of dimensions. Whole sets of dimensions can be blocked, while other dimensions of the same object are 'let in'.

1.4.4.3 (Continued)

In an experiment by Stroop (1935) subjects were presented with a sheet on which names of colours were printed, each name in an ink that was of a different colour than the one named by the word. The subjects had to name the colour in which the words were printed. A control group was presented with coloured squares. Stroop found that both speed and accuracy were lower in the former group than in the latter. Subjects tended to read the names of the colours and had difficulty in naming the colours and ignoring the verbal stimuli. Stroop's test was followed up by many investigators either in an extended version (Klein (1964)), tachistoscopic presentation (Hintzman et al. (1972)), or similar tests of card sorting (Morton (1969a,b,c); Fox, Shor and Steinman (1971)). The relative difficulty of this task resists extended practice (Jensen (1965); Jensen and Rohwer (1966)). It has physiological influences on the subjects heart rate and palmar conduction (Elliott (1969); Elliott, Bankart and Light (1970)). Eye movements were also measured in connection to Stroop's test (Bakan and Shotland (1969)). Finally, the test was carried out under drug stimulations and in noise conditions (Callaway and Stone (1960); Quarton and Talland (1962)). The findings were always similar to Stroop's original experiment.

The writer argues that these results can no longer be interpreted merely on the dimensional level. The group who received the coloured squares, had no particular problem in naming the colour, since they had only one dimension (hue) to name. The other group could not block the meaning of the words since, according to this model, meaning of objects and events is processed by a higher

1.4.4.3 (Continued)

level in the hierarchy. The main program which controlled, co-ordinated and integrated the processing in this task, received two inputs: one from the word processing function and one from the colour processing function. The two inputs were of the same type - a coded name of colours, but they were incompatible. The main program selects information on the basis of their different meaning and not of some physical differences. This is why such a program has difficulties in choosing the right input and blocking the other. This type of situation is very similar to simultaneous performance of two very similar tasks, but here the required performance of one of the tasks was to ignore it. As we shall see later, simultaneous performance of two very similar tasks is most difficult. Even so, the writer believes that given sufficient practice subjects would be able to improve their performance in such a situation. This can be done not so much by 'training' the main program to a more efficient selection, but by focusing their attention on the physical sides of their task (such as looking only at the first or last letters, or concentrating on the upper or lower half of the words).

As Stroop's experiment demonstrated, the varying of dimensions does not always imply that the blocking of the irrelevant information takes place at a dimensional level. Experiments carried out by Hodge (1959) - with visual stimuli - and by Montague (1965)- with auditory stimulation, serve as additional examples: the design of these experiments requires that one group of subjects receive variation on several dimensions, where sometimes one set of dimensions is relevant and sometimes another set is relevant.

1.4.4.3 (Continued)

For the other group, the irrelevant dimension is never relevant throughout the experiment. The results of both investigations indicated that performance was more degraded by irrelevant information, when the subjects had previously responded on the basis of that information, than when it had been irrelevant throughout the entire experiment.

In terms of our model, the difficulty does not lie within the dimensional processing, but within the higher levels. A constant change in the experimenter's instructions as to which dimension ought to be paid attention to, causes confusion in the high level programs. These programs tend to instruct the dimensions to block a particular set which was irrelevant a short while ago, but not any longer. These programs are built to instruct in the 'old way' and they resist the change.

These examples of filtering interactions between the dimensional levels and those levels which are above them, bring us to the next level of selection functioning.

c) Low level programs operate mainly on physical features, therefore they are only capable of filtering or selection based on physical features. They receive the criteria as to what signals should be allowed through from higher level programs. For example, such a system might receive the blocking criteria of some monotonous physical signal, say the ticking of a clock (habituation as such will be discussed later in this chapter). Any physical change in the original set of signals will not fit the blocking criteria and therefore will be let through. Hence, we notice the clock if it stops.

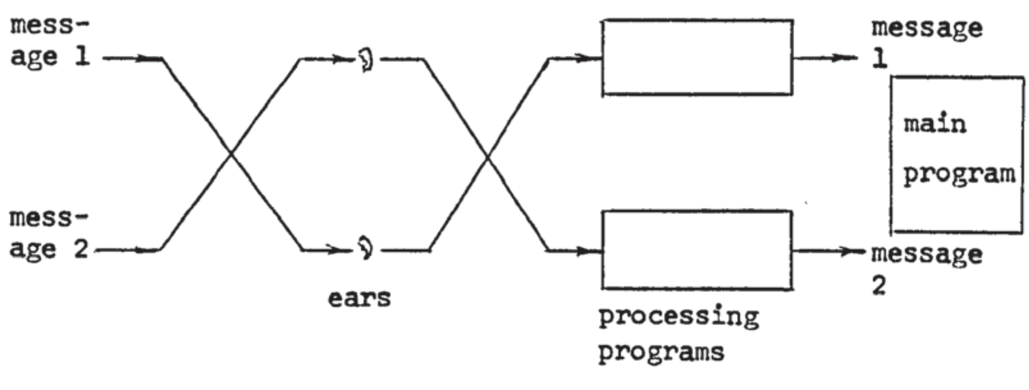
1.4.4.3 (Continued)

The selection of information (i.e. leaving or closing the irrelevant and passing on the relevant) by very low level programs or the peripheral system is 'clean', 'neat' and efficient. So, one cannot see with ones ears or hear with ones fingers.

d) As we go along the different hierarchical levels, the operational basis of the programs are gradually changed into a more meaningful, conceptual process. Hence, they also filter and select information on the basis of its concepts and meanings.

According to this model, each program is under supervision of a higher program. If one carries out an experiment using the paradigm of Treisman (1960), where the input messages between the ears is switched over for a short period and then switched back again, the outcome of such an experiment is as follows: One message, say the digits, are processed by one function, while the other message, say the words, by another function. When the inputs are switched over, the digits will still be processed by their function and the words by theirs. This is due to the specializing function, where each program is specialized to carry out a particular process. In other words, the internal system, through the monitoring (supervising) program, will switch the messages back (Figure 1.4.4).

Figure 1.4.4 Hypothetical switching of messages



1.4.4.3 (Continued)

A similar phenomenon will occur if the two messages are verbal, especially if the content of the switched messages is highly redundent (Treisman (1960)). Gray and Wedderburn (1960) found that when speech was delivered to subjects in both ears simultaneously, so that a meaningful sequence could be formed by choosing syllables or words alternating from each ear, the subjects reported back the meaningful sequence rather than the series of words or syllables presented to one ear or the other.

In these cases the controlling and co-ordinating program switches the messages internally, according to the content of the message. Since such a program operates on concepts and meaning, it 'will see to it' that the process makes sense. In other words, it will co-ordinate and integrate the output of various processing functions into a meaningful message.

Meaningful processing of messages is very important for normal working order of high level programs. Moray and Taylor (1958) found that when they required the subjects to shadow statistical approximation to prose, the subjects perceived the words but could not output them.

(e) The highest possible filtering of information is a conscious rejection of messages. The message is received, understood, but dismissed as totally untrue. The receiver does not believe it and consciously ignores it.

The psychoanalytical school (Freud (1900); Rapaport (1967)) argues that in cases of conflicts between a message and ones own

1.4.4.3 (Continued)

ideas, beliefs and attitudes, the message is supressed to the unconscious and 'not heard'. In terms of the present model this is also regarded as a form of high level blocking of information.

Low level functions block the information very efficiently, while at the high levels such an operation is less efficient and 'clean'. Part of the irrelevant message gets through and is processed. Subjects can, for example, report parts of such a message, especially towards its end (Norman (1969)). Names and highly probable words also get through (Moray (1959); Treisman (1960)). Finally conscious ignorance of messages is a very inefficient method of blocking information.

1.4.4.4 Inter-dependency of function

The model developed in this study is similar in some aspects to a computing system. The idea of a main program which controls and co-ordinates smaller programs and sub-routines is borrowed from the computing system. On the other hand, the number of sub-routines in a computing system is determined by the way in which the main program is constructed. This is only partially true in this model. The main program is the one which contains the instructions given to the person on how to carry out a particular task, and therefore in a way determines what functions are needed in this situation and which programs must process the needed information, but it will not be accurate to say that this is the only way in which the processing structure is decided upon. The flow of information starts at the bottom of the hierarchy, and therefore is the relevant

1.4.4.4 (Continued)

low level sub-routines start to be active, they pass the processed information to higher programs which in turn pass it to even higher programs and so on.

Many low level sub-routines require many higher level programs to control, co-ordinate and integrate them. Few low level programs require fewer higher level programs.

The construction of the processing and programing system as a whole is determined by a composite of the different dimensions which are activated by the incoming signals and by the different types of processing that the information has to undergo. In other words, the different processing levels and the different functions in each level are a function of:

1) what type of task has to be performed.
2) what type of signals are used in the task.

The peripheral and low level programs are mainly determined by the type of signals derived from the task. Signals stimulating many sense modalities, varying over many dimensions, will require many peripheral and low level programs. The higher level programs are determined by two factors:

a) the number of lower level programs.
b) the type of transformation and processing which the information has to undergo.

For example, the letter x printed in red colour appearing in a word printed in black will activate more dimensions and low level

1.4.4.4 (Continued)

programs than a black "x" in a black word. In terms of high level programs, the number of programs which are needed in order to decide whether "x" is a vowel or a consonant, is greater than the number of programs which are needed in order to identify the name of the letter or its physical shape.

The different levels of programs are inter-dependent in other ways as well. On one hand, the processing of high level programs depends on the outcome of the lower levels, on the other hand, there is also a dependency of the lower levels on the higher ones. They depend on the 'instructions' they receive from the higher levels, but they also sometimes depend on the outcome of the higher level processing. There is, for instance, the effect of word context on letter recognition (Reicher (1969); Smith (1969); Wheeler (1970)). The recognition of a letter within a word will be superior to the recognition of the same letter in a nonsense syllable. This in fact hints that a lower level program, which physically or namely identifies letters, is influenced by higher level programs which identify sequences of letters with conceptual meanings.

1.4.4.5 Flexibility of pathways

Although the model developed in this study, emphasizes the functional hierarchy, this does not mean that a higher level processing <u>must always</u> follow the processing of a lower level program. In other words, once a signal has been processed by some low level programs, it can then be transferred

1.4.4.5 (Continued)

simultaneously to several processing levels, provided that the higher ones are not dependent on the outcome of the lower ones. High level programs have access to all the programing levels. Should the need arise, they are capable of extracting any type of information.

Posner (1969) presented considerable evidence that the visual code (physical identity) and the name code for letters are in fact produced in parallel. In the terms of the present model, this means that while the outcome of the dimensions and the low level programs is further transferred for physical identification (A - A same; A - a different), it is also received by a higher level program for name identification. The name identification process, like most higher level processings, is longer than the physical identification process or most lower level processings. Indeed Posner (1969) found that the production of name code is slower than that of visual code.

1.4.4.6 Learning and practice

In terms of the present model, learning is defined as the construction of new internal programs. The construction of these programs is due to new experiences. These programs are usually higher in the functional hierarchy, since most of the peripheral, dimensional and very low level programs are 'built in' mechanisms and are not achieved due to new experiences. Experiments such as the perception of depth using 'visual cliff' (Walk and Gibson (1961)), or preferences of babies to observe some patterns over others without having any previous experience with such patterns (Fantz (1961)), demonstrate some of the innate 'built in'

1.4.4.6 (Continued)

perceptual mechanisms.

The higher level programs have the task of controlling, co-ordinating and integrating the functions of the low level programs and adapt the outcome of the processing to reality. Therefore, such programs can only be constructed and improved by experiences with the real outside world. One cannot perform well a complex task without first 'learning', or constructing inner programs, to deal with this particular situation. One can transfer ones knowledge from one situation to another, but it cannot be a successfull transfer if the two situations do not have similar aspects. In terms of the present model, this means using certain processing functions on a new type of information.

Many deprivation studies (such as Riesen (1947); Beach and Jaynes (1955); Walk and Gibson (1961); Held and Hein (1963)) have shown that the visual ability of animals reared in darkness is considerably inferior to that of the normally reared animal when they are first exposed to the light.

Blind persons who gain their sight, after an operation for instance, are reported (Von Senden (1932); Trans (1960); Hebb (1949)) to have been severely defective. They were for the most part initially capable only of very gross distinctions between figure and ground, and took perhaps months to learn to distinguish between even simple shapes, while some were unable ever to proceed beyond this level of ability. Gregory and Wallace (1963) illustrated that such persons

1.4.4.6 (Continued)

who gained their eyesight after an operation had severe motivational disturbances which may well affect visual performance for the worse.

All these studies and investigations help to demonstrate the importance of past experience. In fact they hint very clearly that if such skills (or such specializing programs as in this model) are not acquired up to a certain stage in life, it is very difficult, if not impossible, to gain them later on.

In order to find out whether lack of practice disturbs the formation of verbal conceptualizations, the writer carried out a pair association learning experiment. The subjects were blind young people in a rehabilitation centre. It was found that blind people were as good as sighted people in learning associations such as room - quiet; echo - long; voice - loud. They did not do very well in associations such as sea - green; leaf - yellow; horizon - straight. Since they never had any visual experiences, they were mainly familiar with well known cliches such as blue sky; green leaves; brown earth etc. a gray sky and yellow leaves had never been experienced by them. Some of the subjects tended to respond to the word 'shadow' by saying 'cool' instead of the right answer 'long'. This mistake demonstrates the main point in the experiment that the poor youngsters have never seen a shadow in their lives, but they did hide away from the sun in shadowed places.

Over learning and excessive practice have a different effect on the central processor:

1.4.4.6 (Continued)

1) They improve the processing programs.

2) They reduce the hierarchical level at which these programs function.

The improvement of processing programs mainly takes the form of shortening them and narrowing their operational basis. In other words, the processing programs become more efficient and if a certain task once required a rather big and complicated program after excessive practice the same processing can be carried out by much more economical and efficient programs. Moray (1967) argues that practice seems to increase channel capacity. Firstly through perceptual learning which leads to a better assessment of the relevant stimulus dimensions, where only some of them would be analysed to identify the signal and irrelevant or redundant ones dropped out, with consequent saving of capacity. This, by the way, would agree with Sutherland's (1964) suggestion of the 'switching in of analysers' as a first stage in perceptual learning. Secondly, he argues, that practice may lead to the discovery of 'more efficient and smaller plans' ('plan' - the term which is used by Miller, Galanter and Pribram (1960) and corresponds with 'program' in the present model).

It is rather like a skilled operator who performs only the necessary movements while his assistant is engaged in a lot of irrelevant activities. The shorter efficient programs enable the skilled operator to have 'all the time in the world', while his assistant usually lags behind always needing more time to complete the operation.

1.4.4.6 (Continued)

The other effect of practice is the reduction of the level at which the programs function. In other words, these programs become less and less central and more and more peripheral. A skilled person carries out his duties with great ease, almost automatically. He spends less time in thinking what to do - which is associated with very high levels of activities, and instead he 'just' reacts in a rather automatic way, which is associated with lower levels of activities.

This reduction in the size of the processing programs and in their centrality leaves out more room in the top of the central processor, or more free processing capacity to be engaged in other activities.

For example a person who learns how to drive a motor-car has, in the initial stages, great troubles to keep the car on the road. He does not have spare capacity to make the decision to operate an indicator before he performs all the necessary manipulations to take a turn. It takes a very skilful driver with a lot of automated operations and spare capacity to win an argument with his wife while driving.

The efficient lower level programs become habits - reinforced, practised and automated patterns of behaviour. The programs are very short, and therefore capable of only a rather limited variety of processing. Being lowered in level they tend to be quite rigid: "Habits and skills are plans (which correspond to programs in the present model) that were originally voluntary, but that have become relatively inflexible, involuntary, automatic. Once the plan that

1.4.4.6 (Continued)

controls a sequence of skilled actions becomes fixed through over-learning, it will function in much the same way as an innate plan is instinctive behaviour" (Miller, Galanter and Pribram (1960) p. 82).

If the same stimulus is presented repeatedly it has one of two effects:

a) If the stimulus requires the same response, then the sequence becomes a habit.

b) If the stimulus does not require a response, then the sequence becomes habituation.

In the first case the stimulus gains priority, and we expect it to come again and again. The system becomes sensitive to it and passes it as quickly as possible through the processing functions.

In the second case, the system blocks the stimulus because it does not require a response, and therefore it does not need processing. The blockage is efficient and, in cases of purely physical stimuli occurs as closely as possible to the peripheral dimensional mechanisms. Should any change occur in the repeated stimulus, any distinguishable change on one of the dimensions, the system will detect it and become aware that something has happened.

A driver who drives on a well-known road ignores all the advertising lights, misleading as they may be and 'pays attention' only to traffic lights to which he is used to. In a different city, which he is not familiar with, he will have difficulties in separating the two types of lights.

1.4.4.6 (Continued)

Sokolov (1960) demonstrates the decrease or disappearance of alpha blocking in the electroencephalogram and the glavanic skin response in human subjects on repeated presentations of the same stimulus. He then altered the stimulus in various ways, and found that the arousal response reappeared not only when the intensity or duration of the habituated stimulus increased, but also when they decreased. This makes it unlikely that the habituation indicates some increased neural threshold or loss of neural sensitivity. He suggested that the habituated neural 'model' served as a template against which inputs were matched. This mis-match between the new stimulus and the neural model, could imply complex levels of analysis, for instance, as a change in meaning with words. In the latter example according to our model, the process of filtering out information takes place at a higher level and not, for example, at the level of filtering pure physical tones.

The amount of change in the stimulus can be measured as information and therefore the different stimulus is processed. Habituation in this sense reflects redundancy.

It has already been mentioned that with practice the central processor gets more free processing capacity and that a new driver for instance, can pay attention to all aspects of driving instead of only some. This actually means that practice allows for some parallel processing to take place. Therefore we are capable of identifying the name of a letter in parallel to identifying its physical shape. We are capable of analysing several different dimensions simultaneously, while prior to the access training we

1.4.4.6 (Continued)

were only capable to process them in series. We are not capable of simultaneous processing of two variations on the same dimension, these have to be processed in serial order. Each of the specialized functional programs is capable to perform only one type of processing in a given moment. It is possible to look simultaneously for a red round figure, since the shape and the colour will be processed simultaneously (after some practice) by two different programs. It is not possible to process simultaneously red and green figures, or square and circular figures (Marcel (1970)).

When unpractised subjects are confronted with a task with which they are not very familiar, their CRT increases at a constant rate as the amount of information conveyed by a stimulus increase (Hick's law, Hick (1952)). Thus, CRT should increase as a logarithmic function of the number of alternative stimuli ($\log_2 N$). This was confirmed by other researchers (Hyman (1953); Brown (1960); Adams (1964) and others).

When subjects are well practised, CRT tends to remain constant, rather than increasing, as the number of alternatives increase (Crossman (1953); Mowbray (1960); Davis, Moray and Treisman (1961)).

'S-R compatibility' also plays an important role in reducing the CRT. The processing capacity itself ranges from 2 to 50 bits/sec., depending on the precise task set. The variation was at first ascribed to differences in 'S-R compatibility' (Fitts and Seeger (1953); thus, with a numerical display, a rate of 5 bits/sec. is

1.4.4.6 (Continued)

typical, but with lights placed directly over keys it may be as high as 25 bits/sec. (Crossman (1956)). Skilled typists and musicians tested with random sequences of letters and notes were found to perform continuously at 25 bits/sec., although their tasks had no obvious compatibility.

Moray (1967) defines high compatibility as "that relation between input and output where the complexity of the mapping transform is at a minimum". In terms of the present model this means that because the 'complexity of the mapping' is at a minimum, the amount of processing required is also at a minimum. This leads to a very short processing time, and therefore the increase in the RT as a function of the amount of information (or number of alternatives) tends to disappear. That is why, for example, Leonard (1959) found that in a highly compatible RT task there was no difference between 2 and 4 choices with minimal practice. Davis et al. (1961) found that relatively little practice was necessary to abolish the difference between 2, 4 and 8 choices with a compatible task. Moray (1967) argued that in an unpublished experiment he found a compatible situation where differences between single and two-choice RT's had disappeared.

1.4.4.7 The influence of load

The term 'load' is not very well defined and there is little agreement among authors as to what is exactly meant by perceptual or mental load. In this model load will be referred to as the amount of activity. Accordingly, if a particular part of the

1.4.4.7 (Continued)

system is said to be loaded, this means that it is very active and engaged in a lot of processing. 'Overloaded' corresponds to overworked required to be involved in activities which are beyond its capacity. This is the formation of a bottle-neck in the process.

It should be emphasized, at this point, that the following typology of load and the various categories suggested here are only hypothetical. They are derived from the proposed model. There may be other types of load which have no bearing to this model and therefore are not mentioned here.

The present model argues that there are three types of load: sensory, processing and speed.

1) Sensory load - refers to a situation in which there are many stimuli reaching one particular sense modality. This can take one of the two following forms:

a) Either there is one relevant set of signals and the rest of the signals are merely noise.

b) Or there are more than one set of relevant signals, with or without noise.

The effect in both cases is the inability to differentiate relevant signals from noise, or separate among the relevant sets of relevant signals. In terms of signal detection theory the sensitivity (d') is too low for the sense to function properly.

Such a situation is overloading the peripheral system, since the system as a whole is not a passive mechanism but a living, dynamic

1.4.4.7 (Continued)

set of organized activities. Therefore, the receptors, dimensions and very low level programs make a considerable effort to find some 'sense' in the burst of signals. As Moray (1967 p. 88) states: "In a noisy input situation more capacity will be allocated to the reception task, so that an optimal signal detection network may be organized". In terms of the present model this means that more and more functioning programs will have to be allocated for such a task and that the main load in the system is in its peripheral, low level activity levels.

Olson (1963) studied the effect of different arrangements of eighteen instrument displays, not only on the performance of the instrument monitoring task, but also on the performance of a secondary simulated driving task being done at the same time. Indeed, he showed that different display arrangements affected both tasks. His results indicated that the more data sources used, the same 'sensory channel' (i.e. referred to vision) the less information could the operator be expected to handle.

2) The second type of load is <u>processing load</u>. This load has two phases:

a) A single function load.

b) A multi functions load.

2.1) A single functioning load relates to a situation in which a particular specialized processing function is required to process almost beyond its capacity. Each of the programs are specialized in processing a particular transformation. Any requirement for this particular transformation is 'addressed' to a particular specialized program. In cases where more than one such trans-

1.4.4.7 (Continued)

formation is required simultaneously, the processing will have to be carried out in serial order. When the rate at which these demands appear is too fast, it will not be possible to maintain good performance. It has already been mentioned earlier that two different values or variations on the same dimension have to be processed in serial order, since they are carried out by the same specialized program. We can, however, with some practice, look for several dimensions simultaneously. Marcel (1970) argues that "one may attend to events simultaneously if they are on two functionally separate channels, but not if they are on functionally the same channel". He found that checking whether a pattern is red and has a vertical bar cannot be done at the same time as checking whether it is green and has a horizontal bar even given extended practice. Given practice, checking whether a pattern is red and has a vertical bar can be done at the same time as checking whether it is a circle and the bar is solid.

In a way this concept of loading a single function fits Broadbent's concept of 'limited capacity channel' in the sense of a transmission line, where the system is limited in the amount of transmission which can be extracted from each individual channel.

2.2) The second type of processing load is a multi functions load. This load refers to a situation in which different functions are processed simultaneously. There is a limit to the number and size of programs that the central processor can contain at one single time. Moray (1967) puts forward the idea that the brain can divide up its limited capacity or its processing network, and allocate it in different ways according to the tasks it fulfills.

1.4.4.7 (Continued)

According to the present model, the more complicated the task, the more room it will take in the central processor. Furthermore many functions need more high level programs to control, co-ordinate and integrate them. Subjects adding another dimension to the complexity of a task not only call for an additional processing program, but also for a higher level one. Therefore, we are quite limited in the number of functions we are capable of processing simultaneously.

There is a difference whether the load is caused by one complicated task or by several easier tasks. The difference between one complicated task or several simpler tasks is in that respect important. If the different tasks originate from different sources and they are not interrelated, correlated, interacted or connected; in other words if they are mutually orthogonal then the tasks are approached as different. If not, then the different tasks only represent various aspects of the same complete task and can safely be integrated into one. The argument put forward in this model is that two simple 'one-transformation demanding' tasks are loading the system more than one complicated 'two-transformation demanding' task. In the case of two simple 'one-transformation demanding' tasks, the transformations must be different otherwise they produce a single function load. The two transformations are organized separately in the central processor and need to be controlled and co-ordinated by a higher level program. This program will further load the system.

1.4.4.7 (Continued)

In the case of one complex 'two-transformation demanding' task, there is no need to co-ordinate between tasks, only between the different aspects of the same task. The fact that it is a one task situation, and all the different aspects are interconnected and form some logical coherence, makes it easier to control and co-ordinate them.

This last point is not only a theoretical one, but it also has an applied value. Simultaneous performance of two completely different tasks is more difficult to perform than an integrated task.

It is obviously very difficult to demonstrate this point. Conrad's (1954) experiments can probably provide an example of such a situation. Conrad refers to the number of separate independent streams of signals as 'the load'. He demonstrated that an increase in this number causes a deterioration in the performance, although the overall rate of presentation is constant. In other words it is easier to respond to one source of information than to several sources, although the total number of response movements is the same. In terms of the present model, each independent source of information is treated as an independent task. It is easier to respond to fewer sources with many stimuli than to more sources with fewer stimuli. This is compatible with the argument that it is more difficult to perform several easier tasks than few complicated ones.

The influence of a time-sharing situation in respect to processing load will be dealt with later on.

1.4.4.7 (Continued)

3) The third type of load is speed load. In a high speed task situation the operator is asked to perform his task as quickly as possible. In a continuous task, the rate of change in the stimuli is very high and in a descrete task the rate at which the stimuli appear is very high. In both these situations the effect of the speed on the central processor is identical. It must ensure that the input signal will be processed in the quickest, or shortest possible way. This will have two effects on the processing programs:

a) They will be under pressure to become more efficient and to be kept as short as possible.

b) The central processor will try and 'push' the processing program to a low hierarchical level.

Short processing programs which are kept as close as possible to the periphery enable the signal to be processed in the shortest possible time.

Both of these effects are the result of practice, and indeed, practice is indispensable for the performance of speedy tasks.

Since the program must be kept short, the central processor cannot lengthen the main program very much, and thus does not have enough capacity to process the feedback signals and to keep track of the quality of the performance. In practical terms this means that the quality of performance is poorer in such a situation and that more errors are committed because decisions are taken too quickly, without prior analysis of the incoming messages.

1.4.4.7 (Continued)

In a speed load situation only a relatively small part of the central processor is active, while the rest is not. This does not mean that it can be put to work simultaneously, without a serious deterioration in the speeded task. In order to perform two types of processing, the central processor will have to construct an even higher level program to control and co-ordinate the two tasks. This will lengthen the way in which the high speed signals are processed. Thus, the first effect would be a slowing down of the speed task. Another effect would be a change in the rate of performing the tasks. The main program which has to co-ordinate between the two tasks, has a changing momentary load according to the changes occurring in the two tasks. This means that at some points in time co-ordination is easier than at other points. The result is that sometimes the signals will be processed quicker and sometimes slower, and hence the change in rate of performance.

This last point is true not only in speeded tasks, where the effect may be stronger, but in any simultaneous performance. Michon (1966) for example measured tapping regularity as an index of perceptual motor load. He argues that "load will cause 'traffic control' problems in the central nervous system, so that actions will be executed in an irregular fashion."

There are numerous methods by which researchers have tried to estimate the load on an operator, including the so-called 'secondary task' method (some of them were reviewed by Rolfe (1971)). In an attempt to separate different aspects of work load, the concepts 'physical load' and 'mental load' (or sometimes called 'perceptual

1.4.4.7 (Continued)

motor load' - Michon (1966)) were employed. Mental load became an overall term for any type of load which is not physical. Researchers used it indiscriminately with very little attempt to analyse its different aspects.

One of the main theories in the justification of the use of secondary tasks, was put forward by Brown (1964). He argued that the difference between a man's total capacity and the perceptual load imposed by any task, is his reserve capacity. Hence, occupying the reserve capacity must enable the measurement of the perceptual capacity. According to this type of theory, a given secondary task may help in comparing the perceptual load of two different tasks.

The present model contradicts Brown's approach. Adding a secondary task to an existing primary task means also the construction of a third program which has the task of co-ordination between the two tasks. The nature of this main program, i.e. its size, complexity, and its place in the functional hierarchy, depends very much on the two tasks to be performed. If the two tasks are difficult to co-ordinate, being completely incompatible, then this co-ordinating program will have to be large and complex and it will probably occupy a higher level in the central processor. Two compatible easy to co-ordinate tasks, may demand a relatively simple main program. This fact by itself does not prevent us from using Brown's method in estimating the perceptual load of a particular task. On the other hand, such an estimation used on its own - without a comparison with the perceptual load of a different task - makes very little sense. By trying to compare two unknown perceptual loads we

1.4.4.7 (Continued)

also compare two unknown main programs and this makes the whole comparison invalid.

The writer argrees, however, that it is possible to compare two perceptual loads, under very specific situations, which become 'a particular case'. So, for example, when the two tasks to be compared are almost identical, and each of them is performed with an identical secondary task - the main programs which co-ordinate each of the pairs of tasks are so similar, that they can be considered as one single program which co-ordinates the first pair and then the second pair. Accordingly, it is permissible to compare driving in different conditions by using a secondary task (as did Brown and Poulton (1961) and Brown (1962 a, b)), but it is unacceptable to compare mental arithmetic with playing an instrument by means of a secondary task such as tapping. This may lead the investigator to the unlikely conclusion that even the simplest mental arithmetic is more loading than the most complicated piece of music, relying on the fact that mental arithmetic causes tapping irregularity, and playing music does not.

An experiment carried out by Schouten et al.(1962) could be used to demonstrate this point. They used a standard task, to which was added a number of alternative and different second tasks. Subjects were instructed to carry out two tasks simultaneously, and measurements were made to determine the degree of mutual impairment. All the second tasks showed a general decrement in performance, however, the degree of impairment was not uniform for all tasks.

1.4.4.7 (Continued)

A possible explanation of the evidence discussed here, is that many of the investigators of 'mental load' have failed to differenciate between the aspects of the load. They treated sensory load, or speed load, as occupying the 'full capacity' of the central processor, without realizing that they might put the heavy load only on a part of the central processor.

1.4.4.8 Selective criteria

Most of the ideas on how the central processor selects relevant messages from irrelevant messages have already been discussed. The idea which is put forward here concerns the changing of the selective criteria. When a performance on a new task is about to begin, the higher level programs have to set new programs for processing the new information. It also has to make sure that new criteria are set for filtering out the irrelevant information. This new filtering instruction has to be established in all the different hierarchical levels.

In practical terms, it means that the reaction to the first stimulus is usually delayed until the central processor messages set up all the necessary changes. It is a similar idea to a 'set up time' in operational research, where an operator has to set up all the necessary tools and devices to carry out the new task.

1.4.4.9 Time-sharing

Time-sharing is the sharing of a given period of time, between two or more tasks. The present model only deals with the two extreme situations in which two shared tasks are either performed in succession or simultaneously.

The mixed cases in which performance is partially successive and partially simultaneous are, in fact, special cases which are composed of the two extreme situations.

Each shared task is analysed according to two main aspects: 'sense modality' and 'transformation'.

'Sense modality' - the sense or senses which are stimulated by a particular task. In the present model, 'sense modality' refers to the peripheral system including the receptors, dimensions and even some of the very low level programs.

'Transformation' - refers to the task itself, to the type of operation which has to be carried out, and to the changes and processes which the incoming signal undergoes in order to become an overt response. In the present model, 'transformation' refers to the central system, including all the programs which specialize in this particular processing.

To sum up, each of the shared tasks are examined in terms of the peripheral and the central systems which are needed to process the task signals.

1.4.4.9 (Continued)

When two tasks are shared, either simultaneously or successively, their analysis refers to:

1) Whether they can be said to stimulate the same or different sense modalities.

2) Whether they use the same or different transformations.

These two aspects encompass a whole range of possibilities (e.g. same and different sense modalities, and various degrees of similarity between the transformations).

It should be emphasized, at this point, that the developed mode concentrates on the perceptual part of the central processor. Therefore the above proposed factors influence the receiving system.

In any type of time-sharing situation other factors may also play an important role. For example, the last decision made by the system may influence the future decisions. The 'set of thinking' - the 'rigidity in problem solving', or 'Einstellung effect' (Luchins (1946, 1951)), set by the environment (i.e. the tasks) also influences time-shared performance. However, the investigation of the decision mechanisms and the output system are beyond the scope of this investigation.

Figure 1.4.5 sums up the main three factors which characterize the human time-sharing.

1.4.4.9 (Continued)

Figure 1.4.5 Three factors concerning human time-sharing

	Sense modality		Transformation	
	Same	Different	Same	Different
Successive				
Simultaneous				

a) Successive time-sharing

This is the situation in which an operator is performing one task, has to abandon it and then starts performing a different task. Each time when he must leave one task and switch over to another task, there is a sharing situation.

When the operator carries on performing the same task, there is a no-sharing, or zero time-sharing situation.

In any successive time-sharing situation, at the beginning of the new task, there is a change of activity in the central processor. All the irrelevant traces of the old programs and the different criteria, according to which the selections took place at the different levels, must be removed and stored away for the future. New programs and the new selective criteria have to be constructed and inserted instead of the old ones.

This activity of erasing the old programs and inserting the new ones is regarded as a very important stage in the present model.

The most important question with regard to successive time-sharing is how long it takes to switch the performance from one task to

1.4.4.9 (Continued)

another. It is not an easy question to answer and it depends on too many variables to be fully accounted for in this study.

a1) One of the factors which influence time-sharing is the determination of the time-sharing. In other words - who decides that the operator must stop performing one task and switch over to another task. The decision can be self originated, by the operator, or it can be externally determined so that the operator has no idea whether he is about to switch to another task.

Between these two extremes there is continuum of situations in which the operator is more or less aware of the possibility that time-sharing must take place sometime in the future, but is uncertain of the precise moment of the switching.

This model deals with all the range of situations which effect the 'real world' where an operator is expected to switch from one activity to another, is aware of this expectation, but is uncertain about the exact time when it will take place.

The special interest in the externally determined time-sharing is caused by the fact that in this situation the operator is not able to prepare himself for the new task. Accordingly, a change of programs is required at the beginning of the new task.

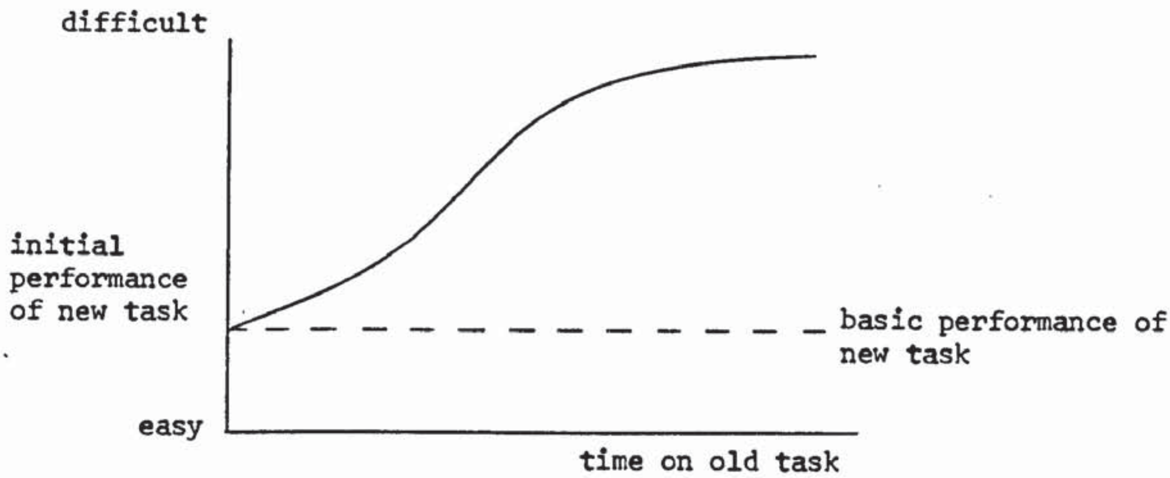
a2) The second factor which determines how long it takes to switch from one task to another is the time spent on the first task. It has already been mentioned that the central processor tries to pass every stimulus on the same pathway on which the previous stimulus has travelled. This is in fact part of the 'habit' to have positive

1.4.4.9 (Continued)

reinforcement of a certain chain of programs which are active at that particular moment.

This means that there is a monotonically increasing correlation between the time spent on a task and the difficulty to leave that task to start a new one. The longer the time spent, the more difficult, or longer, it will be to start a new task. This relationship is probably asymptolic, and from a certain point spending more time on one task will not make much difference in terms of starting another task (See Figure 1.4.6).

Figure 1.4.6 Hypothetical relationship between time spent on one task and difficulty in starting another task



a3) Another factor which influences time-sharing is the similarity between the two shared tasks. This similarity is expressed by two levels (same - different) of the two factors: 'sense modality' and 'transformation' (See Figure 1.4.5).

If the two tasks stimulate the same 'sense modality', using exactly the same stimuli and demanding the same 'transformation', then this is a no time-sharing situation in which the operator continues to

1.4.4.9 (Continued)

perform the same task.

If the two tasks stimulate different sense modalities and demand different transformations, then the process of switching from one task to the other is a time consuming situation. The central processor must erase all the existing programs and insert new ones and also replace all the selective criteria by new ones. This is a long process and the initial performance of the new task is delayed until all the necessary changes have taken place.

An intermediate situation occurs when the two tasks are similar in one aspect but different in another. In this case, the most interesting question is which of the two factors is more influential, 'sense modality' or 'transformation'.

Earlier in the description of the model, it was argued that the peripheral system is simple in its operation and very limited in its scope, and that it carries out logical operations on the physical aspects of the stimuli. The higher level programs carrying out complicated operations have a broad scope of operations and their processing deals with the meaning of messages, not with their physical aspects.

Hence, it is relatively easy to predict that a change in 'transformation programs' is more difficult and therefore takes more time than a change in the 'sense modality' and the peripheral system. In other words, the more influential factor is the 'transformation'. If the

1.4.4.9 (Continued)

two shared tasks have the same or very similar 'transformations', it is relatively easy to time-share between them. If, on the other hand, the two tasks demand different 'transformations' then it is more difficult to time-share between them.

'Sense modality' also plays a role in determining the easiness or quickness at which the switching occurs, but the weight of this factor is not so great and its influences are by far less than that of 'transformation'. 'Sense modality' is responsible for the change of criteria on which the peripheral system operates. 'Transformation' is not only responsible for the change of criteria, but also for changes in a multitude of complex programs. If the two shared tasks require the same type of 'transformation' there is no need to replace the old programs. Accordingly, the sharing process is not time consuming.

For example, a typist can get used, very quickly, to a new typewriter. Typing on two different typewriters represents two tasks which require the same 'transformation'. The same applies to a motorist who changes his motor-car. An example of different 'sense modalities' and same 'transformation' is the copy typing from a printed message or audio typing from an auditory message.

a4) The fourth factor which is likely to influence time-sharing is the compatibility between 'transformations'. Two tasks may require two different 'transformations', which are compatible or incompatible. Compatibility speeds up the sharing process. If the two 'transformations' are at least compatible, it will be easier and quicker to change the processing programs of one task into the processing programs of the other. The fact that the two tasks are compatible

1.4.4.9 (Continued)

means that there is some common denominator, or some common logic, or some kind of connection between the tasks, which makes it easier to switch between them.

For example, it is easier to time-share between different displays which use the same measurement scale, than between different displays which utilize different measuring scales.

b) Simultaneous time-sharing

This is a situation in which an operator is performing two tasks simultaneously. It can be argued that the need to 'follow up' the previous performance through feedback and the need to cope at the same time with new stimulation is, in fact, a simultaneous activity. Therefore, every single performance is to this extent a simultaneous performance. However, the writer has decided that in the context of this model the feedback is considered to be an integral part of task performance, and the capacity it occupies is part of the 'normal', 'ordinary' capacity needed to perform any task. Feedback affects the normal working order of the system only when it is distorted (spacially and/or temporally). Therefore, in the present context, simultaneous time-sharing refers to the need to receive and process two different sets of stimuli originated by two different tasks, simultaneously.

It has already been suggested that the formation of hierarchical processing programs is a function of the complexity of the task. Simultaneous performance of two tasks is in most cases more complex than the individual performance of each of these tasks. Furthermore, in such a situation there is a need for an even higher program in order to control and co-ordinate the performance of each of the tasks.

1.4.4.9 (Continued)

Consequently, such a simultaneous performance whenever possible, is a very loading situation. Even two not very demanding tasks which are performed simultaneously cause some deterioration in the performance. Such a deterioration can take the form of a slower performance of both tasks, or of only one of them. It can also take the form of irregularity in the performance of making more mistakes, of ignoring parts and aspects of the tasks, of memory problems such as forgetting or not recognizing items from the tasks. The actual type of deterioration is of no particular importance in this context. It is, however, important that all experiments or studies carried out on simultaneous performance have shown one or another type of deterioration in the performance!

The most important question concerning time-sharing is not whether there is a deterioration in the performance, but why is there such a deterioration? What are its causes or origins and by what function it is influenced?

The writer suggests that the answer to these questions is rooted in the different aspects of load. Even simple tasks call for more and more processing programs to cope with this demanding situation. The use of many complicated programs slows down the performance. This situation is referred to as a 'multi-functions processing load'.

There are, according to the present model, other types of load. When the shared tasks stimulate the same sense modality it causes 'sensory load'. There are many sources which stimulate a limited sense organ. This causes a serial processing by the peripheral

1.4.4.9 (Continued)

system because the incoming signals must be translated into the inner language, and sorted out along their various dimensions. If the two tasks are composed of long continuous series of signals, the need for serial processing will cause very serious deterioration in the performance of one of the tasks (usually in the 'irrelevant', 'unshadowed', or the one which seems less important), or both of them. Such a situation is extremely difficult to cope with, and in fact there are no studies which show that subjects can perform both tasks.

When the two tasks, or at least one of them has the nature of short bursts of stimulation, the situation is much easier, because the peripheral system is able to process the short bursts of information in the relatively long pauses between the bursts. In other words, there is enough time for sequential processing. Broadbent (1954) showed that if spoken digits were presented in simultaneous pairs, one digit to each ear, the listener had difficulty in recalling the digits pair by pair. He rather preferred to recall all those presented to one ear first and then all those presented to the other. If the interval between successive pairs was increased, the listener became able to recall the digits pair by pair. This experiment demonstrates that when intervals are short it is easier to process first one type of message before processing the other. When intervals between pairs are long enough, processing can alternate between the two messages. When the two bursts of information are not 'truly' simultaneous but instead alternate between the two ears, even at very high presentation rates there is no 'sensory load'. The listener can successfully recall the digits in the actual order

1.4.4.9 (Continued)

of presentation (Moray (1960)).

Treisman (1971) observed that shadowing a message which is rapidly alternated between the two ears is more difficult than shadowing a monaural message.

A series of studies (Axelrod and Guzy (1968); Axelrod, Guzy and Diamond (1968)) showed that the apparent rate of a series of clicks is lower when the clicks are alternated between the two ears than when they are presented to one ear or binaurally. Axelrod and Powazek (1972) showed that the apparent click-rate increases as the spatial separation between the sources is reduced.

The tendency to group items coming from one source is found in many experiments, especially when the rate of presentation is fast (above one pair/second). This phenomenon persists whether the simultaneous presentation is auditory, or auditory and visually (Broadbent and Gregory (1961, 1965); Madsen, Rollins and Senf (1970)). Subjects who are required to report the items in pairs make more errors than when they are allowed to report them source by source. Order information, in particular, is often lost in pair-wise recall (Bryden (1962, 1964); Moray and Barnett (1965)). Training may help to improve performance of pair-wise recall (Moray and Jordan (1966)), but the tasks always remain difficult.

The following experiments demonstrate that when the two simultaneous messages stimulate two different 'sense modalities',the problem of a heavy load on a particular sense does not exist any longer. However,

1.4.4.9 (Continued)

should the two simultaneous messages stimulate the same 'sense modality', a deterioration in the performance would occur.

Brooks (1968) showed that recall of verbal information is readily disrupted by concurrent vocal activity, but not by spatial-visual activity, while recall of spatial-visual information is disrupted more by spatial activity than by vocal activity.

Atwood (1971) showed that when subjects are instructed to encode verbal information as a visual image, the processing of auditory information interferes less with retention than does processing of visual information. However, when instructed to encode information auditorilly, auditory processing interferes more than does visual processing.

Both Mobray (1964) and Kroll et al. (1970) pointed out that auditory shadowing produces poorer recall of a second auditory message than an equivalent visual message.

Treisman and Davies (1972) found that monitoring two auditory or two visual messages was much harder than monitoring messages on different modalities.

Kroll et al. (1970) found that a single target word presented during shadowing is retained better if it is visual than if it is included within the auditory message. Interference is more likely to arise between items presented to the same modality than between items on different modalities (Parkinson (1972)).

1.4.4.9 (Continued)

Subjects were instructed to shadow a continuous auditory message in one ear and to note for later recall an isolated word presented either to the ear (Mowbray (1964)), or visually (Mowbray (1962)). Shadowing was usually disrupted by the presentation of the critical word, and the disruption was more severe when that word was spoken than when it was shown visually.

These experiments showed that even though the basic tasks remain constant the mere stimulation of the same 'sense modality' is enough to cause some sense load and deteriorate the performance.

The problems of multi-functions processing load has already been mentioned. There is no apparent way based on the present model to predict whether two tasks are too complicated to be performed simultaneously. The full capacity of the central processor to harbour different functions was never estimated. At this stage, the writer suggests that the best possible way to find whether two tasks can be performed simultaneously, is to try it out empirically.

'Filling up' the capacity of the central processor is only a theoretical motion and not a practical one. The full capacity of the central processor is probably not the weak link in the 'chain of processing'. Under the condition of complicated simultaneous tasks, particular functions such as some of the receptors, or dimensions, or some of the specializing programs are put under a very heavy load, much earlier than the central processor is 'filled up'.

1.4.4.9 (Continued)

One of the most important aspects of the processing load is the 'single function load'. This situation occurs when a particular specializing function is under heavy load due to the fact that it is under pressure to transform two messages simultaneously. It has already been mentioned that each function is capable of performing only one type of process at a time. In other words, such a function is only capable of serial processing. If the processing of each message is relatively short, the serial operation will only have a small effect on performance. The degree of deterioration in the performance depends on the time required for processing each message. The longer the required process the more serious the deterioration which will occur. If in addition one of the tasks also requires a speedy reaction it becomes almost impossible to carry them out simultaneously.

For example, it is almost impossible to calculate simultaneously two different sets of arithmetic operations. It is also impossible to write two different messages at the same time using both hands.

Mowbray (1953) found that subjects could not listen to one story while reading another. Despite the intention to divide attention, subjects were apparently focusing on only one of the messages. In a subsequent study, Mowbray (1954) simultaneously presented an auditory and a visual message which were to be used in a complex task. His subjects were unable to use the simultaneous messages.

Moray and O'Brien (1967) presented dichotic messages consisting of digits and letters. The subjects pressed a key with the appropriate

1.4.4.9 (Continued)

hand whenever a letter was heard in either ear. When two letters were simultaneously presented to the two ears, subjects pressed at least one key on 99% of such occasions, but they pressed both keys on only 17% of occasions. In a subsequent series of experiments, Moray (1970 a, b) obtained essentially the same results in the detection of transient increments of loudness in tone series. Again, when two simultaneous targets were presented, the listener was very likely to respond to one, but unlikely to respond to both.

These experiments demonstrate that a serious deterioration occurs when both messages require the same type of transformation. Taking into account that in some of these experiments the simultaneous target stimulation was a short discrete event. This only further demonstrates the intensity of the 'single function load' effect.

It ought to be stated that in most of these and of similar experiments practice was not under control, and subjects had relatively short training.

All these restrictions on simultaneous performance do not imply that it is not possible to perform. Treisman (1970); Treisman and Fearnley (1971) presented subjects either with single items or with pairs of precisely synchronized auditory items, consisting either of two nonsense syllables, or of a nonsense syllable and a digit. The subject was to press a key if one of the items was a digit, and another key if neither item was a digit. Evidently the decision that neither of two simultaneous items is a digit could be made in parallel for the two items. The efficiency of parallel processing was less than the efficiency of processing a single item: RT to pairs

1.4.4.9 (Continued)

was longer by about 80 milliseconds than RT to single stimuli.

Kahneman reports an experiment (Kahneman (1973 p. 146)) in which he and his student exposed subjects to brief dichotic word lists, and they pressed a key whenever they heard an animal name.. RTs were measured in two conditions: attention divided between the two ears or focused on one message. He reports 77% detection of the targets in the divided attention condition, demonstrating some ability to deal with both messages. The difference between the mean RTs of the two conditions was 140 milliseconds. Treisman and Davies (1973) found in a similar task that subjects can identify about half of the targets.

In another experiment, with another student Kahneman (1973 p. 147) reports evidence of parallel processing in studies of recognition memory following dichotic presentation of word lists. The results indicated that man can listen with both ears at once and store some part of what he hears, although recognition performance is far poorer than when he listens in only one ear.

Lindsay (1970) reviewed some studies of psychophysical tasks in which attention was divided among different stimuli and among different relevant aspects of the same stimulus. Subjects in these experiments made absolute judgements of various attributes of simultaneous visual and auditory stimuli. They managed to transmit almost as much information on each dimension when they judged both stimuli together as they did when the judgements were made one at a time.

1.4.4.9 (Continued)

When the stimuli to be judged were easily descriminative from one another, attention was effectively divided between the two tasks (Lindsay, Cuddy and Tulving (1965); Tulving and Lindsay (1967)).

Moray and Jordan (1966) presented subjects with three pairs of digits dichotically. The member of each pair arrived simultaneously at opposite ears. Subjects were asked to recall them either vocally, alternating between the ears, or manually on a keyboard which allowed them to respond to both ears at once. Very high levels of recall were achieved in both conditions, but the manual simultaneous conditions was superior.

In an experiment carried out by Allport et al. (1972) it was found that subjects can shadow and at the same time 'take in' complex unrelated visual scenes, or even sight reading piano music. In both cases performance with divided attention was very good, and in the case of sight reading was as good as with individual attention. As a result of their experiment, they suggested a 'multi-channel' hypothesis of a number of independent, specialized processors. Their hypothesis is too general to derive specific predictions from it. It seems as if Allport et al. hints that simultaneous performance of two tasks is 'natural' and the exhibition of limited capacity only happens in some extreme situations.

Their experiment was particularly successful in demonstrating simultaneous performance, because it stimulated two 'sense modalities' and it used pictures and music for sight reading. In terms of the model developed in the present study, the two simultaneous tasks did

1.4.4.9 (Continued)

not use the same internal pathways, and the transformations were completely different. The parts of the experiment where two auditory stimulations were used was not so successful. Recognition memory for auditory words approached chance level (50% errors), which is confirmation of the results obtained by others (Glucksberg and Cowen (1970); Moray (1959); Norman (1969); Mowbray (1964)). Recognition of visually presented words was slightly better, but still a third of their list was mis-identified. These results show that stimulating the same sense causes sensory load and that performance can deteriorate in simultaneous performance.

Rollins and Thibadeau (1973) presented their subjects with passages of prose to one ear accompanied by a list ' to be remembered'. They also had to shadow a prose passage while presented with a list of items. There were four types of lists: words auditorilly, words visually, pictures of common objects and pictures of fictitious characters. They found that the shadowing task interferred with the processing and storage of words whether the words were presented auditorilly or visually and also with the processing of pictures of common objects, but not with pictures of fictitious characters. They argue that the deterioration only happened with information that can be verbally labelled, the last type of list was difficult to verbalize and therefore was stored visually. Their results are in agreement to those of Allport et al.

All these experiments demonstrate the possibility of simultaneous performance. However, they also show that in many situations this performance is not as good as the performance of one task alone.

1.4.4.9 (Continued)

To summarize the functional dynamics of the central processor in human time-sharing:

i) There are mainly two types of time-shared situations: simultaneous and successive.

a) simultaneous time-sharing - is a highly loading situation, caused mainly by external sources to the operator. The performance of the tasks is very poor, and cannot be pursued over long periods of time. Often one of the tasks is very short or it requires very little activity from the operator.

b) successive time-sharing - is a less loading situation. This type of performance occurs frequently in the course of human activities.

ii) The factors which influence these two types of time-sharing are different in nature.

a) under simultaneous conditions it is extremely difficult to time-share between two very similar, but independent or unrelated tasks. Both 'sense modality' and 'transformation' are influential in deteriorating the performance. Two continuous stimulations to the same 'sense modality' cause serious disruption of the performance. If in addition it is required to perform two transformations by use of the same function - such performance becomes extremely difficult.

b) under successive conditions it is relatively easy to time-share between very similar tasks which stimulate the same 'sense modality' and which require

1.4.4.9 (Continued)

the same 'transformation'. 'Transformation' is the most influential of the two factors.

1.4.4.10 Review

The model developed in this thesis describes the human information processing system as a specializing functional hierarchy. It focuses on the aspects concerned with the receiving of messages and the processing of information, rather than on strategies of decision making and response.

Each level of the hierarchy specializes in a different kind of function. The peripheral, low level functions, carry out simple, rigid and limited processing of a vast amount of data, based on the physical characteristics of the incoming signals.

The nature of the functions changes gradually up the hierarchical scale, to become a complex, flexible and extensive processing of limited amounts of data, based on meaning, centrality and importance of the messages. An additional change in function is the transition from mere processing of signals in the periphery to an increasing emphasis on control. Accordingly, the main function of the higher levels is to control, co-ordinate and integrate the activities of the lower functions. In addition, the higher levels have the ability to extract information directly from any of the lower levels.

1.4.4.10 (Continued)

The functions are interdependent: the number and type of low level functions depend on the variety of stimuli and the instructions channelled from the higher levels. The higher levels, in turn, are dependent on the complexity of the task - but also on the number of low level functions.

Filtering out the irrelevant signals is an integral function of the processing activities. At each level of the functional hierarchy, the irrelevant signals are blocked and only the relevant ones are allowed to penetrate to the higher levels.

In low level functions the filtering of signals is based on their physical features, while in the higher levels it is based on meaning and importance. The model also caters for the filtering of messages on conscious grounds of belief or disbelief.

The model provides new references to human abilities:

Learning - is defined as the construction of new internal programs (functions) in relation to new experiences. Practice is the improvement of these programs and the lowering of the level at which they function. Continued practice may lead to habits which are reinforced, well practised and automatic pattern of behaviour.

Mental load - the model differentiates between three types of load:

1) Sensory load:
   a) one set of relevant signals accompanied by noise.
   b) more than one set of signals with, or without noise.

1.4.4.10 (Continued)

2) Processing load:

a) a single function load where two or more messages compete for the same function.

b) a multi-function load where many functions must be used simultaneously in order to cope with complex demands.

3) Speed load:

short, efficient, low level programs which require excessive practice.

<u>Time-sharing</u> - takes the form of successive or simultaneous task performance:

1) Successive time-sharing - the main effect is on the time required to switch from one task to the other task. The switching time depends on:

a) the degree to which the moment of switching is chosen by the subject, or imposed on him externally.

b) the time spent on the first task: the longer the time spent on the task, the more difficult (time-consuming) it is to switch.

c) the similarity between the two tasks in terms of the stimulated 'sense modalities' and the required 'transformations', (i.e. translation between stimulus array and required response). The more similar the tasks, the shorter is the switching time. 'Transformation' is the more influential factor of the two.

d) the compatibility between the two 'transformations'. Compatible 'transformations' are quicker to time-share than incompatible ones.

1.4.4.10 (Continued)

2) Simultaneous time-sharing - the load is the main source of deterioration of performance. The influences of load are as follows:

a) two sets of stimulation to the same 'sense modality' create a sense load.

b) similar 'transformations' create a single function load and different 'transformations' create a multi-functions load.

A combination of several types of load causes very severe deterioration of performance.

2.0 HUMAN TIME-SHARING IN SUCCESSIVE PERFORMANCE

As the title suggests, the three experiments included in this section have in common the performance of successive time-shared tasks.

The functional hierarchical model argues that the most important factor in successive time-sharing, is the initial period in which the operator starts performing the new task. This means that the starting performance will be slower than the rest of the performance.

The model claims that there are several variables which influence this starting performance. This study concentrates on some of them. The experiments look at 'time on old task' as influencing the starting performance of the new task. They also look at the relative influence of factors such as 'transformation', 'sense modality' and compatibility between some aspects of the shared tasks.

The tasks used in the study were a series of RT trials. Series of RTs are usually associated with the study of 'psychological refractory period'. However, in these experiments the writer was not interested in the refractoriness effects, and therefore the stimuli were well spaced and the fore period - or inter-stimulus interval - was varied.

The findings and conclusions of one experiment were naturally employed in the design of the following experiments.

2.1 Time-sharing and the length of stimulus series

The functional hierarchical model developed earlier in this thesis, advocates that the amount of time spent on the 'old' task (i.e. before switching to the 'new' task) is one of the important factors which influence time-sharing. The pathways in the central processor, through which the signals travel, become reinforced as a function of the time spent on a task. As a result of habit, new incoming signals will try to pass through the same pathways. If these signals belong to the old task, in other words if no time-sharing takes place, the central processor will have no difficulty in processing these signals quickly and efficiently. However, if the incoming signals do not fit the existing patterns (i.e. if they belong to a new and different task) some changes will have to take place. The old processing programs and the criteria used for the various filterings will have to be cleared and stored away for future use, and new ones will have to be created. How difficult or time-consuming this operation will be, partially depends among other factors on the 'build up' of the old habits - or the time spent in performing the old task.

Therefore, before any further study of successive time-sharing can be initiated, the dynamic influence of 'time on task' must be studied.

2.1.1 Hypotheses

It is hypothesized that the longer the time spent on a task, the more difficult (i.e. time -consuming) it is to switch to a different task.

The tasks to be used in this experiment are discrete and are composed of a series of RT trials. Each series of trials belongs to a different task. 'Time on task' is expressed as length of series, or the number of trials in each series.

The series vary in their length, so that the subject has no previous knowledge as to when one series is about to be completed and the other to begin. Only at the beginning of a new type of signal does the subject realize that he is forced to change tasks. The initial presentation of the new signal marks the beginning of a new task, and it also marks the moment at which time-sharing takes place. Therefore the RT to the first signal of a new series ('first') includes the 'ordinary time' which would take the subject to react to this particular stimulus, should no switching between tasks occur, plus the need to 'set up' the functions which are required for processing the new signals. The time consumed by these two different activities is additive, in other words the two activities take place in serial order and not in parallel. The time-sharing theory stated earlier argues explicitly that the preparations or set up takes place prior to the performance.

Therefore, it is hypothesized that the longer the series, the greater is the difference between the RT to the first trial ('first') of the following series, and the average RT to the rest of the trials ('rest')

2.1.1 (Continued)

in this following series. In other words, the difference between the RT to the 'first' and the average RT to the 'rest' is a function of the length of the former series: the longer the series, the greater the difference.

2.1.2 Method

2.1.2.1 Experimental design

Each of the two tasks employed in this experiment consisted of a series of trials. The procedure used here was a serial alternation between the tasks.

The main independent variable was the number of trials in (i.e. length of) the series in each of the tasks.

Three types of series were utilized, according to their relative number of trials:

a. short series: composed of 1 - 5 trials

b. medium " : " " 6 - 10 "

c. long " : " " 11 - 15 "

The size of the series was only broadly defined, by upper and lower limits, in order to prevent the subjects from predicting the exact trial in which the second task began.

Three groups of subjects participated in the experiment. Each group was composed of six subjects. The first group performed the experiment with short series, the second with medium series and the third with long series.

The initial task with which each subject began the experiment was randomly chosen.

2.1.2.2 Subjects

Eighteen subjects participated in the experiment. Half of them were secondary school pupils from various schools in Birmingham, and the other half were undergraduate students from The University of Aston in Birmingham. The subjects were assigned randomly to the three experimental groups so that the two kinds of subjects were balanced across groups. The subjects age range was from 16 - 20 years. They were all right-handed with good vision. They volunteered to participate in the experiment, but were paid for their services.

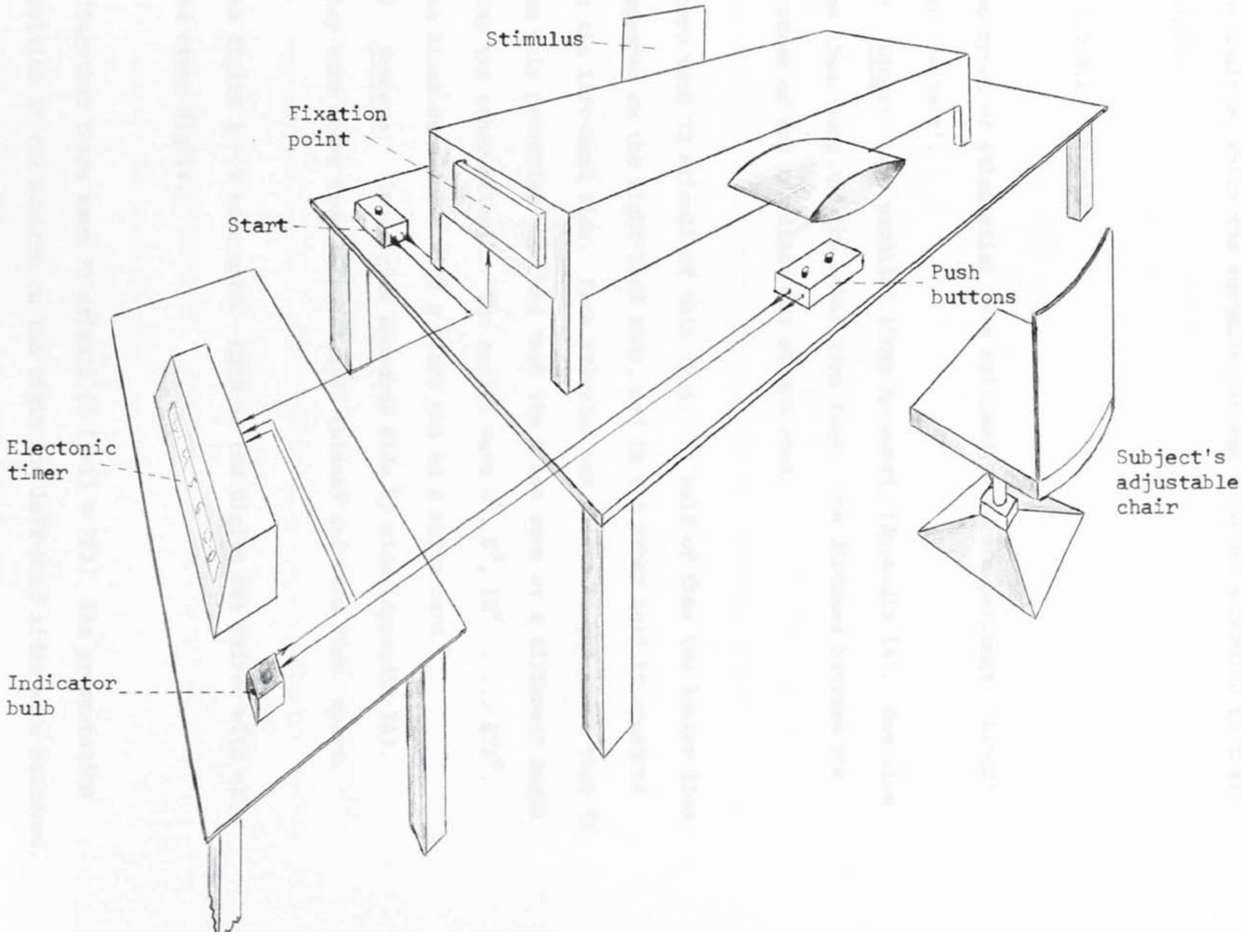
2.1.2.3 Apparatus

The two main devices in the experiment were a tachistoscope and an electronic timer (Figure 2.1.1). The tachistoscope (Behaviour Apparatus H046) was used to present the stimuli to the subject. The subject looked at a fixation point - a black dot on a white back-ground. When a stimulus was presented the fixation point disappeared from the visual field and the stimulus replaced it.

By pressing his 'start' button, the experimenter presented a new stimulus to the subject, and also activated the digital timer. As soon as the subject pressed one of the two push buttons the digital timer stopped, and it reset itself automatically to zero after a second. The experimenter monitored which button the subject pressed by the aid of an indicator bulb.

Each stimulus was presented for the duration of one second and then automatically replaced by the fixation point. The RTs were manually

Figure 2.1.1 Principal hard ware diagram



2.1.2.3 (Continued)

recorded.

The chair on which the subjects sat was adjusted according to their height.

2.1.2.3.1 Stimuli

Two types of stimulation were utilized in this experiment: 'Lines' and 'Numbers'.

1) Lines: Two parallel lines appeared, (Appendix IA). One line was 15mm. long and the other 10mm long. The distance between the centres of the two lines was always 25mm.

There were 72 stimuli of this type. In half of them the longer line appeared on the right-hand side, and in the other half it appeared on the left-hand side. Each stimulus was unique in the sense that it was only presented once and that its lines were at a different angle than the other stimuli. The angles were 0^{o}, 5^{o}, 10^{o} ...... 175^{o}. The lines were drawn with a black pen on a white card.

2) Numbers: Two digits appeared side by side (Appendix IA). They were drawn from Letraset 1292 (black) and were 25mm. apart.

The digits 1 - 9 were used. Each of the digits was paired with all the other digits.

Altogether there were 72 stimuli (9 (9-1) = 72). The presentation position of the numbers on the right and left-hand sides were balanced.

2.1.2.3.1 (Continued)

Each stimulus was unique in the set of stimuli. In carrying out his task the subject had to press the right push button whenever the long line or the higher number appeared on the right-hand side, and to press the left push button whenever they appeared on the left-hand side.

The instructions which were given to the subjects are presented in Appendix IB.

Each of the stimuli was presented for the duration of one second. This is more than the expected duration of a visual RT (which is usually between 300 - 800 m.sec.). The reason for this rather lengthy presentation was to enable the subjects to receive a feedback as to the accuracy of their responses. It was hoped that this feedback may prevent them from reacting quickly but inaccurately.

2.1.2.4 Procedure

2.1.2.4.1 Training

A short period of training was given to each subject before starting the experimental session. This familiarized the subject with the two tasks and enabled the experimenter to find out whether the subject understood the instructions, which had been read to him at the beginning of the session.

The subject was trained separately on the 'numbers' task and on the 'lines' task for 20 trials each. A 5 minute rest period was given to the subject between the training and the experimental sessions.

The first subject to participate in the experiment was used for a pre-test and also gave the experimenter an opportunity to train himself in running the experiment. The analysis of the results includes only the 18 subjects who followed. The results of the very first subject were not used.

2.1.2.4.2 Experimental procedure

Each subject started the experiment with trials from either the 'numbers' task or the 'lines' task, according to a random pre-decision. He was presented with alternative series from both tasks. The length of the series depended on his experimental group, but the total number of trials received by each subject throughout the experiment was always 144. Half of them were from the numbers task and the other half were from the lines task.

The experimenter gave a warning signal by saying "ready" a short while before each stimulus was presented. The rate of presentation was about one stimulus per 5 seconds.

The RTs were manually recorded by the experimenter on the data form (Appendix IC).

2.1.3 Results and analysis

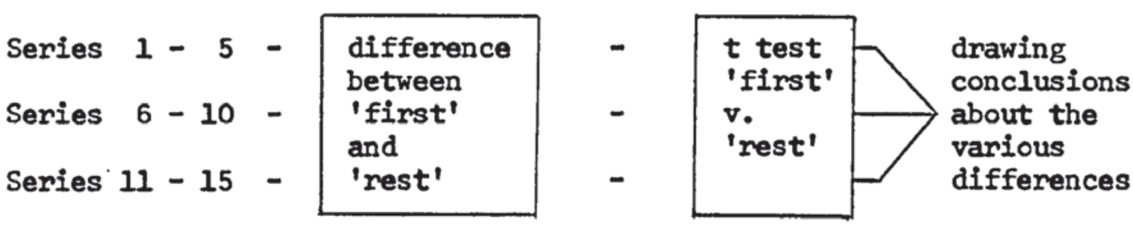
2.1.3.1 Statistical model

As it was argued earlier, the aim of this experiment was to test the hypothesis that the RT to the first stimulus in a series of trials is longer than the average RT to the rest of the series. Furthermore, it was hypothesized that the difference between the first RT and the rest of the RTs depends on the length of the series: the longer the series - the greater the difference is likely to be.

The statistical model which was used for analysing the data was a 'student t test for correlated samples'. This was found to be the right test because the comparison was carried out between two samples only ('first' v. 'rest') and both were performed by each subject.

The proposed method for analysing the results from this experiment is represented in Fugure 2.1.2. According to this method, the RT of the 'first' is compared to the average RT of the 'rest' in each series.

Figure 2.1.2 First experiment: method for analysing results



The significance of these differences is tested for each experimental group. The final conclusions are drawn by comparing the differences found in the groups.

2.1.3.1 (Continued)

This is a very conservative method, but the writer thinks that since very little is known about this type of experiment, the purpose of the experiment would be better served by a cautious analysis. It is possible to make a direct comparison of the first RTs of the three experimental groups. However, very little is known about the dynamics and characteristics of variables influencing the RTs in such situations. For example, there is a possibility that the size of the series influences the basic performance. In other words it is possible that subjects who receive long series, (more successive trials from the same task), produce different RTs than subjects who receive short series. If this is true, then a direct comparison of the three first RTs will not yield any meaningful results, because each first RT is composed of the time consumed on the sharing process and the time consumed on the reaction itself. Accordingly, if both time components were to vary as a function of the length of the series - a direct comparison would not have provided any understanding of their relative influence. An additional comparison of the rest RT would not help to solve the problem. If the additional comparison of the rest does not produce any significant results, this does not mean that the groups are equal. Statistical analyses cannot prove equality between groups. Furthermore, if the three rests are found to be statistically different, then there is no other way of finding the influence of the length of the series on the time consumed by the sharing demands - but to compare each first to its rest and then compare the comparisons.

Before proceeding to analyse the data it is necessary to clarify the criteria according to which raw data was included or otherwise excluded from the statistical analysis.

2.1.3.1 (Continued)

Due to the multitude of possibilities related both to the experimental design and to the different sizes of the series, it was thought useful to deploy these criteria in a flow-chart (see Figure 2.1.3).

To summarize - the minimum requirement for including a series in the calculation, was that a 'correct' response to the first stimulus should be followed by at least another correct response from the same series.

2.1.3.2 Results

Table 2.1.1 sums up the results and the statistical analysis for this experiment:

1) The first feature which requires explanation is the differences between the numbers of compared pairs (Column 3). These differences exist both within each experimental group and between the three groups.

a) Within each group - the differences are due to the fact that some of the series had to be excluded from the analysis (see section 2.1.3.1 and Figure 2.1.3).

b) Between the groups - the number of series which were performed were directly correlated with the number of pairs and inversely correlated with the size of the series. All the subjects who participated in the experiment received the same number of trials (144), and therefore the longer series resulted in fewer pairs for comparison.

Figure 2.1.3 Logic for including series in the analysis

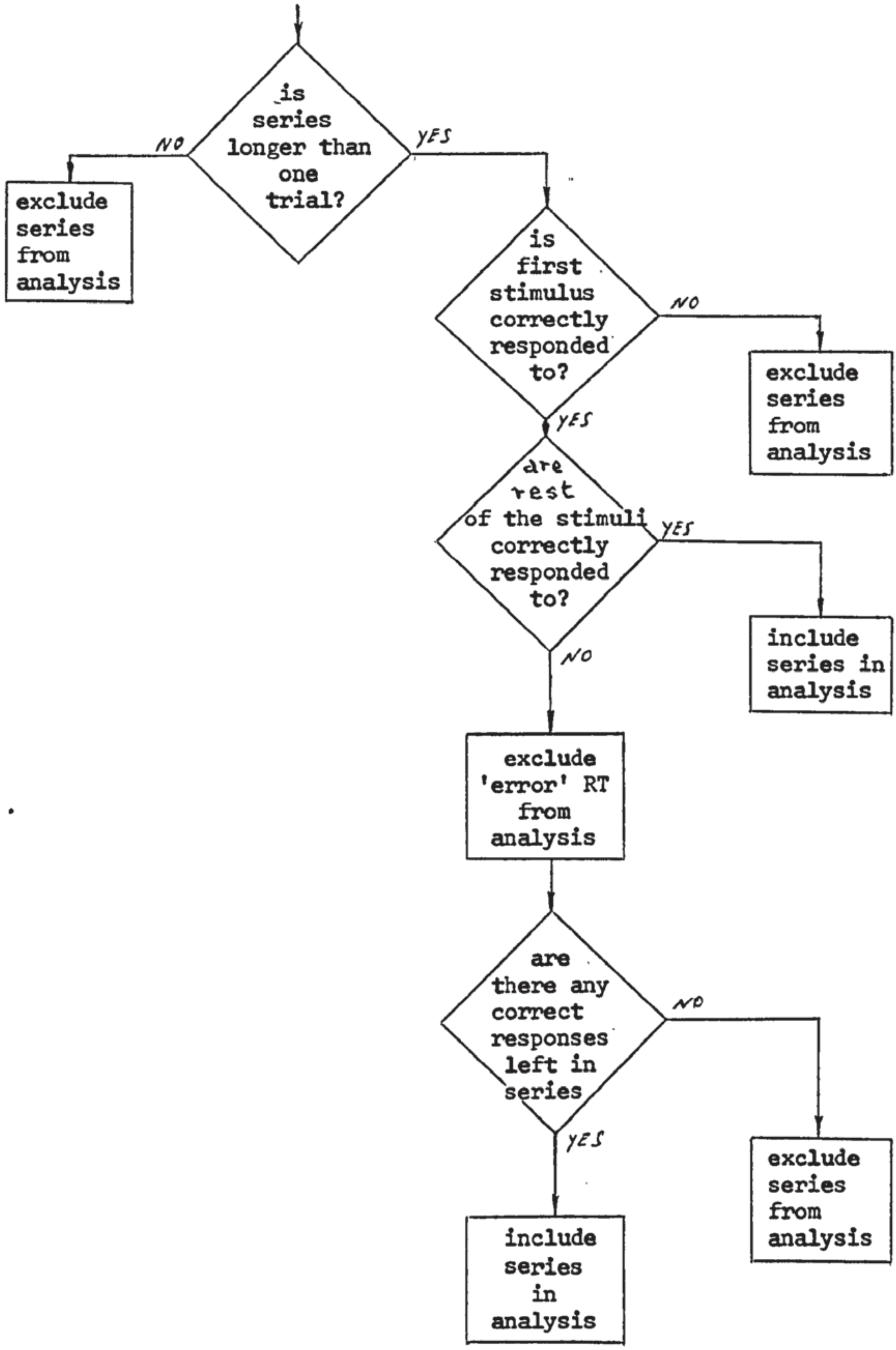


Table 2.1.1 First experiment: summary of results

(1) Size of series	(2) Type of task	(3) Number of compared pairs	(4) First stimuli (mean) m.sec.	(5) The rest of the stimuli (mean) m.sec.	(6) The 'difference' m.sec.	(7) t test	(8) $\hat{\omega}^2$
1 — 5	Lines	121	534.75	511.40	23.35	3.651**	0.0484
	Numbers	116	547.66	528.35	19.31	2.915*	0.0313
6 — 10	Lines	57	595.30	500.81	94.49	8.092**	0.3612
	Numbers	56	664.36	570.76	93.60	5.448**	0.2039
11 — 15	Lines	35	615.97	489.45	126.52	11.271**	0.6429
	Numbers	36	632.14	549.75	82.39	3.726**	0.1518

* $P < .005$ ** $P < .001$

2.1.3.2 (Continued)

2) The sixth column in Table 2.1.1 shows the difference between the mean RT to the first stimuli and the mean RT to the rest of the stimuli. The measurement is in milliseconds.

In the short series of 1 - 5 trials per series, these differences are small, about 20 m.sec. for both lines and numbers tasks. However, in the medium and long series these differences between RT to first and RT to rest become much greater. In medium length series these differences are about 94 m.sec. for both tasks, while in long series the difference is 126 m.sec. for the lines task and 82 m.sec. for the numbers task. Figures 2.1.4 and 2.1.5 present these differences graphically.

This point is further demonstrated in Table 2.1.2. In this table the lines task and the numbers task were combined together. A weighted mean was calculated for the differences in RT for the first and the rest.

From this table it can be clearly seen that there is a positive relationship between the difference and the size of the series:

for short series - the difference is 21.37 m.sec.

for medium series - " " " 94.05 m.sec.

for long series - " " " 104.14 m.sec.

3) 't tests' for correlated samples were carried out on the differences in the mean RT of the first and the mean RT of the rest (Table 2.1.1, column 7). All the results were statistically significant.

Figure 2.1.4 RTs of 'first' and 'rest' according to type of task and length of series

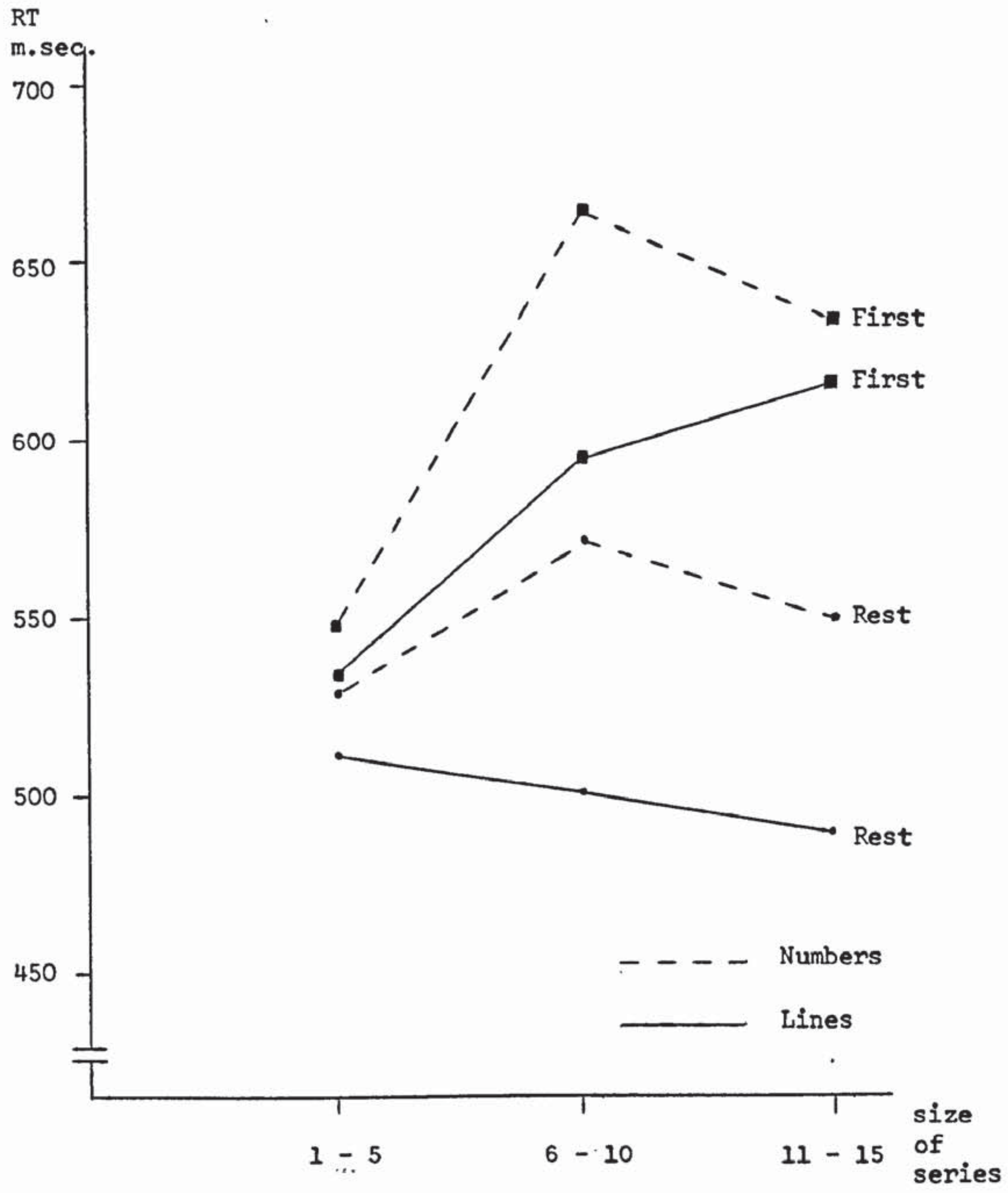
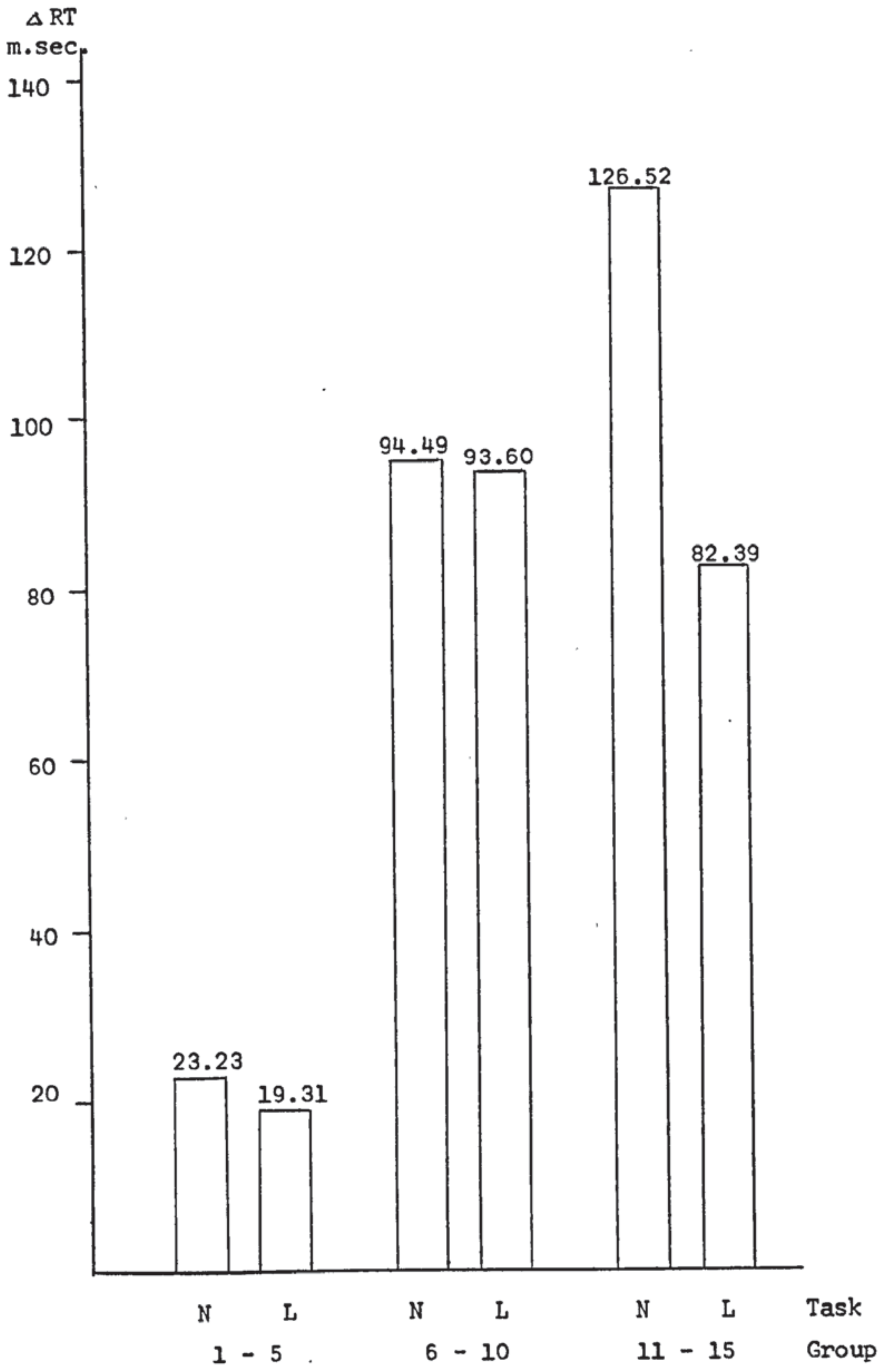


Figure 2.1.5 The difference between 'first' and 'rest' according to type of task and length of series



2.1.3.2 (Continued)

Table 2.1.2 Differences between the 'first' and the 'rest'

		TASK		
Size of series		Lines	Numbers	Combined
1 — 5	Number of pairs	121	116	237
	The 'Difference' in m.sec.	23.35	19.31	21.37
6 —10	Number of pairs	57	56	113
	The 'Difference' in m.sec.	94.49	93.60	94.05
11 —15	Number of pairs	35	36	71
	The 'Difference' in m.sec.	126.52	82.39	104.14

4) The estimation of the magnitude of experimental effects (Table 2.1.1, column 8) will be discussed in section 2.1.3.4.

An interesting feature in the results is the fact that in all the various conditions the RT for the lines task are always shorter than the RT for numbers. These findings are in agreement with the opinion expressed by most subjects, that the lines task is easier than the numbers task. These findings are also compatible with other experimental results employing meaningful or semantic stimuli and physical stimuli (Flaherty and Coren (1974)).

2.1.3.3 Magnitude of treatment effects

The importance of an experimental manipulation is demonstrated by the degree to which we can account for the total variability among subjects by isolating the experimental effects. Hays (1963) is largely responsible for introducing to psychologists an index which attempts to provide an estimate of the efficiency of experimental treatments.

A significant result implies that it is safe to say that some association exists between the experimental manipulation and the resultant behaviour. Such a statement gives no information as to the strength or magnitude of the association.

A combination of significance level and the estimated strength of association will probably yield a more reliable decision than either of these taken alone. Therefore, this technique is employed in this study whenever it is appropriate. The technique is further discussed and developed at a later stage in this study (Appendix IIIC).

2.1.3.4 The strength of association in the first experiment

Hays (1963 p.327) provided the following formula for estimating the strength of the statistical association:

$$\hat{\omega}^2 = \frac{t^2 - 1}{t^2 + N_1 + N_2 - 1}$$

N_1 and N_2 are the number of subjects in each of the groups.

2.1.3.4 (Continued)

The last column ($\hat{\omega}^2$) of Table 2.1.1 was calculated according to the above formula. In 'short series' the $\hat{\omega}^2$ was .0484 for lines and .0313 for numbers. This means that only about 5% and 3%, respectively, of the total variance is accounted for by the experimental treatments.

In the 'medium' and 'long series' much more variance is accounted for (15%, 20%, 36% and 64%).

2.1.3.5 Error analysis

According to the hierarchical functional model developed in this study, successive time-sharing has the effect of consuming time, but it should not impose a heavier load on the operator. Therefore, there is no room to hypothesize that time-sharing brings about more errors than the usual rate expected for that particular task. In other words, it is not expected that relatively more errors were made in the first response, than in the rest of the responses in that series.

Table 2.1.3 contains the number of errors made in each condition and in each task. The table also contains an expected value of errors. The number of expected errors was calculated by dividing the total number of errors by the average length of series for each task in each group of series. For example, the average length of the medium series is 8 $(\frac{6 + 10}{2})$. Therefore the ratio first: rest is 1:7, and the expected number of errors for the numbers task are: $1 (\frac{13}{8}) : 7 (\frac{13}{8})$.

Table 2.1.3 First experiment: errors analysis

Group	Length of series	Task	'First' Observed	'First' 'Expected'	'Rest' Observed	'Rest' 'Expected'	Total
I	1 — 5	Numbers	6	7.33	16	14.66	22
		Lines	2	1	1	2	3
II	6 — 10	Numbers	4	1.63	9	11.37	13
		Lines	0	0	0	0	0
III	11 — 15	Numbers	1	1.46	18	17.54	19
		Lines	0	0.23	3	2.77	3
TOTAL			13	11.65	47	48.34	60

2.1.3.5 (Continued)

Taking into account the number of observed and expected errors, it can be seen from Table 2.1.3 that in half the cases the observed value fails to reach the expected value. The total observed errors made in the first response is only slightly above the expected value.

An attempt to test the differences between the observed and expected values did not yield any significant results:

$\chi^2 = 6.70986 \quad df = 5 \quad .30 > P > .20$

(from Siegel (1956 pp.104-111)).

Altogether 60 errors were made in the experiment out of a total of 2592 reactions (144 stimuli x 18 subjects).

The average percentage of errors is 2.31:

Group	I	made	25	errors	which	is	2.89%
"	II	"	13	"	"	"	1.50%
"	III	"	22	"	"	"	2.55%

These error rates are compatible with the findings of other investigators in similar tasks (see Smith (1968) for review).

2.1.4 Discussion

The results of this experiment show that an operator does indeed require a short period of time for successively switching from performing one task to performing another.

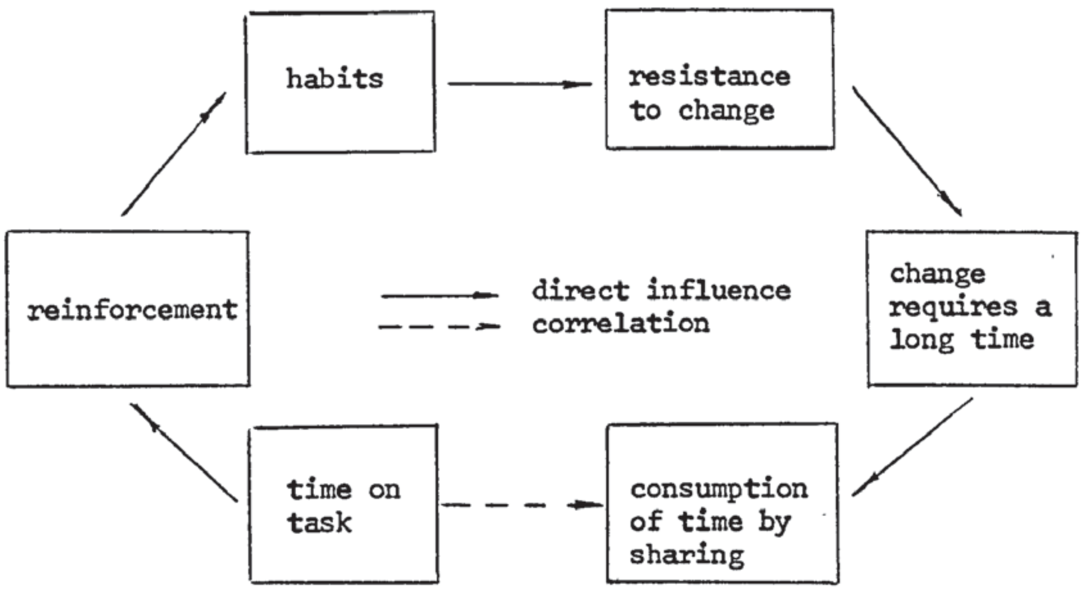
In operational terms, it was demonstrated that the performance on the 'first' trials was slower than the average performance on the 'rest', hence leading towards the acceptance of this hypothesis.

It was further hypothesized that the longer the performance on the previous task - the more time-consuming will the sharing process be. In terms of this experiment, in long and medium length series, the RT to the first trail was expected to vary considerably from the RT to the rest. However, in short series no big discrepancy was anticipated between the first and the rest.

The results of the experiment lead to the acceptance of all these hypotheses. Thus, in relation to the proposed model, this means that a long performance reinforces the particular functions, programs, or pathways, through which the signals travel. The need to switch away from such habituated paths will be more time-consuming than the need to switch away from non-habituated paths. The time consumed on the switching operation is a function of the degree of resistance to change. This resistance is determined by the formation of a habit. Habits can only be formed after spending a relatively long time in performing a task (Figure 2.1.6).

2.1.4 (Continued)

Figure 2.1.6 Time on task as influencing time-sharing



The hierarchical model predicts that the longer the time spent on the previous task, the longer it takes to start a new task. The hypothetical relationship appears in Figure 1.4.6. It is possible to check this hypothetical relationship by plotting a graph based on these results (Figure 2.1.7). The abcissa is the number of trials in the previous series (i.e. number of trials before time-sharing took place). The ordinate is the RT to the first stimulus (after time-sharing took place). The graph is composed of the RTs from both tasks.

Despite the fact that the experiment was not designed initially to test this relationship, the results follow closely the hypothetical curve.

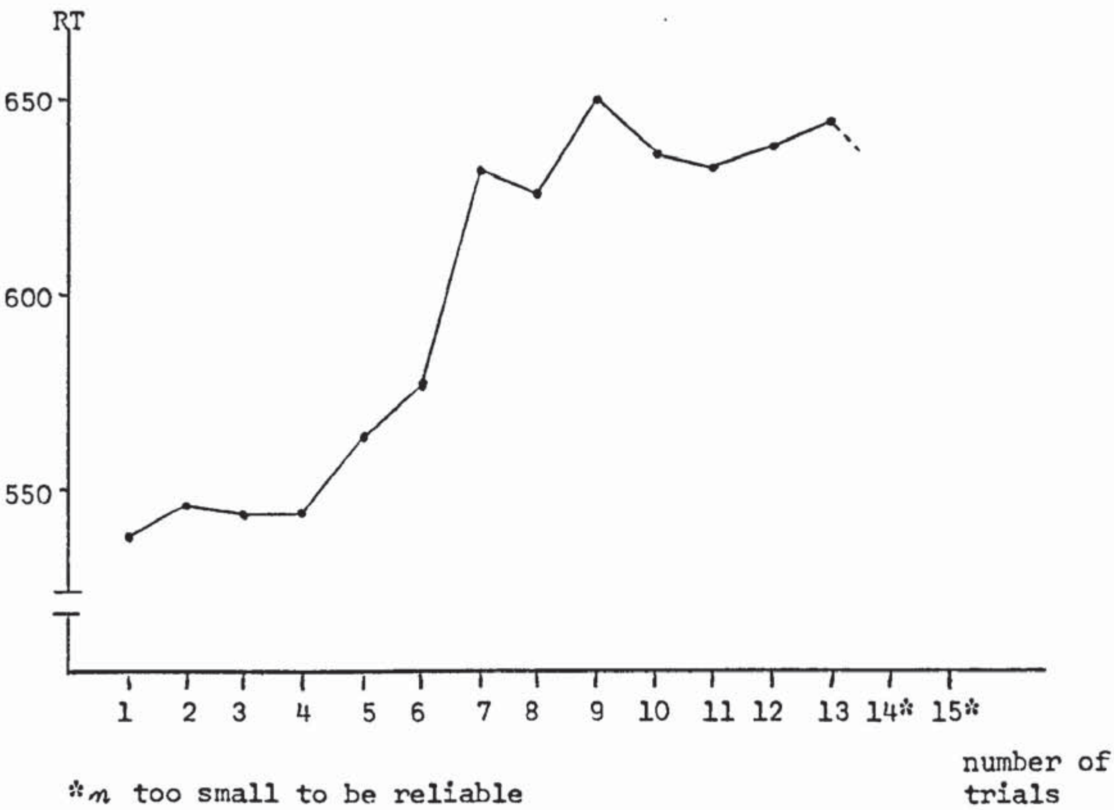
There are other possible explanations to the findings of this experiment. One such possible explanation is that for medium and long series the subjects could clearly distinguish between the two alternating tasks:

2.1.4 (Continued)

they could identify each of the series with a given task, and they knew that one task followed the other. This is not the case with the short series. These series were so short that they could appear to the subjects as essentially one continuous task, presented in two types of stimulation: numbers and lines.

According to this argument, subjects in the short series condition had only one task to perform with no time-sharing. Hence the very small difference between first and rest. The fact that this difference is significant only points to its persistency, but does not rule out the fact that in terms of magnitude (est. ω^2) it is negligible.

Figure 2.1.7 RT to first as a function of number of trials in previous series



*n too small to be reliable

2.1.4 (Continued)

This explanation relies on the existence of subjective perception of how subjects perceive the particular experimental situation. The investigation of subjective perception does not lend itself to rigorously controlled experimental research. The subjects who participated in the short series conditions could not make clear comments on the nature of the tasks they were required to perform.

However, if they did perceive only one complex task, then in each trial they were faced with four choices - two tasks x two choices. It is true that this is not a 'classical four choice RT' situation, since the subjects had only two push buttons to respond with, but nevertheless they had a more difficult decision to make. According to Hick's Law (Hick (1952)) or numerous other RT experiments, the 'basic RT' of these subjects should have increased. In other words their RT to rest ought to have been longer than the RT to rest of the other subjects.

A close examination of the data shows that this is not the case. The calculated mean RT of both tasks - only to the rest of the series, shows that in:

short	series	mean	RT	is	519.70 m.sec.
medium	"	"	"	"	535.48 m.sec.
long	"	"	"	"	520.02 m.sec.

In other words, subjects belonging to the short series condition did not have longer RTs than the rest of the subjects. Therefore, this alternative explanation has to be ruled out.

2.1.4 (Continued)

One other possible explanation for the relatively small difference between the RT to first and rest in short series lies in the fact that the subjects who participated in this condition performed far more switching-over from one task to the other, than those who participated in the other two conditions. Since all the subjects in the three groups had to respond to the same number of stimuli, those who received long series had the least opportunities to switch from one task to the other. In other words it is suggested that subjects in the short series condition could have learnt how to time-share more efficiently due to their extended practice.

If this is so, then it should be expected to find a difference between time-sharing at the beginning of the performance and time-sharing towards the end of the performance.

In order to test this hypothesis, a statistical analysis of variance (ANOVA) is carried out to compare the RTs to the first stimuli in the series included in the first (upper) quarter of the short series, and the RTs to the first stimuli in the last (lower) quarter of the short series.

Four different factors can be identified as influencing the dependent variable in this model (Table 2.1.4):

Factor A - the upper and lower quarters. Each subject responded to 144 stimuli in the experiment. These stimuli were arranged in series of 1 - 5 stimuli each. On average, the length of the series was 3 stimuli. The number of series per subject was $\frac{144}{3} = 48$. Each of the quarters were made of 12 series ($\frac{48}{4}$).

2.1.4 (Continued)

Table 2.1.4 <u>Training effect model</u>

S C A

B

task	no. of stimuli / subjects	Upper Quarter						Lower Quarter					
		1	2	3	4	5	6	1	2	3	4	5	6
Numbers	1												
	2												
	3												
	4												
	5												
	6												
Lines	1												
	2												
	3												
	4												
	5												
	6												

<u>Factor B</u> - the task

There were two tasks involved in the analysis - the 'lines' and the 'numbers' task.

<u>Factor C</u> - the number of stimuli

It was already mentioned above that the comparison involves only the first stimulus from each series. Twelve series contribute to each of the quarters; half of them are from one type of task and the other half from the other task. Factor C is composed of six levels, or six RTs, contributed by each stimulus from each of the tasks (Factor B),

2.1.4 (Continued)

from each of the quarters (Factor A).

Factor C is required in the analysis only for purely statistical reasons. It has no psychological or theoretical importance. One may regard this factor as merely a source of 'within cell' variance. Therefore, the statistical model and all the following calculations do include this factor, but in the analysis of variance tables (Appendix ID - Table ID1 and Table 2.1.6) neither this factor, nor all the interactions which include it are to be analysed. This unorthodox method of presenting the analysis of variance does not affect any of the analysed factors.

Factor S - the subjects

The results of all the six subjects who participated in the 1— 5 condition are analysed.

As it can be seen from the training effect model (Table 2.1.4) the same subjects participated in all the conditions. The proper method of analysing the data is by a three way (+ subjects factor) analysis of variance with repeated measures in all three factors. The computational formulae needed for the analysis of this design are presented in Appendix ID - Table ID1. As it has been mentioned already, factor C and all its interactions are not included in the final analysis, but they are taken into consideration with regard to the other factors.

Table 2.1.5 presents the mean RTs of the factors under investigation in this analysis. The means of factor A (quarters) and factor B (tasks) appear in the margin of the table and the interactions of

2.1.4 (Continued)

these two factors form the mid-part of the table.

Table 2.1.5 Mean RTs (in m.sec.) according to quarters and tasks

Quarter \ Task	Numbers	Lines	Combined
Upper	545.47	544.11	544.79
Lower	545.33	536.52	540.93
Combined	545.40	540.32	542.86

As it can be seen from the summary of the analysis of variance (Table 2.1.6), none of the factors yield any significant results. This means that the hypothesis that time-shared performance improves with time was not demonstrated in this experiment. This also means that no interacting effect was found between type of taks and improvement in time-sharing performance.

In view of these results, the explanation that the difference between RT to first and rest is relatively small in short series due to excess practice, has to be rejected.

Another possible argument can be put forward by stating that the effect of sharing, not only influences the first stimulus in a series, but the second one as well. In terms of the proposed model this is not possible because all 'mental set-up' (the erasing of the previous

2.1.4 (Continued)

functions and the construction of new ones) takes place before the actual performance begins.

Table 2.1.6 Training effect: summary of analysis

Source	SS	df	MS	F
S	298,839.80	5	59,767.96	
A	536.69	1	536.69	< 1
AxS	40,574.05	5	8,114.81	
B	930.25	1	930.25	< 1
BxS	35,846.00	5	7,169.20	
C	-			
CxS	-			
AxB	498.78	1	498.78	< 1
AxBxS	6,478.31	5	1,295.66	
AxC	-			
AxCxS	-			
BxC	-			
BxCxS	-			
AxBxC	-			
AxBxCxS	-			
TOTAL	917.551.22	143		

The mean RT for the second stimulus was calculated in each of the three experimental groups:

short series - RT to second 517.30 m.sec. (to 'rest' 519.70)

medium " - " " " 531.28 " (" " 535.48)

long " - " " " 518.53 " (" " 520.02)

2.1.4 (Continued)

As it can be seen in all the three groups, the RT to the second stimuli was not longer than the average RT to the rest of the group, (including the second), in fact it was slightly shorter. This indicates that all the 'set-up' activity needed for time-sharing takes place during the first trial.

To summarize, the first dependent variable used in this experiment was RT. It was found that the number of stimuli in a series influences the time consumed on reacting to the first stimulus in the following series.

The second dependent variable was the number of errors made by the subjects. No significant difference was found between the errors made in responding to the first stimulus as opposed to the number of errors made in the rest of the series, taking into account the relative sizes of first and rest. Instead, it seems that the errors are more or less randomly distributed in the various conditions of the experiment.

These findings are compatible with the predictions of the model. Time-sharing is a time-consuming process, but it should not increase the errors made during the initial performance.

2.2 Time-sharing and the compatibility between transformations

According to the functional hierarchical model, the programs used by the central processor - in a time-sharing situation - to process the signals from the former task, must be replaced by new programs needed for processing the new task. The question arises whether this replacement is easier (i.e. less time-consuming) in compatible tasks than in incompatible tasks.

If the two tasks are different, this means that the two programs which are needed to process them are different. If the two tasks are different but compatible, this means that the programs are different but employ the same principle, or have a similar structure. The question is whether it is easier or less time-consuming to replace one set of programs by another if the two have a similar structure than if they have different and incompatible structures.

The functional model advocates that the more similar the transformations demanded by two shared tasks, the shorter is the time consumed by the sharing process. If this principle applies also to compatibility between transformations, then the more compatible situation should yield shorter sharing times than the less compatible situation.

Although in the first experiment 'transformation' as such was not mentioned, careful examination reveals that two types of transformations were actually used:

a) - conceptual - for the 'numbers' task

b) - physical - for the 'lines' task

2.2 (Continued)

a) - The numbers task required a comparison between two numbers. This means that the subject had to transform two digital symbols into concepts (numbers) and then compare them along a conceptual scale of numerical differentiation.

b) - The lines task required a comparison between two lines. This means that the subject had to perform a physical comparison between two parallel lines along a physical scale of length differentiation.

The two types of transformations were different in terms of their scales of comparison. However, they were compatible in as much as both required looking for the item which was more than the other, whether on a conceptual or on a physical scale.

The notion of 'bigger', or 'more than...' was common to both tasks and hence it can be said that the previous experiment employed two different but compatible transformations.

In the present experiment the compatibility between the two transformations will be varied and the consumption of time in response to the first stimulus will serve as a dependent variable.

2.2.1 Hypotheses

It is hypothesized that the time-sharing process is less time-consuming for 'compatible transformations' than the 'incompatible transformations'.

Accordingly, the difference between the time needed for performing the first trial in a series and the average time for the rest of the series, is expected to be smaller in the 'compatible' group than in the 'incompatible' group.

2.2.2 Method

2.2.2.1 Experimental design

The conclusions of the first experiment were used in the design of the present study. It was decided to use only medium sized series (between 6 - 10 trials per series). This type of series was found suitable since it is long enough to yield a considerable sharing effect (i.e. considerable consumption of time), and short enough to provide a relatively large number of series ('switching') needed for statistical analysis.

Two basic tasks were utilized in this experiment, 'numbers' and 'lines'. The stimuli from the previous experiment were used again (see section 2.1.2.3.1, and Appendix IA). Two conditions were employed in the experiment:

Condition I - The compatible condition.

In this condition the subjects performed the two tasks exactly like the previous experiment (reacting to the longer line or to the higher number).

Condition II - The incompatible condition.

In this condition the subjects responded to the higher number (identical to the previous experiment) but to the shorter line.

The second condition was incompatible because the subjects had to respond to the bigger conceptual value and the smaller physical value. For subjects instructions, see Appendix IIA.

2.2.2.1 (Continued)

The initial task with which each subject began the experiment was randomly chosen.

Each of the stimuli was presented for the duration of one second.

2.2.2.2 Subjects

Twelve subjects participated in the experiment. They were drawn from the same population as those who participated in the previous experiment (see section 2.1.2.2).

2.2.2.3 Apparatus

The apparatus used in this experiment was identical to that used in the previous experiment (see section 2.1.2.3 and Figure 2.1.1).

2.2.2.4 Procedure

2.2.2.4.1 Training

The training in this experiment was carried out for the same reasons, and in the same manner, as in the previous experiment (see section 2.1.2.4.1).

2.2.2.4.2 Experimental procedure

The procedure in this experiment was similar to the previous one (section 2.1.2.4.2). The differences being that in this experiment

2.2.2.4.2 (Continued)

there were only two and not three groups, and the length of the series was between 6 - 10 stimuli for both groups.

2.2.3 Results and Analysis

2.2.3.1 Statistical model

The aim of this experiment was to test the hypothesis that the time-sharing process is less time-consuming for 'compatible' transformations than for 'incompatible' transformations.

The statistical model which was used for analysing the data was a 'student t test'. This test was required because of the need to compare two means: the mean RT for the 'first' stimuli under the compatible transformations condition and the mean RT for the first stimuli under the incompatible transformations condition.

Unlike the first experiment which utilized a series of different lengths, the tasks in this experiment are composed only of medium sized series (6 - 10 trials per series). Therefore, the argument put forward in the first experiment (section 2.1.3.1) about the possible influence of the size of the series on the RTs for the rest of the series does not apply any longer. In other words, in the first experiment the various lengths of series could influence both RTs, to first and to rest, and hence the need to compare differences. In this experiment the possibility does not exist any longer, and hence the RTs to first of both conditions can be directly compared.

The only difference between the two experimental conditions should be expressed in the RT to first. There is no reason to expect a difference in RTs to the two rests, since both conditions employed almost identical tasks, (the number task was identical and the lines task was reversed but equally difficult to perform in both cases),

2.2.3.1 (Continued)

and the subjects were randomly assigned to the two groups.

2.2.3.2 Results

In this experiment, as in the other experiments carried out in this study, the error RTs - when the subject responded with the wrong hand - were eliminated from the analysis. Altogether eight errors were made in response to the first stimuli: three were made by subjects in the compatible condition and five were made by subjects in the incompatible condition. There is no room to assume that the number of errors differed between the groups. The low rate of error found in this experiment is in good agreement with the rate found in the previous experiment, for the medium sized series.

The mean RT to the rest of the series for the two tasks in the compatible condition was 529.37 m.sec. For the incompatible group the mean RT was 537.72 m.sec. As it was stated before (section 2.2.3.1) there is no reason to expect that the two means would differ. This lack of difference provides justification for the planned comparison between the two firsts.

Table 2.2.1 sums up the RT results and the statistical analysis for this experiment. The first column presents the two types of tasks, separate and then combined together. The second column includes the following symbols:

n - the number of correct first RTs

ΣX - the sum of these RTs (in m.sec.)

ΣX^2 - the sum of squares (in m.sec.)

$\overline{X}$ - the mean (in m.sec.)

2.2.3.2 (Continued)

The third and fourth columns contain the data and the calculations. Group I is the compatible transformations, while Group II the incompatible transformations.

The results of the 't' tests appear in the fifth column, and the sixth column is an estimation of the strength of association or, in other words, an estimation of the experimental effect.

'n', the number of correct first RTs, varies between the two experimental groups and between the two tasks for two reasons:

1) The length of the series was decided upon in a random way, varying between 6 - 10 trials per series. Therefore, it is possible to have different numbers of series for different subjects.

2) In cases where the first stimulus in a series is wrongly responded to, the corresponding RT is excluded from the analysis, which brings about different numbers in each condition.

As it can be seen from Table 2.2.1, the first RT in Group I is always shorter than the RT in Group II (also see Figure 2.2.1). These results are in accordance with the hypothesis that it is less time-consuming to time-share between tasks with compatible transformations than between tasks which have incompatible transformations.

When the two tasks were combined together, a t test yielded significant results. However, when the two tasks were tested separately, the difference between the two groups was found significant only in the case of the lines task.

2.2.3.2 (Continued)

Table 2.2.1 Second experiment: summary of results

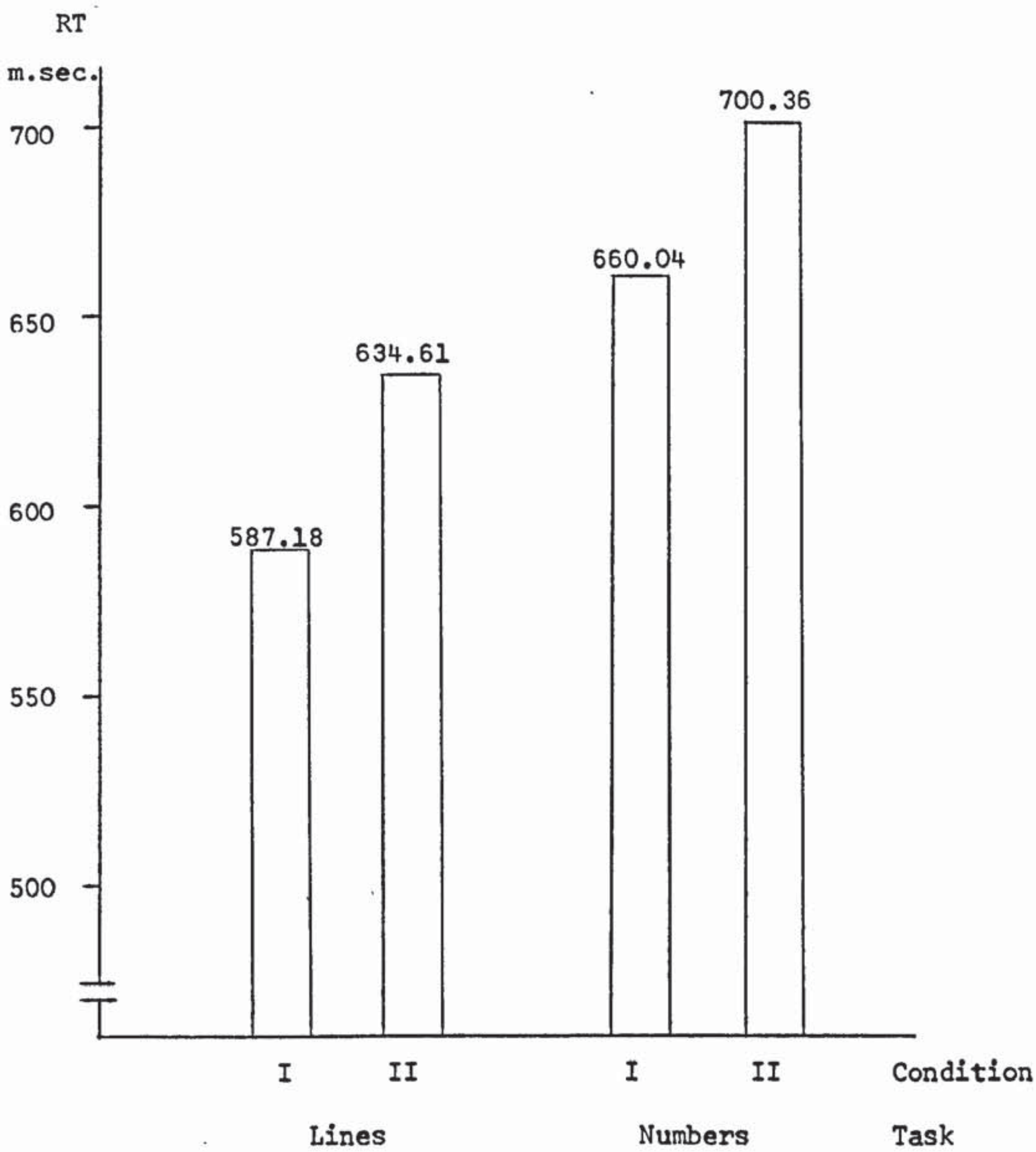
Type of stimulus		Group I ('compatible')	Group II ('incompatible')	't' test	$\hat{\omega}^2$
Lines	n X X^2 $\bar{X}$	57 33,469 20,376,819 587.18	51 32,365 21,031,649 634.61	2.296*	0.0381
Numbers	n X X^2 $\bar{X}$	54 35,642 25,527,340 660.04	53 37,119 27,158,533 700.36	1.201	0.0041
Combined results ('total')	n X X^2 $\bar{X}$	111 69,111 54,904,159 622.62	104 69,484 48,190,182 668.12	2.258*	0.0187

* $P < .025$ one trial

The failure to reach the significance level in one of the tasks, hints that the magnitude of the experimental effect is very small. In estimating the strength of association - in the combined case - it was found that only about 2% of the variance of the RTs is due to the compatible - incompatible treatment (Table 2.2.1). In the case of the lines task the strength of association was found to be less than 4%.

The difference between the mean RTs of Group I and II for the lines task is 47.43 m.sec. (634.61 - 587.18).

Figure 2.2.1 RT of the 'first' only according to experimental condition and task



2.2.3.2 (Continued)

The difference between the mean RTs of Group I and II for the numbers task is 40.32 m.sec. (700.36 - 660.04).

The difference between the mean RTs for Group I and II when the two tasks are combined together is 45.50 m.sec. (668.12 - 622.62).

To summarize, this data suggests that the RT for incompatible transformations is on average 45 m.sec. longer than the RT for compatible transformations.

2.2.4 Discussion

Experimental condition I (compatible) is in fact identical to that of 'medium sized series' (6 - 10 trials per series) in the previous experiments. Indeed the results obtained in these two situations are almost identical. The mean RTs (in m.sec.) for the first stimuli were:

	previous experiment (medium sized series)	present experiment (compatible condition)
'lines task'	595.30	587.18
'numbers task'	664.36	660.04

These almost identical results, in addition to the fact that in this experiment the mean RTs to rest, in both compatible and incompatible conditions, were also extremely similar (529.37 m.sec. and 537.72 m.sec. respectively), only enhance the argument put forward in the 'statistical model' (section 2.2.3.1). The argument claimed that in this particular experiment the first of both conditions can be directly compared.

The results of this comparison yield that it is quicker - less time-consuming - to time-share between two tasks demanding different but compatible transformations, than between two tasks demanding different and incompatible transformations.

The overall findings (combined) are statistically significant (Table 2.2.1). However, this only means that there is a clear and steady association between the compatibility or incompatibility of the transformations and the time consumed on the sharing process.

2.2.4 (Continued)

However, an estimation of the strength of this association reveals that it is very weak ($\hat{\omega}^2$ = 0.0187). In other words, the variable compatible - incompatible accounts for about 2% of the variance of the RTs.

In a sharing situation, the bulk of the consumed time is due to the need to replace one set of programs with another set of programs. Only a small amount of time - approximately 40 - 45 m.sec. - can be saved by the fact that the two sets are programmed to process compatible tasks.

These findings and conclusions are in full agreement with the predictions made by the model regarding the specializing functions.

Further examination of the results (Table 2.2.1) reveals that the difference between the compatible and incompatible conditions appear to be significant for the lines task, but not for the numbers task. There are several possible explanations to this outcome:

1) The first possible explanation is that the same magnitude of effect exists in both tasks. The difference between the two conditions for the lines task is 47.43 m.sec. (634.61 - 587.18). For the numbers tasks it is 40.32 m.sec. (700.36 - 660.04). For both tasks the differences are very similar. In other words the same principle is activated in both cases. The fact that for the lines task, the experimental effect is significant, while for the numbers task it is not, is due to the difference in the degree of difficulty in performing these tasks. The lines task is easier than the numbers task, therefore the 'basic - ordinary' RT to lines is shorter than that to

2.2.4 (Continued)

numbers. This was also demonstrated in the results of the previous experiment, where the RTs to rest numbers were always longer than the RTs to rest lines (Table 2.1.1). The treatment in this experiment - compatibility v. incompatibility - could have a fixed effect on the dependent variable, by adding (or subtracting) about 40 - 47 m.sec. to the time-sharing process. If this is so, then adding this effect to a basically short RT will cause a strong statistical effect - i.e. a relatively bigger 't' test, a smaller significance level, and a larger estimation of magnitude of experimental effect. If the same effect is added to a basically longer RT (in the case of numbers task), then all the statistical effects will be very weak, with a small, not significant t test and a negligible experimental effect.

2) The second possible explanation, to the differences of experimental effects in both tasks, again lies in the difference between the difficulty to perform these tasks. The numbers task is more difficult to perform than the lines task. Experiments in simultaneous time-sharing (Mowbray (1952, 1953, 1954): review by Welford (1968 p.132)) have shown that in such situations the easier task usually undergoes more severe deterioration than the difficult task.

If this principle holds also in successive time-sharing, then the easier task (lines) will deteriorate more than the difficult task (numbers).

3) The third possible explanation is that the difference between the compatible and the incompatible conditions was due to the fact that the numbers task was identical in both conditions, but the lines task was reversed. The use of two lines task which were not identical may have added a few m.sec. to the experimental effect of

2.2.4 (Continued)

compatibility v. incompatibility.

To summarize, time-sharing consumes less time when the shared tasks have at least one common feature (i.e. compatibility), than when the shared tasks are antagonistic to each other in one of their features.

2.3 Time-sharing, sense modality and transformation

According to the hierarchical functional model, the type of peripheral system and the type of low level programs which are activated in any task performance are depended also on the stimulated sense modality. The type of higher level programs depends on the type of transformation demanded by the task.

Both 'sense modality' and transformation determine the amount of time consumed in a successive time-sharing situation. The variation of these two factors will provide useful information about their relative influence on time-sharing.

In this part of the study, the transformation factor is extended so as to include two conditions:

1) the two time-shared tasks demand the same transformation.

2) the two time-shared tasks demand completely different transformations.

In the previous experiment the time-shared tasks stimulated only the visual sense. In this experiment the investigation also includes audition tasks.

2.3.1 Hypotheses

It is generally hypothesized that the more similar the shared tasks - the easier - less time-consuming - it is to time-share between them.

The similarity between the tasks is expressed in terms of the stimulated sense modalities and the demanded transformations. These two variables correspond to low and high levels in the central processor. The proposed functional model argues that peripheral and low level programs are only capable of quick and simple processing. Therefore, only a short additional time will be needed for the sharing process if the two shared tasks stimulate different, rather than the same, sense modalities. The high level programs are capable of long and complex processing. Therefore, if the two shared tasks demand different, rather than the same, transformations - a relatively long period of time will have to be added to the sharing process.

Both sense modality and transformation influence time-sharing, but the latter carries a greater weight. In other words, time-sharing between same or different transformations will cause more variation in the time-consumption of the sharing process, than will time-sharing between same or different sense modalities. In fact, it is hypothesized that sense modality will have only a marginal effect while transformation will have a major effect on time-sharing.

2.3.2 Method

2.3.2.1 Experimental design

Five different CRT tasks were used throughout the experiment. A full description of the tasks is given in section 2.3.2.3.1. A short summary of the task characteristics are given in Table 2.3.1.

Table 2.3.1 Summary of the CRT task characteristics

Task	Sense modality	Transformation
Words (vis.)	Vision	Conceptual comparison
Words (aud.)	Audition	" "
Numbers	Vision	" "
Lines	Vision	Physical comparison
Pips	Audition	" "

Four pairs of tasks were combined by time-sharing the 'visual words' task with every one of the other four tasks. Table 2.3.2 shows the similarities and the differences between the visual words task and the other tasks.

Table 2.3.2 The similarities and differences between visual words task and the other CRT tasks

			transformations	sense modalities
Words (vis.)	Words (aud.)	-	same	different
	Numbers	-	"	same
	Lines	-	different	"
	Pips	-	"	different

2.3.2.1 (Continued)

This experimental design provided four different pairs of time-shared tasks, but with one task common to all. Hence, it forms common ground on which comparisons can be made.

The purpose of this study is to look into time-shared performance within versus between sense modalities on same versus different transformations. Table 2.3.3 sums up the main concepts of this experiment.

Table 2.3.3 The main concepts of the third experiment

		Transformation	
		Same	Different
Sense	Within	Words (vis.) - numbers	Words (vis.) - lines
Modality	Between	Words (vis.) - words (aud.)	Words (vis.) - pips

The experiment was composed of six factors (Table 2.3.4):

Factor A - transformation

level 1. same

level 2. different

Factor B - sense modality

level 1. within (the same sense modality)

level 2. between (different sense modalities)

Factor C - first v. rest

level 1. first (the first trial in a new series)

level 2. rest (the rest of the trials in a series)

Factor D - series (the number of trials in a series.

The length of all the series in this experiment was between 6 - 10 trials. This number of trials per series was decided upon as a

Table 2.3.4 Third experiment: the experimental design

Ⓐ Transformation	Ⓑ Sense modality	Ⓢ Subject	Ⓓ First 1	Ⓒ 2....	Ⓓ Rest 5..... max. 10	Ⓔ 1... 8...max 12
Same	Within	1 . . . 6				
	Between	7 . . . 12				
Different	Within	13 . . . 18				
	Between	19 . . . 24				

2.3.2.1 (Continued)

result of the findings of the previous experiments. These trials are a 'source of variation' which is statistically calculated in factor D.

Factor D is nested in factor C, where C_1 (first) includes only D_1, while C_2 (rest) includes all the others (D_2, D_3 ... max. D_{10}).

Factor E - repetitions (the number of task repetitions).

Each subject switches back and forth between the two shared tasks. The variation due to the repetition of each task is statistically calculated in factor E.

The total number of stimuli presented to each subject in the experiment was 144. Half the stimuli were always from the visual words task and the other half from the other task. Each task was presented in series of between 6 - 10 trials. Thus the number of task changes was between 8 - 12.

Factor S - subjects

Twenty four subjects took part in the experiment. They were divided into four groups based on the four experimental conditions.

2.3.2.2 Subjects

Twenty four subjects participated in the experiment. They were all undergraduate students at The University of Aston in Birmingham. They were all between 18 and 21 years of age, right-handed, with good vision and hearing. They volunteered to participate in the experiment, but received small fees for their services.

2.3.2.3 Apparatus

The hardware of this experiment (Figure 2.3.1) was conceived to fulfil two main functions: to provide stimulation and to record the subject's responses.

1) The apparatus concerned with the stimulation was composed of:
   - a stereophonic tape-recorder (Ferograph - series 7).
   - a slide projector (Kodak Carousel S; f = 100mm).
   - slides with the visual stimulation.
   - a screen.
2) The apparatus concerned with the responses was composed of:
   - two subject response push buttons.
   - an electronic timer (Digital Timer type TSA661A from Vemmer Electronics Ltd.).
   - a print-out unit (Kienzle D44 Digital Printer).

Additional electronic devices, such as a 'pulse generator' were connected to the apparatus, in order to enable the system to function electronically.

The tape-recorder channels were used as follows:
The first channel - served to operate the slide projector.
The second channel - provided auditory stimulation whenever required.

As Figure 2.3.1 indicates, the slide projector was operated by pulses recorded on the first channel of the tape-recorder. The slides were prearranged in the cartridge in the required order.

Figure 2.3.1 Third experiment: principal hard wave diagram

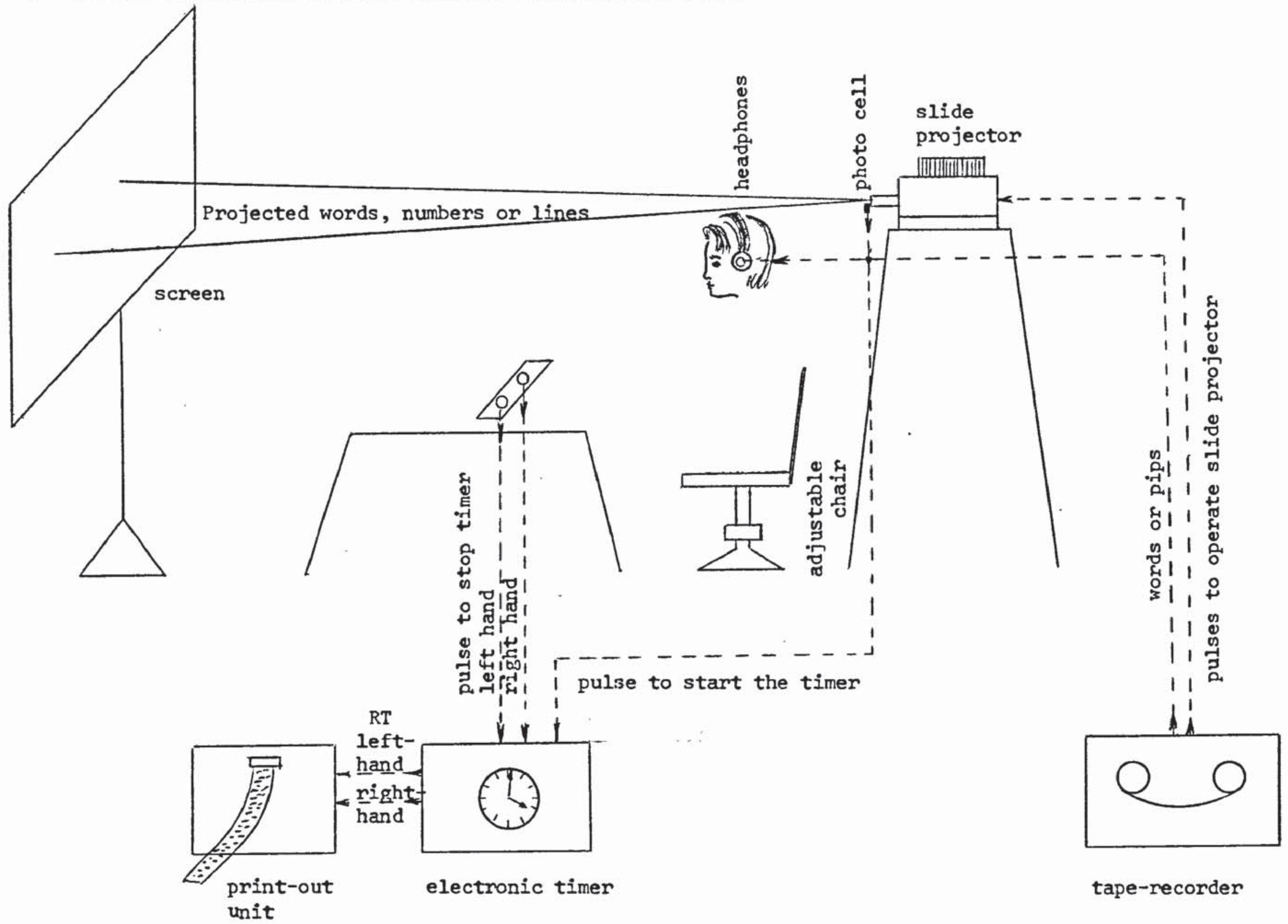
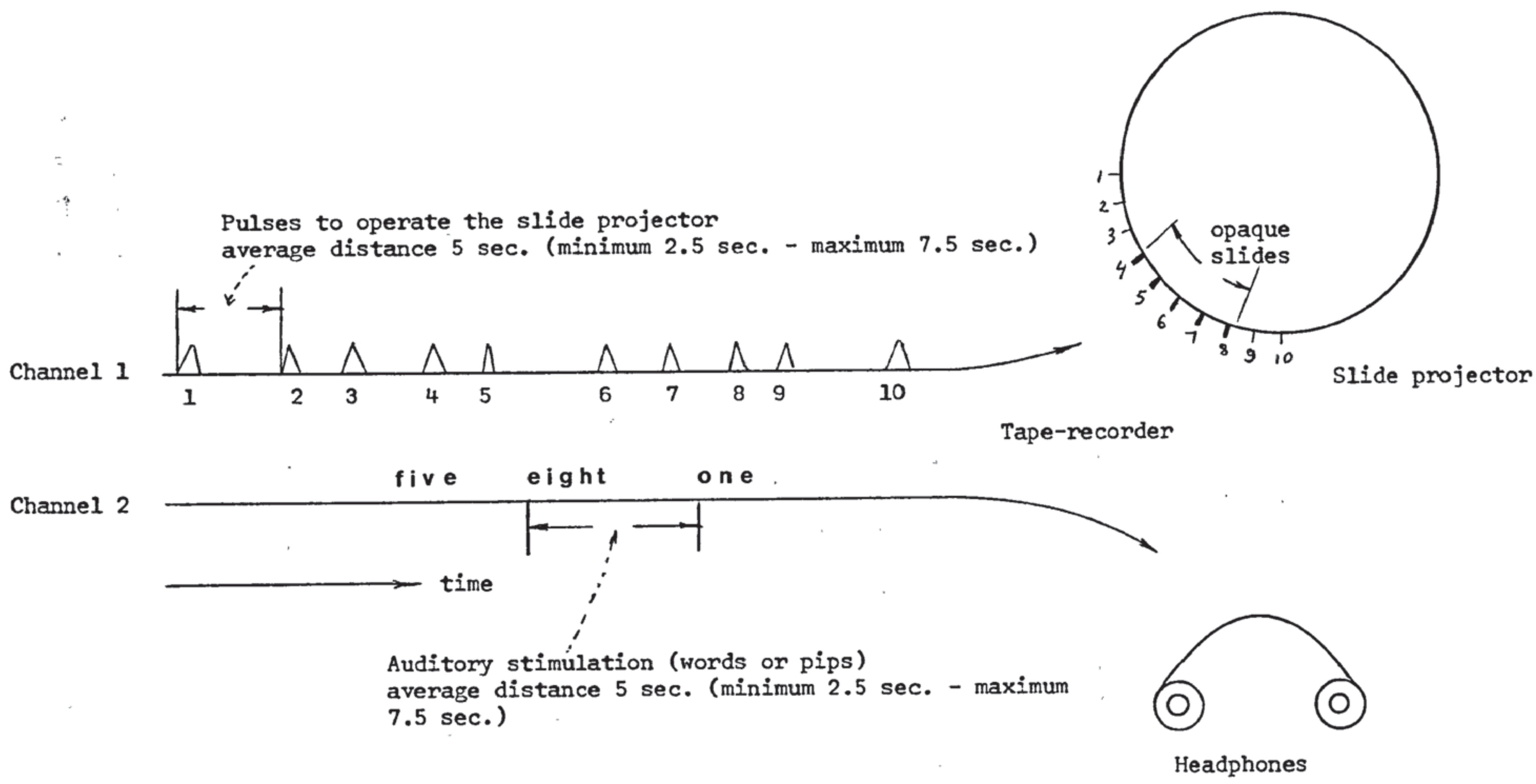


Figure 2.3.2 Third experiment: principal soft wave diagram



2.3.2.3 (Continued)

When a slide was projected on the screen, a little photo-cell became active and sent a pulse to the electronic timer to start the timing. The timer stopped when the subject pressed one of the two push buttons. The print-out unit recorded two data:

a) the RT.

b) the hand with which the response was made.

The photo-cell was needed in the system in order to ensure that the RT measuring started at the same time as the image was projected.

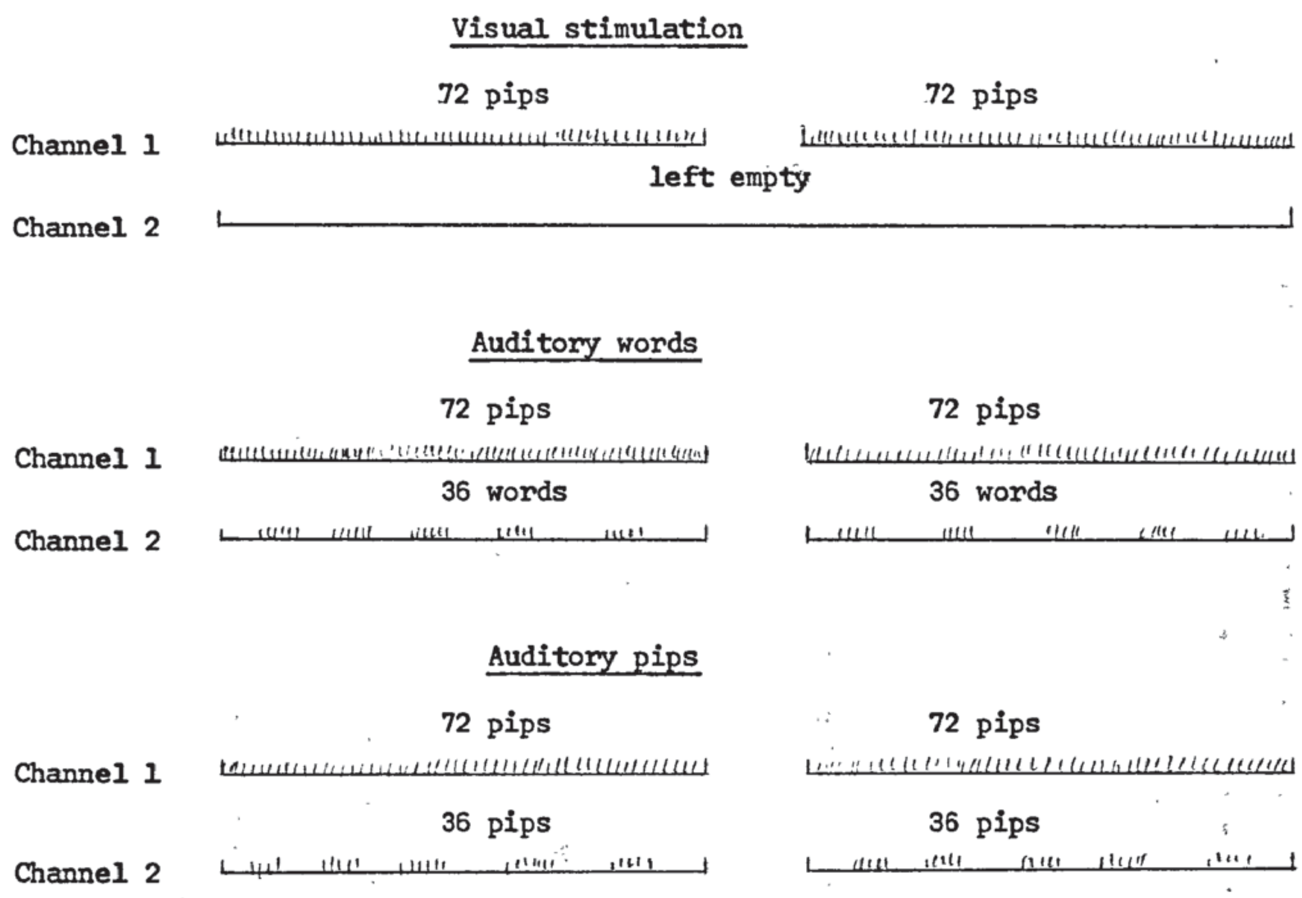
There was a risk that the presence or absence of noise from the slide change mechanism may prepare subjects for a change to a visual task, or to an auditory task, respectively. To prevent this, opaque slides were included in the magazine, for selection during auditory tasks (Figure 2.3.2).

An additional tape was pre-recorded for each of the experimental groups, according to the tasks which they were expected to perform. There were three types of tapes (Figure 2.3.3). Channel 1 was always used for driving the slide projector. Channel 2 was used for auditory stimulation.

The experiment was carried out in a room lit with an ordinary fluorescent light (80 watt, white super five).

The projected stimuli were bright so that the subjects had no difficulty in seeing them. The reason for using a lit rather than

Figure 2.3.3 Third experiment: content of tapes



2.3.2.3 (Continued)

a dark room, was to avoid phenomena such as dark adaption, eye movement, eye correction and blinking, which could be caused by projecting slides in a dark room.

The subjects sat approximately 270cm. away from the screen. The size of the projected images were between 15 x 75mm. and 5 x 315mm. The images were large enough to be read easily without requiring eye movements.

2.3.2.3.1 Stimuli

Two types of stimulation were utilized in the experiment: visual and auditory.

1) <u>The visual stimulation:</u>

<u>Words</u> - each stimulus consisted of one word which represented a number (i.e. 'one', 'five' etc.) The numbers were between 1 and 9. The subjects' task was to respond with the right hand when he saw an even number, and with his left hand when he saw an odd number.

<u>Numbers</u> - each stimulus consisted of one digit. The subject's task was identical to that of visual words.

<u>Lines</u> - the stimuli were identical to those used in previous experiments, but they only appeared at 0^o, 30^o, 60^o, 90^o, 120^o and 150^o. The subjects' task was the same as in the first experiment - reacting to the longer line.

2) <u>The auditory stimulation:</u>

<u>Words</u> - the task and the stimuli were similar to visual words, but instead of seeing numbers they were heard.

2.3.2.3.1 (Continued)

Pips - Subjects heard two types of pips, one at a time. One pip was a loud (80dB) tone (sine wave) at 400 H_2, the other was a softer (70dB) tone at 2.5kH_2. The subjects' task was to press the right button when hearing the louder - low frequency pips, and to press the left button when hearing the soft - high frequency pips.

All the stimuli in this experiment were presented for a duration of one second.

2.3.2.4 Procedure

The subjects had to be trained in order to be able to perform their tasks well. They were trained separately on each task. During this period they became familiar with the different tasks and gained skill in performing them.

The training session lasted 15 minutes. Between the training and the experiment the subjects had a rest of 5 minutes.

The instructions (Appendix IIIA) were read to the subjects at the beginning of the training session.

2.3.2.4.2 Experimental procedure

The subjects were assigned randomly to the four different experimental groups (Table 2.3.3) and were trained in advance. The initial task with which each subject began the experiment was randomly chosen. After 6 - 10 trials in one task the subject was switched to the other task and then back to the first task etc.

2.3.2.4.2 (Continued)

Each subject received 144 stimuli at a rate of about one stimulus per five seconds (minimum 2.5sec. and maximum 7.5sec. between stimuli).

2.3.3 Results and analysis

2.3.3.1 Statistical model

In order to determine the most appropriate statistical model for analysing the data of this experiment it is necessary to take into consideration all the various factors and sources of variation.

From the 'Experimental design' (section 2.3.2.1) it can be seen that six different factors influence the dependent variable (CRT). Some of these factors are nested within others and some include repeated measures from the same subjects. Therefore, the appropriate statistical model for analysing these results should have the following characteristics: ANOVA, with hierarchical design for repeated observations.

The choice of the statistical model is further influenced by the unequal group sizes. There are two main causes for the unequal group sizes:

1) The exclusion of error responses from the analysis. In this experiment, unlike the first experiment, only individual error RTs are excluded from the analysis. The exclusions of whole series - as it was done in the first experiment - is no longer necessary, since all the subjects received medium sized series.

This exclusion results in the reduction of the RT - frequency within each cell.

There are two sources of error RTs in this experiment:

2.3.3.1 (Continued)

a) Human errors. Usually they are done unintentionally, but nevertheless a reaction with the 'wrong' hand can occur from time to time.

b) Machine errors. In the previous experiments the apparatus was relatively simple and therefore this phenomenon did not occur. In this experiment, with very sensitive electronic equipment, failure to register the subjects' RTs was expected to occur from time to time.

2) The second reason for unequal group sizes was due to the experimental design (Table 2.3.4). Out of the six factors in this experiment, two (D and E) were designed to include unequal samples.

Factor D - the number of trials in a series - randomly varies from 6 - 10 trials in each series. This procedure, used in the previous experiments, prevents the subject from knowing the precise trial at which he is about to switch from one task to another.

This 'random variation' causes an uneven distribution of the observations among the cells (i.e. unequal cell frequencies) in the statistical analysis.

Factor E - the number of task repetitions varies randomly between 8 - 12 times per subject. This means that for some subjects there were more series than for others (i.e. unequal cell frequencies).

These sources of unequal group sizes are most important in determining the type of statistical model.

Three procedures are commonly used in analysing experiments with unequal sample sizes: 'weighted' means, 'unweighted' means and 'least

2.3.3.1 (Continued)

squares'.

In the case of the analysis of 'unweighted' means each treatment mean is allowed to contribute equally to the determination of the 'sum of squares'. In direct contrast, the analysis of weighted means and also the least squares analysis, allow each treatment mean to influence the sum of squares by an amount which is proportional to the number of 'readings' in that condition. For further discussion and for the various methods of calculation the reader is referred to Winer (1971 ed. pp.402 - 422) and to Keppel (1973, 17). It is necessary to mention, though, that only when the loss of observations in cells is essentially random, or in no way directly related to the experimental variables, then the data may appropriately be analysed by the method of unweighted means. Otherwise, the analyses of weighted means or least squares are justified.

Therefore, in order to be able to choose between the different mentioned methods, the causes for unequal group sizes in this experiment must be carefully examined.

The sources of the unequality have already been identified:

1) error RTs - by human and machine.

2) design of the experiment.

1a) Human errors - in the first experiment it was found that the human errors are more or less randomly distributed (section 2.1.3.5). Accordingly we may assume that in this experiment as well, there will be no connection between the experimental variables and the loss of

2.3.3.1 (Continued)

observations. At a later stage in the experiment (section 2.3.3.3.3) it will be shown that the error analysis does not yield any significant results.

1b) Machine errors - the apparatus failed, from time to time, to record the subjects' RTs. This failure was due to external factors and in no way was it connected with any of the experimental variables.

2) Experimental design - the experiment was designed with varying lengths (factor D) and numbers (factor E) of series in order to prevent the subject from knowing when switching takes place. This was not correlated to any of the hypotheses investigated in this experiment.

Since all the reasons for unequal sample sizes are not directly related to the experimental variables, the appropriate analysis of the data is by the method of unweighted means.

To summarize, the correct analysis for the data of this experiment is ANOVA, for six random and fixed factors, with repeated measures, nested factors for unweighted means.

In this experiment, unlike the previous ones, the pairs of tasks are different for each experimental condition (see Table 2.3.3). These tasks differ, of course, in the time needed to respond to their stimulation (RT). Therefore, one can no longer compare the 'first' RTs from the various tasks, and draw meaningful conclusions about the time-sharing process. Rather, the method of the first experiment, in which the comparison is made among the 'differences' (between the first and the rest in each series) is more appropriate.

2.3.3.1 (Continued)

Hence, in order to put the hypotheses to the test, it is required to carry out planned comparisons, between the 'first' and the 'rest' in each of the main conditions (see Table 2.3.5).

Table 2.3.5 The third experiment: planned comparisons

'first' v. 'rest'	in factor	at level	statistical symbol
"	transformation	same	C at A_1
"		different	C at A_2
"	sense modality	within	C at B_1
"		between	C at B_2
"	transformation and sense modality	same/within	C at AB_{11}
"		same/between	C at AB_{12}
"		different/within	C at AB_{21}
"		different/between	C at AB_{22}

Hays (1963 pp.459-477), Keppel (1973 pp.85-105) and others, argue that planned comparisons are, or may be, carried out instead of the ordinary analysis of variance and F test. At any rate, these planned comparisons can be made whether the overall F is significant or not.

The writer holds the same views about planned comparisons and F test. However, he thinks that in this particular case, an overall ANOVA can be very useful in providing additional information, because the planned comparisons are only made between the two levels of factor C (first v. rest) at the different levels of the other factors. The overall F tests complete the picture by testing other experimental effects.

2.3.3.1 (Continued)

Therefore, it was decided to carry out the ANOVA and proceed with the planned comparisons - regardless of the significance of the F test.

In this analysis some of the experimental factors (D and E) are merely 'sources of variance' and have no theoretical implications. These factors exist as a result of this particular experimental design and not because they are meaningful derivations from the hypotheses under investigation.

Therefore, it has been decided that those factors and all their possible interactions will not be included in the table which summarizes the analysis. This procedure results in a simpler table, easier to follow, where all the unnecessary factors are eliminated.

Such a procedure does not affect the analysis of the other factors, since all the sources of variation have been included in the calculations in the usual manner (for a similar procedure, see section 2.1.4). For the computational formulae of the ANOVA and their explanation, see Appendex IIIB.

The last aspect to be taken into consideration before carrying out the analysis is the shared tasks. In the experiment there are four different experimental groups determined by factors A and B. Each of these groups has to time-share between two tasks (see Table 2.3.3), out of which one task - visual words - is common to all the four groups. Only the other task is varied according to the transformation (factor A) and sense modality (factor B). As it was mentioned earlier, this design provides common ground for comparison.

2.3.3.1 (Continued)

The writer has decided, therefore, to separate, in the analysis, the common task from the others. This results in having to carry out two separate analyses, one for visual words and the other for all the rest of the tasks.

All the statistical considerations mentioned earlier, about the type of analysis with the nested factors, the repeated measures, missing data and planned comparisons apply to both analyses.

2.3.3.2 Magnitude of treatment effects in selected ANOVA designs

The need and importance of estimating the strength of effects or magnitude of treatments in analysing the results of experiments have already been emphasized earlier in this thesis (section 2.1.3.3). The concepts and the formula which were adopted thereafter were best suited for uncomplicated experiments.

In this experiment the analysis of the data takes the form of a fairly complicated ANOVA with nested, mixed (random and fixed) factors with repeated measures in unequal number of observations. The previous formula is unsuitable in this situation.

The development of suitable formulae for this and similar experimental designs and a critical literature survey are included in Appendex IIIC.

2.3.3.3 Results

As it was already mentioned in section 2.3.3.1 the results are divided

2.3.3.3 (Continued)

into two parts:

part one - the visual words task

part two - all the other tasks

2.3.3.3.1 The visual words task

The defining and the computational formulae for the entire analysis are presented in Appendix IIIB. The data (RT in m.sec.) from the visual words task appear in Table 2.3.6, while Table 2.3.7 summarizes the RTs from the visual words task throughout all the conditions in the experiment. Table 2.3.7 contains:

n - the numbers of RTs in each category

ΣX - the sum of those RTs (in m.sec.)

ΣX^2 - their sum of squares (in m.sec.)

SD - the standard deviation in each category

$\overline{X}$ - the mean RT in each category (in m.sec.)

ΔX - the difference between the mean RT (in m.sec.) for the 'first' and the 'rest' in the various conditions.

The three most important statistical variables (A, B and C) are marked in the table (2.3.7). The other variables (D and E) and (S) are all combined into 'the numbers of RTs' (i.e.'n'), according to the various categories.

The necessary error terms ('subjects within groups') are extracted from Table 2.3.6. All the other terms needed for the ANOVA are calculated from the means matrix (Appendix IIID). The harmonic mean

Table 2.3.6 Visual words task: results matrix

TRANSFORMATION (A)	SENSE (B)	SUBJECT NO. (S)	FIRST (C) N	FIRST ΣX	REST N	REST ΣX	TOTAL N	TOTAL ΣX
SAME	WITHIN	1	10	7,637	61	35,194	71	42,831
		2	9	6,611	62	41,515	71	48,126
		12	8	4,576	61	33,371	69	37,947
		15	9	6,653	55	41,183	64	47,836
		20	9	7,671	55	35,406	64	43,077
		21	10	4,932	58	29,628	68	34,560
		T	55	38,080	352	216,297	407	254.377
	BETWEEN	6	9	7,722	60	38,810	69	46,532
		8	8	6,087	57	32,455	65	38,542
		11	9	5,767	57	31,645	66	37,412
		14	7	4,055	61	35,702	68	39,757
		17	5	2,995	58	33,583	63	36,578
		19	7	5,575	62	39,284	69	44,859
		T	45	32,201	355	211,479	400	243,680
DIFFERENT	WITHIN	3	9	7,379	62	36,948	71	44,327
		7	10	7,592	62	35,812	72	43,404
		9	9	6,328	59	36,165	68	42,493
		13	9	5,744	54	30,808	63	36,552
		22	10	6,771	60	33,459	70	40,230
		24	10	7,261	61	35,980	71	43,241
		T	57	41,075	358	209,172	415	250,247
	BETWEEN	4	8	5,298	57	31,248	65	36,546
		5	8	5,807	57	28,703	65	34,510
		10	6	5,223	57	36,728	63	41,951
		16	6	3,505	57	32,174	63	35,679
		18	6	3,992	62	37,894	68	41,886
		23	9	6,712	59	32,897	68	39,609
		T	43	30,537	349	199,644	392	230,181
TOTAL	Same		100	70,281	707	427,776	807	498,057
	Different		100	71,612	707	408,816	807	480,428
	Within		112	79,155	710	425,469	822	504,624
	Between		88	62,738	704	411,123	792	473,861
TOTAL			200	141,893	1,414	836,592	1,614	978,485

Table 2.3.7 Visual words task: a summary matrix

(B) Sense modality	(A) / (C)	TRANSFORMATION: SAME, FIRST	SAME, REST	DIFFERENT, FIRST	DIFFERENT, REST	TOTAL, FIRST	TOTAL, REST
WITHIN	n	55	352	57	358	112	710
	ΣX	38,080	216,297	41,075	209,172	79,155	425,469
	ΣX^2	28,773,072	142,535,783	31,258,895	129,861,358	60,031,967	272,397,141
	SD	211.16	165.59	172.15	146.35	191.95	156.81
	$\overline{X}$	692.36	614.48	720.61	584.27	706.74	599.25
	$\Delta\overline{X}$	77.88		136.34		107.49	
BETWEEN	n	45	355	43	349	88	704
	ΣX	32,201	211,479	30,537	199,644	62,738	411,123
	ΣX^2	24,417,373	134,548,731	22,829,941	119,892,032	47,247,314	254,440,763
	SD	176.78	155.56	165.01	127.83	170.17	142.88
	$\overline{X}$	715.57	595.71	710.16	572.04	712.93	583.98
	$\Delta\overline{X}$	119.86		138.12		128.95	
TOTAL	n	100	707	100	707	200	1,414
	ΣX	70,281	427,776	71,612	408,816	141,893	836,592
	ΣX^2	53,190,445	277,084,514	54,088,836	249,753,390	107,279,281	526,837,904
	SD	195.82	160.80	168.35	137.55	182.26	150.18
	$\overline{X}$	702.81	605.05	716.12	578.24	709.46	591.64
	$\Delta\overline{X}$	97.76		137.88		117.82	

2.3.3.3.1 (Continued)

needed for the ANOVA was developed in Appendix IIIB (based on Keppel 1973 p.357). For the exact statistical calculations see Appendix IIIE.

Table 2.3.8 Visual words task: summary of analysis

Source	SS	df	MS	F
Between Subjects				
A (transformation)	6,124.12	1	6,124.12	<1
B (sense modality)	11,003.62	1	11,003.62	<1
AxB	2,742.83	1	2,743.83	<1
SwAxB	4,169,412.00	20	208,470.60	
Within Subjects				
C (first,rest)	2,255,641.80	1	2,255,641.80	42.10*
AxC	79,840.44	1	79,840.44	1.49
BxC	13,297.98	1	13,297.98	<1
AxBxC	11,973.00	1	11,973.00	<1
CxSwAxB	1,071,555.00	20	53,577.75	

* $p < .001$

Table 2.3.8 summarizes the analysis of variance for visual words. This summary is based on the considerations and the statistical model developed earlier. As it can be seen from the table, out of the three factors and all their possible interactions, only factor C ('first' v. 'rest') yields significant results.

As it has already been mentioned before, the omnibus F (regardless of its significance level) will be seceded by planned comparisons within factor C at the different levels of the other two factors A and B (Table 2.3.5).

2.3.3.3.1 (Continued)

For the various statistical calculations and their validation see Appendix IIIF.

After validating the method and the calculations of the sum of squares, we may pursue with the comparisons. Table 2.3.9 sums up the planned comparisons for visual words task.

Table 2.3.9 Visual words task: planned comparisons

Source	SS	df	MS	F	$\hat{\omega}^2$ ***
SSc at A1	743,369	1	743,369	13.874*	0.31
SSc at A2	1,592,113	1	1,592,113	29.716**	0.69
SSc at B1	961,278	1	961,278	17.942**	0.42
SSc at B2	1,307,662	1	1,307,662	24.410**	0.58
SSc at AB11	247,297	1	247,297	4.615	0.09
SSc at AB12	521,326	1	521,326	9.730*	0.22
SSc at AB21	790,806	1	790,806	14.760*	0.34
SSc at AB22	801,325	1	801,325	14.960**	0.35
CxSwAxB	1,071,555	20	53,577.75		

* $p < .01$ ** $p < .001$ *** the estimations were rounded

The first two rows in the table contain the comparison between the 'first' and the 'rest' (factor C) at the two levels of factor A. The following two rows contain the comparison of 'first' and 'rest' at the two levels of factor B and the next four rows contain the comparison at the intersecting levels of factors A and B. The last row is the error term for all the comparisons. It is the same error term used in the omnibus analysis of variance (Table 2.3.8).

2.3.3.3.1 (Continued)

The calculations of the sums of squares (SS) precede Table 2.3.9. The degrees of freedom (df) obtained from the number of compared levels of factor C (two levels) minus one at each of the other factors (A, B and AxB). The mean squares (S) and F are obtained in the usual way.

From Table 2.3.9, it can be seen that in most cases the difference between the two levels of factor C are significant at 1% or 0.1%.

The strength of the comparison ($\hat{\omega}^2$) was estimated following the procedure developed by the writer (Appendix IIIC).

For the calculations of these estimations and a check on their accuracy see Appendix IIIG.

2.3.3.3.2 All the other tasks

The previous section dealt with the results for the visual words task. This section analyses the results for all the other four tasks.

The data for all the other tasks appear in Table 2.3.10, while Table 2.3.11 sums up the RTs (in m.sec.) from each of the other tasks in the experiment. These tables are similar to Tables 2.3.6 and 2.3.7, and contain the same symbols.

A matrix of RT means is needed for analysing the data with an 'un-weighted means' method. Appendix IIIH (Table IIIH1) provides this matrix.

2.3.3.3.2 (Continued)

All the necessary error terms ('subjects within groups') are extracted from Table 2.3.11. The harmonic mean for all the other tasks, is calculated in the same manner, taking into account the same considerations, as the harmonic mean for the visual words task. For the precise statistical calculations see Appendix III I.

Table 2.3.12 summarizes the analysis of variance for all the other tasks. This summary is based on the statistical model developed earlier (Appendix IIIB).

As it can be seen from the table, out of the three factors and all their interactions, only factor C ('first' v. 'rest') and the interaction between factor C and factor A ('transformation') yield significant results.

The following stage is the planned comparisons within factor C at the different levels of the other two (Table 2.3.5). These planned comparisons should be carried out regardless of the results of Table 2.3.12.

For the calculations needed for the comparisons and their validation, see Appendix IIIJ.

After validating the calculations of the sum of squares, we may pursue with the comparisons. Table 2.3.13, sums up the planned comparisons for 'all the other tasks'.

Table 2.3.10 All the other tasks: results matrix

TRANSFORMATION	SENSE	Subject No. (S)	FIRST (C) N	FIRST ΣX	REST N	REST ΣX	TOTAL N	TOTAL ΣX
SAME	WITHIN	1	10	6,320	61	35,678	71	41,998
		2	10	6,356	61	37,492	71	43,848
		12	7	4,160	61	31,701	68	35,861
		15	9	5,846	55	38,413	64	44,259
		20	9	7,402	54	34,603	63	42,005
		21	10	4,461	61	27,742	71	32,203
		T	55	34,545	353	205,629	408	240,174
	(B) BETWEEN	6	8	6,172	56	40,360	64	46,532
		8	9	5,341	60	31,901	69	37,242
		11	8	4,782	61	40,244	69	45,026
		14	9	5,670	62	36,283	71	41,953
		17	7	4,091	57	32,812	64	36,903
		19	6	4,006	59	37,465	65	41,471
		T	47	30,062	355	219,065	402	249,127
(A) DIFFERENT	WITHIN	3	10	6,636	62	33,407	72	40,043
		7	10	6,085	62	28,785	72	34,870
		9	10	5,363	61	27,456	71	32,819
		13	10	6,626	61	28,760	71	35,386
		22	9	5,895	63	31,205	72	37,100
		24	10	6,626	62	32,250	72	38,876
		T	59	37,231	371	181,863	430	219,094
	(B) BETWEEN	4	8	5,525	58	28,551	66	34,076
		5	9	8,871	60	28,396	69	37,267
		10	8	4,735	60	23,646	68	28,381
		16	7	3,603	58	22,850	65	26,453
		18	8	5,483	54	24,442	62	29,925
		23	7	4,609	54	26,983	61	31,592
		T	47	32,826	344	154,868	391	187,694
TOTAL	Same		102	64,607	708	424,694	810	489,301
	Different		106	70,057	715	336,731	821	406,788
	Within		114	71,776	724	387,492	838	459,268
	Between		94	62,888	699	373,933	793	436,821
TOTAL			208	134,664	1,423	761,425	1,631	896,089

Table 2.3.11 All the other tasks: summary matrix

(B)		(A) / (C)	TRANSFORMATION: SAME, FIRST	TRANSFORMATION: SAME, REST	TRANSFORMATION: DIFFERENT, FIRST	TRANSFORMATION: DIFFERENT, REST	TOTAL: FIRST	TOTAL: REST
SENSE MODALITY	WITHIN		Numbers		Lines			
		n	55	353	59	371	114	724
		ΣX	34,545	205,629	37,231	181,863	71,776	387,492
		ΣX^2	23,919,995	130,973,419	25,044,989	96,629,589	48,964,984	227,603,008
		SD	202.87	178.30	163.52	142.19	137.01	167.20
		$\overline{X}$	628.09	582.51	631.03	490.19	629.61	535.20
		$\Delta\overline{X}$	45.58		140.84		94.41	
	BETWEEN		Auditory words		Pips			
		n	47	355	47	344	94	699
		ΣX	30,062	219,065	32,826	154,868	62,888	373,933
		ΣX^2	20,027,562	142,682,143	27,284,830	75,944,330	47,312,392	218,626,443
		SD	131.82	145.56	307.80	134.69	237.34	163.19
		$\overline{X}$	639.61	617.08	698.42	450.19	669.02	534.95
		$\Delta\overline{X}$	22.53		248.23		134.07	
TOTAL		n	102	708	106	175	208	1,423
		ΣX	64,607	424,694	70.057	336,731	134,664	761,425
		ΣX^2	43,947,557	273,655,562	42,329,819	172,573,919	96,277,376	446,229,481
		SD	173.07	163.51	239.60	139.97	209.58	165.18
		$\overline{X}$	633.40	599.85	660.91	470.95	647.42	535.08
		$\Delta\overline{X}$	33.55		189.96		112.34	

Table 2.3.12 All the other tasks: summary of analysis

Source	SS	df	MS	F
Between Subjects				
A (transformation)	433,584.21	1	433,584.21	1.55
B (sense modality)	21,475.92	1	21,475.92	<1
AxB	969.21	1	969.21	<1
SwAxB	5,602,389.00	20	280,110.45	
Within Subjects				
C (first, rest)	2,376,082.12	1	2,376,082.12	45.27*
AxC	963,750.56	1	963,750.56	18.36*
BxC	90,962.30	1	90,962.30	1.73
AxBxC	112,046.85	1	112,046.85	2.13
CxSwAxB	1,049,664.00	20	52,483.20	

* $p < .001$

Table 2.3.13 All the other tasks: planned comparisons

Source	SS	df	MS	F	$\hat{\omega}^2$***
SSc at A1	156,658	1	156,658	2.984	0.03
SSc at A2	3,183,174	1	3,183,174	60.651**	0.97
SSc at B1	768,620	1	768,620	14.645*	0.30
SSc at B2	1,698,424	1	1,698,424	32.361**	0.70
SSc at AB11	87,877	1	87,877	1.67	0.01
SSc at AB12	69,330	1	69,330	1.32	0.005
SSc at AB21	890,031	1	890,031	16.96**	0.25
SSc at AB22	2,495,604	1	2,495,604	47.55**	0.73
CxSwAxB	1,049,664	20	52,483.2		

* $p < .01$ ** $p < .001$ *** : the estimations were rounded

2.3.3.3.2 (Continued)

Table 2.3.13 is similar to Table 2.3.9 where the first two rows contain the comparison between the 'first' and the 'rest' at the two levels of factor A; the following two rows - at the two levels of factor B; the next four rows - at the intersecting levels of factors A and B. The last row is the error term for all the comparisons extracted from the overall analysis of variance (Table 2.3.12).

The sums of squares (SS) were calculated in Appendix IIIJ. The degrees of freedom were obtained in a similar manner to Table 2.3.9. The mean squares (MS) and F were calculated in the usual way.

From Table 2.3.13, it can be seen that first versus rest, at factor A1 (same-transformation), or the intersections of A1 and any of the levels of B, did not yield any significant results. At factor A2 (different-transformations) and any of the levels of B the results were significant at α = 0.1%. First versus rest was significant at both levels of factor B, though the level of significance was higher at B1 than at B2.

The strength of the comparison ($\hat{\omega}^2$) was estimated according to the procedure developed by the writer in Appendix IIIC. For the calculations of these estimations and a check on their accuracy see Appendix IIIK.

2.3.3.3.3 Error analysis

The hierarchical functional model does not suggest that relatively more errors should be made in responding to the first stimulus in a series than in responding to the rest of the series. Indeed, in an

2.3.3.3.3 (Continued)

error analysis carried out in the first experiment (section 2.1.3.5) no such significant different was found.

Table 2.3.14 contains the number of subjects' errors (machine errors are excluded) made in each of the four main conditions of the experiment. The table also contains an expected value of errors. The number of expected errors, was calculated in the same manner as it was done in the first experiment (section 2.1.3.5).

From Table 2.3.14 it can be seen that in most cases the discrepancy between the observed and expected numbers is very small. An attempt to test these differences according to first and rest in the four main experimental groups, did not yield any significant results.

$$\chi^2 = 5.49428 \quad df = 3 \quad .20 > p > .10$$

(from Siegel (1956 pp.104 - 111)).

Altogether, 114 human errors were made in the experiment, out of a total of 3,456 reactions (144 stimuli x 24 subjects). The average percentage of human errors is about 3.30%. This average is slightly higher than the one found in the first experiment. The reason is probably because the tasks involved in this experiment were slightly more difficult.

Table 2.3.14 Third experiment: error analysis

		TRANSFORMATION														
		SAME					DIFFERENT					TOTAL				
		FIRST		REST		T	FIRST		REST		T	FIRST		REST		T
		O	E	O	E		O	E	O	E		O	E	O	E	
SENSE MODALITY	WITHIN	5	5.875	42	41.125	47	2	1.875	13	13.125	15	7	7.75	55	54.25	62
	BETWEEN	7	3.875	24	27.125	31	5	2.625	16	18.375	21	12	6.5	40	45.5	52
	TOTAL	12	9.75	66	68.25	78	7	4.5	29	31.5	36	19	14.25	95	99.75	114

2.3.4 Discussion

In the previous experiments time-sharing was studied by using two tasks which demanded different transformations.

The experiment which is analysed in this study broadens the theoretical scope of the previous ones on two levels:

First, the tasks which are utilized for the time-sharing process use not only different but also the same transformations.

Secondly, time-sharing takes place not only within the same sense modality (vision) but also between different sense modalities (vision - audition).

The analyses of the experimental results were carried out using the unweighted means method (Appendix IIID, Table IIID1, and Appendix IIIH, Table IIIH1). In order to facilitate the discussion of these results two new summary tables (2.3.15 and 2.3.16) are constructed, based on the above mentioned summary means matrices. The new tables are similar to Tables 2.3.7 and 2.3.11. However, the new summary tables (2.3.15 and 2.3.16) are based on unweighted means and they include a summary of the statistical results, while Tables 2.3.7 and 2.3.11 are based on weighted means and do not include any statistical decisions. Since the two sets of summary tables are based on different methods of calculation, there is a slight difference in the means which they display.

The two tables contain the three main factors in this experiment:

factor A: 'transformation', same - different

Table 2.3.15 Visual words task: summary of results

SENSE MODALITY			TRANSFORMATION		
			SAME	DIFFERENT	COMBINED
	WITHIN	$\bar{X}$ first	692.500	720.602	706.551
		$\bar{X}$ rest	616.160	584.082	600.119
		$\Delta\bar{X}$ diff.	76.340	136.520	106.432
		F	4.615	14.760	17.942
		p	not significant	$<.01$	$<.001$
		$\hat{\omega}^2$	0.09	0.34	0.42
	BETWEEN	$\bar{X}$ first	705.723	708.980	707.352
		$\bar{X}$ rest	594.878	571.555	583.217
		$\Delta\bar{X}$ diff.	110.845	137.425	124.135
		F	9.730	14.960	24.410
		p	$<.01$	$<.001$	$<.001$
		$\hat{\omega}^2$	0.22	0.35	0.58
	COMBINED	$\bar{X}$ first	699.112	714.791	706.952
		$\bar{X}$ rest	605.518	577.818	591.668
		$\Delta\bar{X}$ diff.	93.594	136.973	115.284
		F	13.874	29.716	42.100
		p	$<.01$	$<.001$	$<.001$
		$\hat{\omega}^2$	0.31	0.69	-

Table 2.3.16 All the other tasks: summary of results

			TRANSFORMATION		
			SAME	DIFFERENT	COMBINED
SENSE MODALITY	WITHIN	$\bar{X}$ first	629.962	631.433	630.698
		$\bar{X}$ rest	585.527	490.020	537.773
		$\Delta\bar{X}$ diff.	44.435	141.413	92.925
		F	1.670	16.960	14.645
		p	not significant	$<.001$	$<.01$
		$\hat{\omega}^2$	0.01	0.25	0.30
	BETWEEN	$\bar{X}$ first	640.795	687.775	664.285
		$\bar{X}$ rest	601.327	450.978	526.153
		$\Delta\bar{X}$ diff.	39.468	236.797	138.132
		F	1.320	47.550	32.361
		p	not significant	$<.001$	$<.001$
		$\hat{\omega}^2$	0.005	0.73	0.70
	COMBINED	$\bar{X}$ first	635.378	659.604	647.492
		$\bar{X}$ rest	593.427	470.499	531.963
		$\Delta\bar{X}$ diff.	41.951	189.105	115.529
		F	2.984	60.651	45.270
		p	not significant	$<.001$	$<.001$
		$\hat{\omega}^2$	0.03	0.97	-

2.3.4 (Continued)

factor B: 'sense modality', within - between

factor C: 'stimuli', first - rest

The numbers which correspond to the firsts and the rests are mean RTs in m.sec. The tables also contain:

$\Delta\bar{X}$ diff. - the differences between first and rest (in m.sec.)

F - F tests which were carried out on these differences

p - the level of significance of these tests

$\hat{\omega}^2$ - the magnitude of the experimental effects

The bottom right-hand side corner of each table (combined transformation and sense modality) contains the results from the overall analyses. This means that, the '$\bar{X}$ first' is the grand mean of the RTs to the first stimulus - either in the visual words task or in all the other tasks. The '$\bar{X}$ rest' is the grand mean of the RTs to the rest of the stimuli in the series '$\Delta\bar{X}$ diff.' - is the total experimental effect (of factor C). The 'F' ratios and the 'p' (level of significance) were extracted from the overall ANOVA (Table 2.3.8 and Table 2.3.12).

The discussion of the outcome of this experiment will also be facilitated by graphical presentations. Figure 2.3.4 and Figure 2.3.5 show the difference between the RT to the first and the RT to the rest of the series according to transformation and sense modality. Both figures are based on the row data of the experiment (i.e. on weighted means, Table 2.3.7 and Table 2.3.11).

The tables and graphical presentation of the various results are meant to facilitate the further discussions of the experimental outcome.

Figure 2.3.4 Visual words task: differences between first and rest according to transformation and sense modality

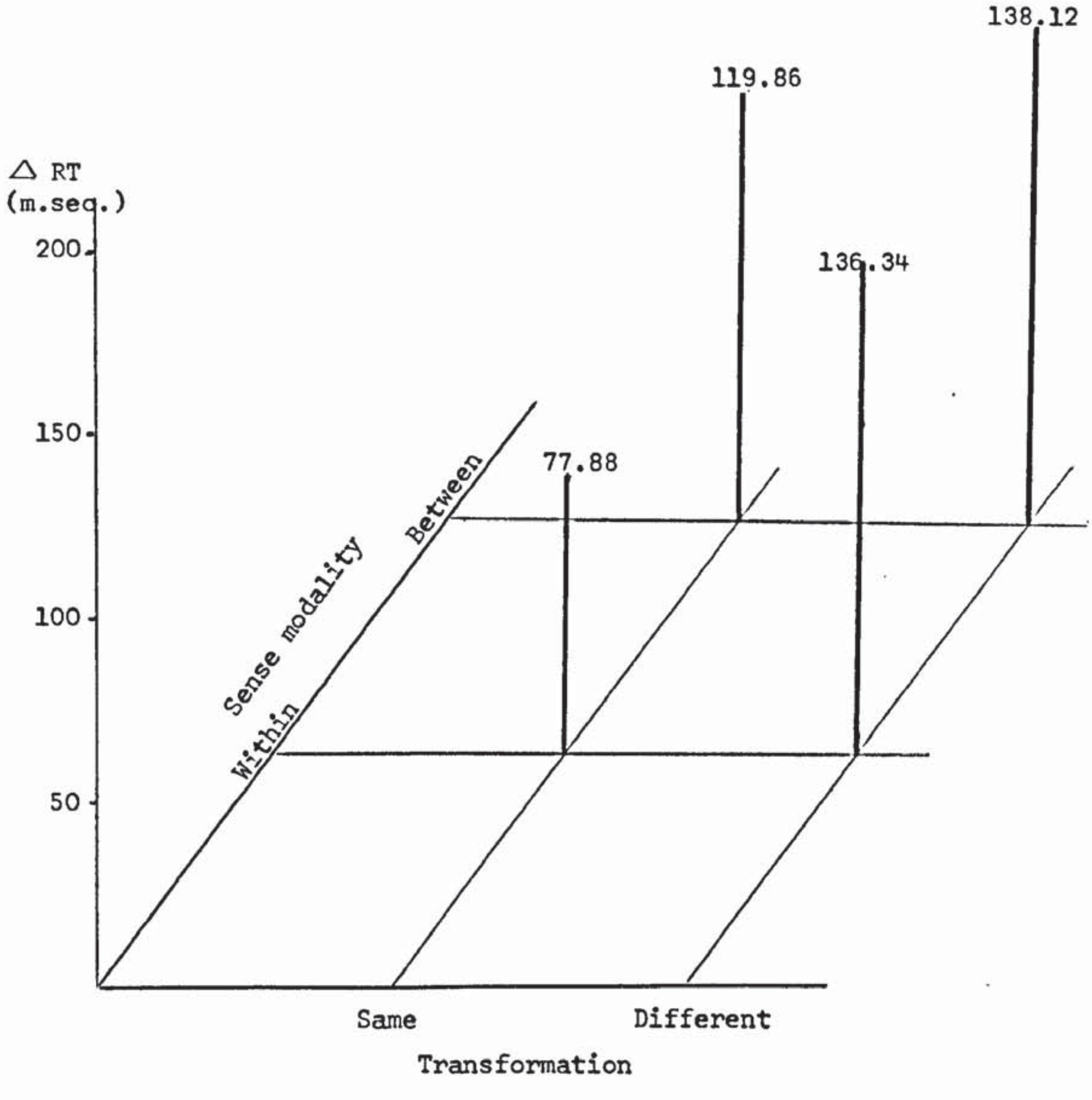
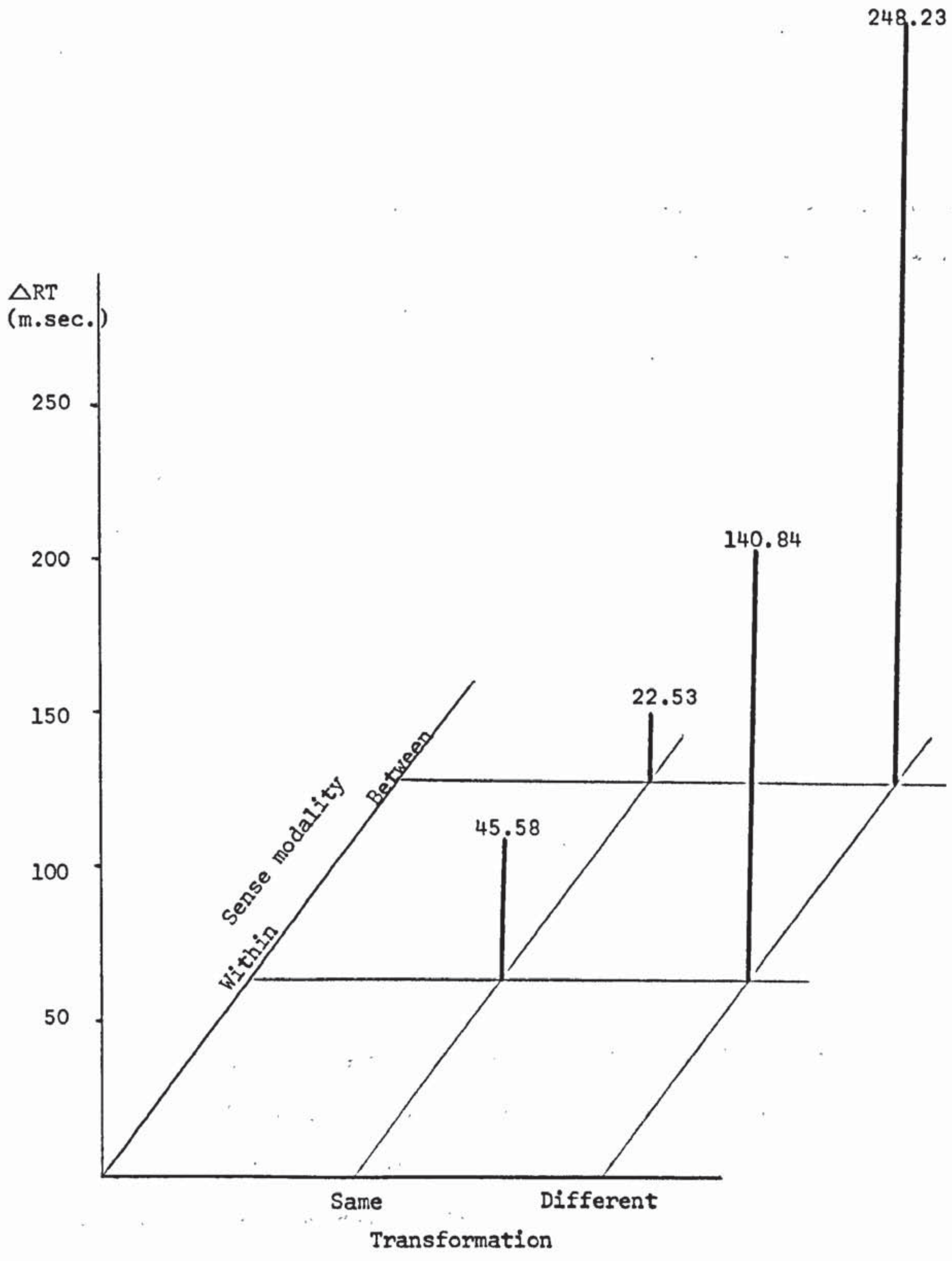


Figure 2.3.5 All the other tasks: differences between first and rest according to transformation and sense modality



2.3.4 (Continued)

The hierarchical model claims that the more similar two shared tasks are, the less time is consumed on the sharing process. Both transformation and sense modality contribute to the similarity between tasks. Therefore, it is argued that both factors influence time-sharing. However, transformation influences the higher levels of the central processor which bears a greater weight on the information processing procedure. The sense modality influences the peripheral system and the low level programs. They carry out simple operations, therefore they have a simple structure which can be quickly 'set-up'.

Therefore, a change in sense modality (factor B) is expected to have a small and even a marginal impact on time-sharing (i.e. factor C - first v. rest) as compared to that of transformation (factor A).

The experiment examines the overall influence of these two factors and also their interacting influence on time-sharing.

Before the above examination can take place the other dependent variable in this experiment (i.e. the error rate) will be discussed.

2.3.4.1 Errors and practice

The error analysis (section 2.3.3.3.3) did not yield any significant results. This means that a claim that relatively more errors are made in responding to the first stimulus in a series than to the rest of the series, is not supported by the findings of this experiment.

2.3.4.1 (Continued)

Another point which ought to be mentioned is the fact that the results in this experiment were not subject to improvement through practice. Testing the second half of the total number of stimuli in all the series shown to each of the subjects (i.e. 72 stimuli) against the first half, did not yield any significant results. (These findings are not included in the results because they were calculated automatically while analysing the data). This means that within the one experimental session no improvement in RT was found.

The lack of 'practice effect' or 'error effect' will only enhance the conclusions reached in this experiment.

2.3.4.2 Influence of sense modality and transformation on overall performance

The writer did not expect to find any significant effects on the overall RT due to factors A, B or their interaction. Indeed we cannot conclude as a result of the two ANOVA (Table 2.3.8 and Table 2.3.12), that tasks demanding one type of transformation, or tasks which stimulate one type of sense modality take longer to react to than tasks demanding another type of transformation, or tasks which stimulate another sense modality. The interacting effect of these two factors also did not yield any significant effect.

The only factor which was found to have any significant effect - except factor C which is discussed later on - is the interaction of factor A and C in the analysis of all the other tasks (Table 2.3.12).

2.3.4.2. (Continued)

This suggests that probably transformation has a significant effect on the way in which factor C influences the dependent variable (the RTs).

2.3.4.3 Influence of first versus rest on overall performance

One of the major aims of this study was to demonstrate that the first stimulus in a series takes longer to react to than the rest of the stimuli in the series. Indeed the finding that factor C yields significant results in both ANOVA (Table 2.3.8 and Table 2.3.12) demonstrates this hypothesis once more.

The attention of the reader is drawn to the fact that in both ANOVA factor C yields similar F ratio (42.10 and 45.27). Furthermore, Table 2.3.15 and Table 2.3.16 reveal that the overall differences between RT to first and RT to rest ($\Delta\overline{X}$ diff. at the bottom of the right-hand side corner) are almost identical in both cases - visual words task and all the other tasks (115.284 m.sec. and 115.529 m.sec. respectively).

This fact suggests (taking into account the specific psychological manipulations utilized in this experiment) that the omnibus effect of time-sharing is constant in terms of time-consumption - regardless of the type of task used in the experiment. In other words, the average amount of time consumed on time-sharing in the various conditions and employing different types of tasks is identical (115.284 m.sec. vs. 115.529 m.sec.).

This finding is a major support to the hypothesis that the 'set-up time' is a result of preparatory set-up activities which are independent of and prior to the actual task performance. The 115 m.sec. found here

2.3.4.3 (Continued)

only demonstrates that the same mechanism is operated in each case, a mechanism which has the duty to replace the 'old programs' by new ones. Under two identical conditions this replacement operation takes the same amount of time even though the replaced programs are quite different.

2.3.4.4 Influence of first versus rest on performance as a function of transformation

This section aims to assess the influence of transformation on the time consumed by the sharing process.

The bottom rows of Tables 2.3.15 and 2.3.16 summarize the effect of transformation on time-sharing. In both visual words task and all the other tasks, the first stimulus in a series takes longer to react to than the rest of the stimuli. This difference is smaller in the case of same transformation than in the case of different transformations. In the case of visual words task, the difference between first and rest is significant under both same and different transformations. The strengths of the experimental effects ($\hat{\omega}^2$) show that the effect under different transformations is much stronger than the effect under same transformation (the results are extracted from Table 2.3.9 - SSc at A1 and SSc at A2).

In the case of all the other tasks, (Table 2.3.16) under the same transformation the difference between the first and the rest failed to reach the significance level. Under different transformations, the difference was significant and the strength of the experimental effect was 97%. In other words, this result suggests that 97% of the total difference between the first and the rest are due to the effect of different

2.3.4.4 (Continued)

transformations, and the other 3% are due to the effect of same transformation. (The results are extracted from Table 2.3.13 - SSc at A1 and SSc at A2).

The results of both Tables 2.3.15 and 2.3.16 suggest very strongly that a relatively short time is consumed on the sharing process in the case of time-sharing between two tasks which have the same transformation. This point is not so when the two shared tasks are of different transformations. This is compatible with the prediction of the functional hierarchical model, which claims that the replacement of one set of processing programs by another is a time-consuming operation.

2.3.4.5 Influence of first versus rest on performance as a function of sense modality.

The right-hand side column of Tables 2.3.15 and 2.3.16 summarizes the effect of sense modality on time-sharing. In both visual words task and all the other tasks, the first takes significantly longer to react to than the rest. This is true whether the sharing occurs within the same sense modality or between different sense modalities. (The results are extracted from Tables 2.3.9 and 2.3.13 - SSc at B1 and SSc at B2).

The estimation of the strength of experimental effect reveals that in visual words 42% of the difference between the first and the rest are due to the effect of 'within sense modality' while 58% are due to the effect of 'between sense modalities'. This suggests that the total variation between first and rest in visual words task is almost equally divided between the two conditions of within and between sense modalities.

2.3.4.5 (Continued)

In other words, it makes very little difference on the sharing process whether the two time-shared tasks stimulate the same or different sense modalities.

The results from all the other tasks are more decisive than those from the visual words task. They show that 30% of the variation between first and rest are related to the effect of within sense modality while 70% are related to between sense modalities. This suggests that it is probably more time-consuming to switch between sense modalities than within sense modality. These two results hint that the effect of sense modality on time-sharing is quite small.

The effect of sense modality and the effect of transformation on time-sharing are in full agreement with the prediction of the model. Setting-up high level programs takes longer than setting up peripheral and low level programs.

2.3.4.6 Influence of first versus rest on performance as a function of interaction between transformation and sense modality

Up to this point, the discussion has dealt only with the 'omnibus' effects of sense modality and of transformation (factor C at A1, at A2, at B1, and at B2). From now on, the discussion will centre on the interacting effects of both factors (factor C at AB11, at AB12, at AB21 and at AB22).

The interacting effects are studied with the aid of Table 2.3.15 and Table 2.3.16. The attention of the reader is drawn to the fact that the

2.3.4.6 (Continued)

margines ('combined') of these tables are not the sum of the interactions. In other words the combined effect of factor A, or factor B, is not the sum of the interactions of factors A and B. Also,

$$\Sigma C \text{ at } ABab \neq \frac{\Sigma C \text{ at } Aa + \Sigma C \text{ at } Bb}{2}$$

The full equations are more complicated. For example:

$$SSc \text{ at } ABab = SSc + SS_{ABC} + SS_{AC} + SS_{BC}$$

Therefore, the inner values which appear in Table 2.3.15 and Table 2.3.16, do not add up to values which appear at the margines. This is true for the F values as well as for the $\hat{\omega}^2$ values.

From the examination of Tables 2.3.15 and 2.3.16 and also from Figures 2.3.4 and 2.3.5 it can be seen that the biggest difference between first and rest is found in the condition different transformations : between sense modalities. This is true for both the visual words task and all the other tasks.

In relation to the shortest difference, the answer is not as decisive. In the visual words task, it is found in the condition same transformation : within sense modality, while in all the other tasks it lies in the condition same transformation : between sense modalities. One common denominator can still be found between these two different answers : the shortest possible difference lies within the condition of same transformation. The longest difference, as it was already mentioned, is found in different transformations.

The most important question with regard to the interaction situation is which of the two factors - sense modality or transformation - has the greatest influence on time-sharing.

2.3.4.6 (Continued)

It seems that the visual words task (Table 2.3.15 and Figure 2.3.4) does not provide a decisive answer to this question. Both sense modality and transformation seem to have similar effects, although the effect of sense modality seems a bit weaker.

All the other tasks (Table 2.3.16 and Figure 2.3.5) provide clearer information as to which of the factors is more influential in an interacting situation. It can be seen that same transformation yields the smallest differences, while different transformation yields the greatest difference. Sense modality does not seem to play any important role, although it does have a marginal influence on the results. This conclusion is compatible with the predictions of the hierarchical model.

2.3.4.7 Estimation of combined effects

Throughout this experiment the analysis of the results has been split into two separate analyses - one for the visual words task and one for all the other tasks.

In this brief account the two different analyses are pooled together. This is done very briefly by combining only the estimation of the experimental effects (average of est. $\hat{\omega}^2$ based on data from Tables 2.3.15 and 2.3.16).

Table 2.3.17 reveals all the three major points of this experiment:

1) Both transformation and sense modality have an influence on time-sharing.

2) The influence of transformation is by far greater than the

2.3.4.7 (Continued)

influence of sense modality.

3) There is an interacting effect of both factors on time-sharing, and the influence of transformation in this interaction is greater than the effect of sense modality.

Table 2.3.17 Summary of estimation of magnitude of experimental effects

		TRANSFORMATION		
		same	different	combined
sense modality	within	5%	30%	36%
	between	11%	54%	64%
	combined	17%	83%	—

All these three conclusions are predicted by the model. These results clearly demonstrate the hypothesis that a change in the higher levels of processing programs has a greater impact than a change in the low and periphery levels (associated with a change in same modality). There is an interacting effect of high and low level changes, but still the high levels consume most of the set-up time in such situations.

3.0 HUMAN TIME-SHARING IN SIMULTANEOUS PERFORMANCE

The single channel hypothesis (Broadbent (1958); Craik (1948); Welford (1952)) is usually studied through experiments which call for simultaneous attention to two closely similar tasks (Moray (1969b); Allport, Antonis and Reynolds (1972)). The recent reaffirmations of this hypothesis (Broadbent,(1971); Deutsch and Deutsch (1963); Gerver (1974); Kahneman (1970, 1973); Das, Kirby and Jarman (1975); Kristofferson (1967); Lindsay (1970); Meiselman (1974); Moray (1967, 1969b); Morton and Broadbent (1967); Neisser (1967); Norman (1968); Smith (1969); Swets and Kristofferson (1970); Welford (1968)) is in many cases based on experiments which used two completely different tasks simultaneously.

According to the hierarchical model suggested in this thesis, the simultaneous employment of two tasks which demand the same transformation causes 'single function processing load'. This type of load will impair very much the performance of either one of the tasks or of both tasks. There have already been numerous studies which demonstrate this hypothesis. Therefore the writer proposes to investigate this subject from a slightly different angle.

The hierarchical model further claims that any simultaneous performance causes some 'multi-functions processing load'. The need to perform two different transformations simultaneously also calls for an additional high level program to control and co-ordinate between these two transformations. This additional program will cause some deterioration in the performance of either one or both tasks. The degree of deterioration depends on factors such as the complexity of the two transformations,

3.0 (Continued)

the difficulty in controlling and co-ordinating the two transformations, the amount of practice given to the operator in such a simultaneous performance.

Lately a number of experiments have demonstrated that parallel processing of concurrent verbal stimuli is possible. In two important experiments, Treisman (1970); Treisman and Fearnley (1971)) demonstrates that a decision that neither of two simultaneous items is a digit could be made in parallel for the two items. Treisman also found that the efficiency of parallel processing was less than the efficiency of processing a single item: RT to pairs was longer by about 80 milli. seconds than RT to single stimulus.

Similar results were obtained by Ninio and Kahneman (1974). They found an increase from 7% to 26% in missed target words and an increase from 605 to 741 m.sec. in mean RT when subjects had to monitor two channels rather than one. In a similar experiment Treisman and Davis (1973) obtained an even worse deterioration when their subjects were unable to detect more than half the targets.

Sometimes the investigators claim that in their experiments simultaneous performance was as good as the performance of each of the individual tasks. A close examination of their results reveals that they failed to find any significant difference between the divided and undivided attention, but this does not mean that there is no difference between the two conditions. Indeed, the simultaneous performance is usually not as good as the individual performances. Such are the findings of

3.0 (Continued)

Allport (1971); Allport, Antonis and Reynolds (1972) or Rollins and Thibadeau (1973) or Wright, Holloway and Aldrich (1974).

Therefore, it should also be expected to find such deterioration in the simultaneous performances of the present experiment. But the interest here is also focused on the various factors - sense modality, transformation, type of stimuli - and their influence on this deterioration.

Ostry, Moray and Marks[1] emphasize that most selective listening experiments so far reported in the literature give data from observers who had received very little practice, and that such data must be regarded as highly unstable measures of human performance. For example, they claim that in the study carried out by Moray and O'Brien (1967) the practice given to the subjects was far too short. Ostry, Moray and Marks argue that "there might be massive practice effects in tasks of the kind used by Moray and O'Brien, and that such practice effects might throw considerable light on attentional mechanisms."

Recently, Underwood (1974) has reported that extended shadowing practice causes considerable improvement in detecting targets in both attended and unattended messages.

Although the present experiment was carried out prior to the publication of the above quoted studies, the writer felt that massive practice is needed in order to draw meaningful conclusions from simultaneous performance, especially when it involves shadowing.

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[1] Personal communication concerning "Attention, practice, and semantic targets", manuscript in preparation.

3.1 Hypotheses

It is hypothesized that any simultaneous time-sharing will cause some deterioration in performance.

However, the main deterioration in this experiment is expected to be caused by sense modality. Accordingly, greater impairment should be found in simultaneous performance of tasks which stimulate the same rather than different sense modalities.

Transformation, which is the other main factor employed in this study is not expected to have a great effect on the deterioration of performance. The shared tasks in this experiment always demand different transformations and thus create multi-functions load. This type of load does not tend to vary much if the tasks are roughly the same. In this experiment the shadowing task is always the same and the other shared task is always a CRT task with two choices. This means that whether the second task demands a physical comparison or a conceptual comparison, this will only have a small effect on the degree of impairment.

Contrary to the argument put forward by Rollins and Thibadeau (1973), the writer does not think that the use of words or 'verbal labels' as such, in both simultaneous tasks causes any deterioration in their performance. It is not the words which are important, but what they represent, the transformation they demand and the sense they stimulate. Therefore, the writer does not expect any deterioration to be caused by using words as stimuli.

3.2 Method

3.2.1 Experimental design

Six different tasks were used in the experiment: one shadowing task and five CRT tasks. The shadowing task was performed simultaneously with every one of the CRT tasks, thus creating five pairs of task performance. Each of the CRT tasks was also performed separately, to form a 'control' condition.

The five CRT tasks were identical to those used in the previous experiment (section 2.3.2.3.1).

Each of these five tasks had a common denominator with at least one of the other CRT tasks (Table 3.1), thus enabling to trace the sources of deterioration caused by the simultaneous performance of each of the tasks with a shadowing task.

The experiment was composed of five main factors (Table 3.2).

Factor A - the five CRT tasks:

visual words, numbers, lines, auditory words, pips.

Factor B - which has two levels:

1) the control level - where each of the five CRT tasks is performed separately.

2) the experimental level - where each of the five CRT tasks is performed simultaneously with the shadowing task.

Factor C -

1) at the control level (B_1), it has three purposes:

3.2.1 (Continued)

a) It includes 'before - after' sub-conditions in order to trace any after-effects which may result from the simultaneous performance.

b) It can detect improvement through practice.

c) It increases the sample size which otherwise would have been relatively small.

2) at the experimental level (B_2), it mainly serves as a repeated factor, thus increasing the sample size for the experimental condition, but it also assists in tracing practice effects.

Table 3.1 Fourth experiment: logical connections between tasks

The tasks	Common denominator	Main factor
Visual words, auditory words	The use of words	Words
Visual words, auditory words, numbers	Conceptual comparison)	Transformation
Lines, pips	Physical comparison)	
Visual words, numbers, lines	Visual stimulation)	Sense modality
Auditory words, pips	Auditory stimulation)	

Factor D - is composed of twelve trials for each of the CRT tasks.

Factor S - the subjects' factor. Five subjects took part in the experiment, each participated in all the conditions.

Each subject started the experiment with a different CRT task; the other four tasks followed in a random order. For each of the control and experimental conditions, the same initial task was performed, followed by the others in different random orders.

Table 3.2 Fourth experiment: experimental design

(B)	(C)	(S) Subjects \ trials (D)	(A) Words visual	Numbers	Lines	Words auditory	Pips
			1......12	1......12	1......12	1......12	1......12
Control	Before	1 . . . 5					
	After	1 . . . 5					
Experimental	Exp.1	1 . . . 5					
	Exp. 2	1 . . . 5					
	Exp.3	1 . . . 5					

3.2.2 Subjects

Five subjects participated in the experiment. They were all first year students at The University of Aston in Birmingham. They were all between 18 and 19 years of age, right-handed, with good vision and hearing. They volunteered to participate in the experiment, but they were also paid for their services.

3.2.3 Apparatus

The apparatus for this experiment was almost identical to the apparatus used in the previous experiment (section 2.3.2.3, and Figure 3.1).

In this experiment two tape-recorders were used, one with two channels. The two channels were used as follows:

- on the first channel were recordings of all the messages for shadowing.
- on the other channel were recordings of:

1) pulses for activating the slide projector

or

2) words and pips for auditory stimulation.

The experimenter controlled this channel via a selection switch.

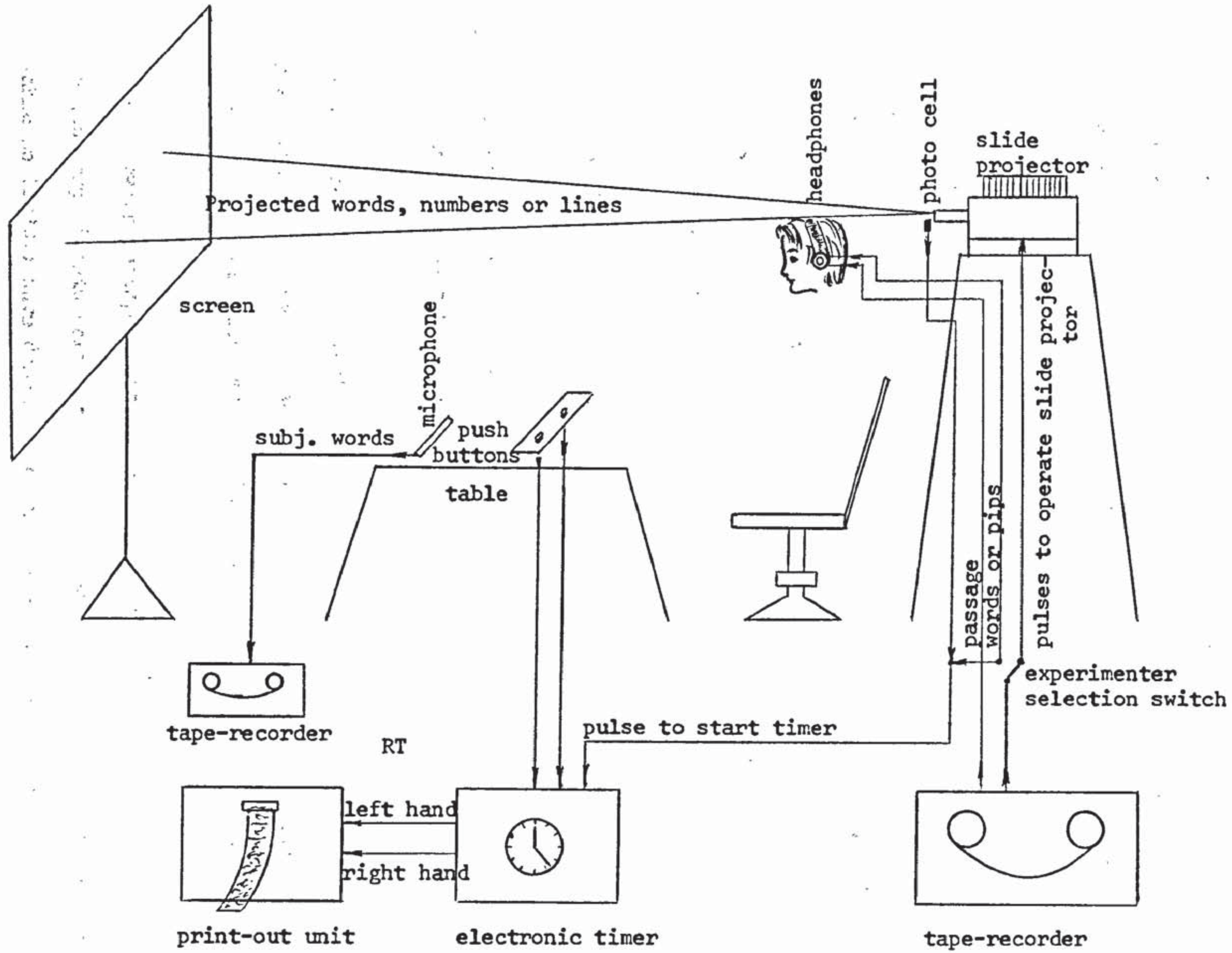
The second tape-recorder was used for recording the shadowed responses.

3.2.3.1 Stimuli

The stimuli used in this experiment were almost identical to those used in the previous one (section 2.3.2.3.1). The only difference was in the pips task. In the previous experiment the pips differed in loudness. In this experiment the two kinds of pips (one at $400H_2$ and the other at $2.5kH_2$) were perceived as equally loud. This effect was achieved by recording and then playing back both types of pips at 70ρHon (65 $dB^{\pm}$ 1dB) ("Accoustic noise measurements", 1973 p.25).

This procedure reduced the differentiation between the two stimuli on the loudness dimension. However, the reason for this procedure is that

Figure 3.1 Fourth experiment: principal hardware diagram



3.2.3.1 (Continued)

in this experiment the two stimuli must also be played back with a shadowing passage. If they are not equally loud, the louder pip may attract the attention of the subjects more than the quieter pip. This effect was found not only with 'pure tones' (Moray (1970a,b)), but also with verbal messages (Treisman (1960, 1964a,b)). Such an effect would unnecessarily increase the variability of the experimental results.

The shadowing passages (Appendix IVA) were extracted from short stories by Somerset Maughan (1951). They all contained about 150 words, were matched for difficulty and were recorded by a male speaker with a plain English accent. The duration of each passage was of one minute (± 3 secs.) This means that the rate of shadowing was 2.5 words per second. This rate was set because the rate used by Broadbent (2 words/sec.) is argued to be too slow (Moray (1969b); Moray and Jordan (1966)), while the rate used by Moray (3 words/sec.) was found in the pre-test (section 3.2.4.1) to be too fast.

The other messages - of auditory words - were recorded as in the previous experiment by a female speaker.

Each of the CRT tasks lasted for one minute in which 12 stimuli were presented for one second each at the rate of about one stimulus per 5 seconds (minimum inter stimuli interval was 2.5 sec. maximum 7.5 sec.).

The shadowing passages were played back to the subject's right ear. Various experiments carried out by Kahneman and others (for review see Kahneman (1973)) have demonstrated that the right ear is the dominant ear, particularly when right-handed subjects are being verbally

3.2.3.1 (Continued)

stimulated .

The other auditory stimulation (auditory words and pips tasks) was received by the subject's left ear.

3.2.4 Procedure

3.2.4.1 Pre-test

The need for a pre-test arose from the complexity of the experiment, and in carrying it out a series of purposes were achieved:

1) The hardware was tested and as a result some modifications were made.

2) The experimenter trained in running the experiment and in handling the equipment.

3) The subjects' performance was observed and valuable data was gathered in relation to the number of trials required for training them and the necessary number and duration of rest periods.

4) The shadowing task was analysed in terms of the rate at which it can be properly performed. The rate was set at 2.5 words per second.

The data collected from this pre-test is not included in the study, and the subjects who participated in it did not participate in the actual experiment.

3.2.4.2 Training

Shadowing, and especially simultaneous performance of shadowing with an additional task, puts a heavy strain on the subject. It was found in the pre-test (section 3.2.4.1) that without adequate training subjects cannot be expected to cope with such a difficult situation.

The need for adequate practice was stressed in several articles mainly by Moray (1969b); Moray and Jordan (1966); Ostry, Moray and

3.2.4.2 (Continued)

Marks[1]; Underwood (1974) and was also discussed in the introduction to this experiment (section 3.0).

Also, the writer was not interested in the learning process as such. Therefore, the subjects were well trained and did not improve their performance during the experiment itself. Thus it helps to eliminate this source of undesired variation from the results.

Each subject was trained in three stages (Figure 3.2):

Stage 1 Each subject was trained separately on each of the five CRT tasks. He was presented with 40 trials for each task.

Stage 2 Each subject was trained in shadowing. The rate at which he shadowed was increased from 60 words per minute to 150 words per minute. The increase was made in three stages. In each stage the subject read three passages.

Stage 3 The subject performed simultaneously each CRT task with the shadowing task. The rate of presentation of the shadowing task was increased in the same manner as in the second stage. Each of the five CRT tasks was performed three times at each rate of speed. In other words, at this stage each subject performed 45 simultaneous performances.

The training took place a day prior to the experiment. Before the actual experiment, each subject had another short period of training of each CRT task with shadowing. Between this short re-training and the experiment the subject had a 10 minute rest period.

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[1] Personal communication

Figure 3.2 Training and experimental schedules

Task	Rate of presentation	Training schedules				Experimental schedules				
		Stage 1	Stage 2	Stage 3	Short re-training	Before	Exp.1	Exp.2	Exp.3	After
The five CRT tasks	12 CRT/min.	—		— — —	—	—	—	—	—	—
Shadowing task (	1 word/sec.		—	—						
(	1.5-2 words/sec.		—	—						
(	2.5 words/sec.		—	—	—		—	—	—	

3.2.4.2 (Continued)

The emphasis in the training was on the shadowing. The subjects were instructed and trained to carry on with the shadowing task irrespective of their difficulties or inabilities to cope with the second task. Indeed, due to the intensive training, the subjects were able to shadow equally well with or without a simultaneous task.

3.2.4.3 Experimental procedure

Each subject started the experiment by performing all the five CRT tasks (factor A in Table 3.2) without shadowing (factors BC_{11}). He then proceeded to perform each of these tasks simultaneously with a shadowing task (factor B_2), repeating the process three times (factors BC_{21}, BC_{22}, BC_{23}). The subject never shadowed twice the same passage. He finished the experiment by having to perform all the five CRT tasks without shadowing (factor BC_{12}) in the same manner as in the initial stage (also see Figure 3.2).

Altogether each subject was expected to react 300 times during the experiment.

3.3 Results and analysis

3.3.1 Shadowing analysis

The different independent variables employed in this experiment are expected to influence the performance of the CRT tasks. The subjects were instructed and trained to shadow the passages irrespective of their difficulties in the CRT tasks. However, before examining the RT results, it is necessary to look at the shadowing performance.

The most important question with respect to shadowing is whether it varies while being performed with different CRT tasks. In other words - does shadowing when time-sharing with one CRT task differ from shadowing with another CRT task.

The two criteria of number of shadowed words and the length of shadowing did not prove to be useful methods for this differentiation. Most of the subjects shadowed all the words, and the odd stuttering or mis-pronunciation did not provide any criteria according to which categorization of shadowed passages could be made. The subjects spoke for about one minute, which is also the length of the passage read to him.

A third method for examining the shadowing performance was through the employment of 'judges'. Five students served as judges. Their duty was to listen to the recordings made of the subject's shadowing and to try to decide which of the five CRT tasks the subject was performing while making the recording.

3.3.1 (Continued)

The judges knew that each CRT task was performed three times by each subject. They were also told that probably shadowing while performing an auditory task is the most difficult situation, and therefore the shadowing performance would not be as good as shadowing while performing a visual task. As it can be seen from Table 3.3, their decisions were far from correct. In fact, it seems that the judges could not differentiate between the different tasks, and therefore distributed them more or less in a random order. The total mean for 'hit' (emphasized squares) is 20.54% while the percentage for chance is 20.

These results indicate that shadowing while performing one CRT task was as good as shadowing while performing another CRT. This means that the difficulty in time-sharing did not cause any marked variations in the shadowing performance. It was, however, expected that these difficulties would be expressed in the CRT. Therefore, a statistical model for analysing the RT may now be developed.

Table 3.3 The judges decisions matrix (in percentages)

The task to be judged	The judges decision					
	Visual words	Auditory words	Numbers	Lines	Pips	Total
Visual words	16.0	25.3	26.7	22.7	9.3	100
Auditory words	13.3	20.0	18.7	21.3	26.7	100
Numbers	21.3	14.7	25.3	18.7	20.0	100
Lines	26.7	21.3	20.0	14.7	17.3	100
Pips	22.7	18.7	9.3	22.7	26.7	100
Total	100	100	100	100	100	-

3.3.2 Statistical model

From the 'experimental design' (section 3.2.1) it can be seen that five different factors influence the dependent variable (CRT). Some of these factors are nested within others, and some include repeated measures from the same subjects. The adequate statistical model for analysing these results is an ANOVA with hierarchical design for repeated observations.

Another factor which must be taken into consideration in choosing the statistical model is the error responses. Like in the previous experiment the error RTs were excluded from the analysis. Owing to the exclusion of human errors and machine errors, the various groups of 'readings' in this experiment became unequal. The reader is referred to the 'Statistical model' of the previous experiment (section 2.3.3.1) for the various argumentations which form the basis for developing the statistical model. Most of the arguments put forward there also apply to this experiment.

Accordingly, it was decided to use the unweighted means method.

In this experiment, unlike all the previous ones, the notion 'first v. rest' is no longer meaningful, and the basis for the analysis are the tasks (factor A) which are composed of twelve trials (factor D) performed in the various experimental conditions (factor B and C) by the five subjects (factor S) - (see Table 3.2).

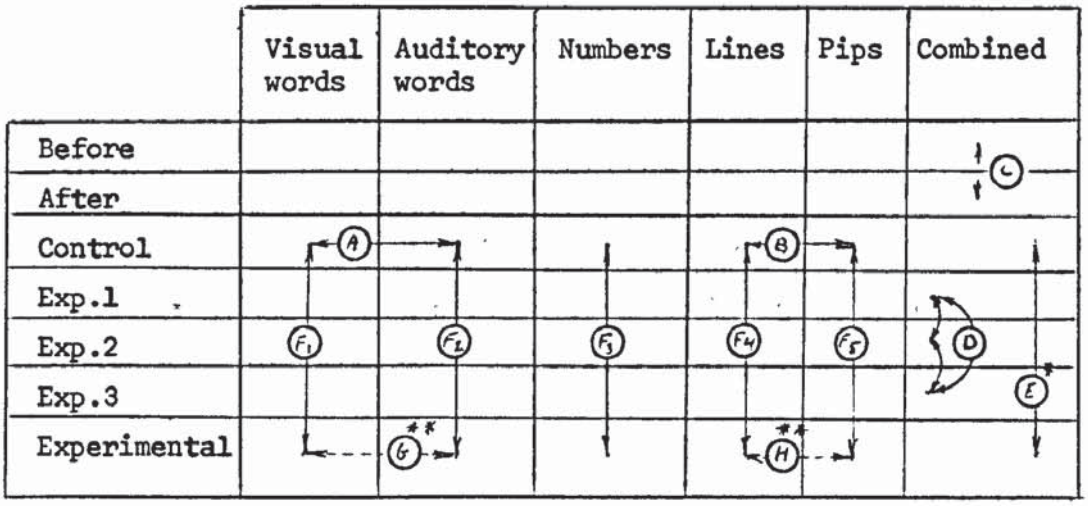
Before carrying out the ANOVA, a few preliminary comparisons will be made.

3.3.2 (Continued)

1) In the 'Experimental design' (section 3.2.1) some logical connection was expected to be found among various combinations of tasks (Table 3.1). Some of these 'logical connections' can be tested in specific comparisons. For example, visual words task and auditory words task are almost identical except for the fact that they stimulate different sense modalities. Therefore, in the control condition, these two tasks are not expected to differ (Table 3.4, comparison A).

In a similar manner, the lines task and the pips task are also not expected to vary significantly in a control condition. Both these tasks demand physical comparisons of stimuli and therefore ought to yield similar RTs (Table 3.4, comparison B).

Table 3.4 Fourth experiment: comparisons



* This comparison is the effect of factor B in the ANOVA.

** These comparisons appear in a separate appendix.

3.3.2 (Continued)

2) A comparison between 'before' and 'after' (C_1 v. C_2; comparison C in Table 3.4). The combination of the before and after forms the control condition (Table 3.2). This comparison aims to detect whether there any any after-effects on the performance of the CRT tasks due to the simultaneous performance in the experimental situation.

According to the hierarchical model no such after-effects are expected to be found. Indeed in the hypotheses to this experiment it was not expected to find any difference between before and after conditions.

3) A comparison between the three experimental levels (C_3, C_4 and C_5). These three levels form the experimental condition. The comparison aims to find practice effects, i.e. whether the subject can improve his performance during the experiment (Table 3.4, comparison D).

It was not hypothesized that such a difference will be found, because the subjects could not be expected to make significant improvements in their performance during the experiment after extended practice.

These two comparisons within the control and within the experimental conditions, can also be said to test the homegeneity of the sub-levels (factor C) which they are composed of. In other words if a significant difference is found between the before and the after conditions then they cannot be pooled together to form the control condition, and the same applies to the three levels of the experimental condition.

After carrying out these specific comparisons, the overall ANOVA is calculated.

3.3.2 (Continued)

These calculations are followed by planned comparisons which are carried out regardless of the ANOVA statistical outcome.

The planned comparisons are statistical contrasts between the control and experimental conditions within each of the tasks (factor B at each level of factor A; Table 3.4, comparison F).

The last planned comparisons are a contrast between the visual words task and the auditory words task in the experimental condition, and also a comparison between the lines task and the pips task in the experimental condition (Table 3.4, comparisons G and H).

It can be argued that these last two comparisons are redundant non-orthogonal because of all the comparisons made before. This is a valid claim. However, in some of the previous comparisons hypotheses of 'no difference' were formulated. Since these hypotheses cannot be directly demonstrated, the writer has decided to add the comparisons G and H. These comparisons appear later in a separate appendix, and are not referred to in the study.

In this experiment, like in the previous one, the writer was not interested in the effect of the trials within the series (factor D in both experiments). Therefore, it has been decided that this factor and all its interactions would be excluded from the ANOVA summary table. This procedure has been used before in this thesis and it does not affect any of the other variables. For the computational formulae of the ANOVA and their explanations see Appendix IVB.

3.3.3 Results

Table 3.5 sums up the RT results according to experimental condition and type of task. This table also includes a sub-division of the tasks according to the sense modality which they stimulate.

Each of the cells in the table contains:

n	E
ΣX	
ΣX^2	$\overline{X}$

n - the number of RTs in each cell

ΣX - the sum of those RTs (in m.sec.)

ΣX^2 - their sum of squares (in m.sec.)

E - the number of human errors

$\overline{X} = \frac{\Sigma X}{n}$ - the mean RT in each cell (in m.sec.)

A more detailed account of the results is given in Appendix IVC.

It has already been mentioned (section 3.3.2) that before carrying out the overall ANOVA a number of comparisons would be made.

The contrast between the two words tasks and the contrast between the lines task and the pips task (comparisons A and B according to Table 3.4) appear in Table 3.6.

Due to the number of factors in this experiment and the fact that there are repeated measures in this design, the denominator for the 'error term' is calculated according to the following formula:

Table 3.5 Fourth experiment: summary matrix

		Visual stimulation				Auditory stimulation			TOTAL
		Visual words	Numbers	Lines	TOTAL	Auditory Words	Pips	TOTAL	
Control	Before	54 4 27,098 13,833,576 501.81	58 1 27,668 13,567,426 477.03	60 0 23,604 9,486,176 393.40	172 5 78,370 36,887,178 455.64	57 0 29,777 16,716,365 522.40	58 1 22,405 9,200,659 386.29	115 1 52,182 25,917,024 453.75	287 6 130,552 62,804,202 454.89
	After	55 3 28,831 15,819,975 524.20	54 4 25,999 12,979,629 481.46	59 1 23,080 9,587,774 391.18	168 8 77,910 38,387,378 463.75	49 4 24,461 13,240,295 499.20	58 1 22,466 10,016,060 387.34	107 5 46,927 23,256,355 438.57	275 13 124,837 61,643,733 453.95
	TOTAL	109 7 55,929 29,653,551 513.11	112 5 53,667 26,547,055 479.16	119 1 46,684 19,073,950 392.30	340 13 156,280 75,274,556 459.64	106 4 54,238 29,956,660 511.67	116 2 44,871 19,216,719 386.81	222 6 99,109 49,173,379 446.43	562 19 255,389 124,447,935 454.43
Experiment	Exp.1	57 2 32,232 19,254,536 565.47	52 7 28,165 15,909,227 541.63	57 1 28,102 14,464,810 493.01	166 10 88,499 49,628,573 533.12	54 6 34,678 24,645,826 642.18	49 9 28,441 18,866,973 580.42	103 15 63,119 43,512,799 612.81	269 25 151,618 93,141,372 563.64
	Exp.2	52 3 30,810 19,341,540 592.50	49 6 27,492 16,568,868 561.06	58 0 28,062 15,163,628 483.82	159 9 86,364 51,074,036 543.16	50 9 37,419 32,962,647 748.30	51 6 30,278 20,595,388 593.68	101 15 67,697 53,558,035 670.27	260 24 154,061 104,632,071 592.54
	Exp.3	57 1 33,622 22,027,016 589.86	53 2 28,348 16,137,552 534.86	54 1 23,632 11,016,712 437.63	164 4 85,602 49,181,280 521.96	52 5 35,284 26,184,258 678.53	55 2 33,105 21,761,705 601.90	107 7 68,389 47,945,963 639.15	271 11 153,991 97,127,243 568.23
	TOTAL	166 6 96,664 60,623,092 582.31	154 15 84,005 48,615,647 545.48	169 2 79,796 40,645,150 472.16	489 23 260,465 149,883,889 532.64	156 20 107,381 83,792,731 688.33	155 17 91,824 61,224,066 592.41	311 37 199,205 145,016,797 640.53	800 60 459,670 294,900,686 574.59
TOTAL		275 13 152,593 90,276,643 554.88	266 20 137,672 75,162,702 517.56	288 3 126,480 59,719,100 439.17	829 36 416,745 225,158,445 502.71	262 24 161,619 113,749,391 616.87	271 19 136,695 80,440,785 504.41	533 43 298,314 194,190,176 559.69	1362 79 715,059 419,348,621 525.01

3.3.3 (Continued)

$$\frac{MS\ error\ a + (b-1)\ MS\ error\ ab}{b}$$

The reader is referred to Winer (1971 pp.539 - 559). The experimental design discussed by Winer is not identical to this particular design, but the writer has made the necessary modification.

In some cases the appropriate F ratio cannot be constructed by direct application of the rules based upon expected values of mean squares. For these cases, Satterthwaite (1946) composed an approximation for calculating the degrees of freedom. Winer (1971 p.545 and pp.375 - 378) defined the range between a lower and an upper limit for degrees of freedom. This corresponds to more or less conservative approaches.

In these particular comparisons the F ratios obtained remain below unity, regardless of the method used. Indeed a close examination of the visual and auditory words tasks in the control condition reveals that in both tasks the mean RTs obtained are very similar (513.11 m.sec. and 511.67 m.sec. respectively). The mean RTs for lines task and for pips task in the control condition is also very close (392.30 m.sec. and 386.81 m.sec. respectively). These means are extracted from Table 3.5 and are based on calculations derived from the raw data. The statistical comparisons, like all the other statistical calculations in this study, are based on the 'unweighted means method' (for summary means matrices see Appendix IVC, Tables IVC7 - 8). There are slight differences between the means obtained by the two calculation methods. The same phenomenon occurred in the previous experiment (section 2.3.3.3). For the statistical calculations, see Appendix IVD.

3.3.3 (Continued)

Table 3.6 'Control comparisons': visual - auditory words, lines - pips

Source	SS	df	MS	F
A vis. w. - A aud. w. at B_1	1,608.09	1	1,608,09	< 1
A lines - A pips at B_1	1,276.37	1	1,276.37	< 1
error*		upper lim.100 lower lim. 20	64,156.31	

* see text

The comparisons which follow according to Table 3.4 are:

comparison C - before - after (within control condition)

comparison D - exp. 1 - 2 - 3 (within experimental condition)

comparison E - control - experimental

These three comparisons are included in the overall ANOVA (Table 3.7):

comparison C - is factor C within B_1

comparison D - is factor C within B_2

comparison E - is factor B

The overall ANOVA is based on the statistical model developed earlier (Appendix IVB). The various terms needed for Table 3.7 are calculated in Appendix IVE, and the harmonic mean is calculated in Appendix IVD2.

As it can be seen from the summary of the ANOVA, neither comparison C (factor CwB_1 - before - after) nor comparison D (factor CwB_2 - exp.1 - exp.2 - exp.3) yielded any significant results. This means that no significant difference can be demonstrated between the 'before' and the 'after' conditions, and also that no significant difference can be demonstrated among the three repetitions of the experimental condition.

3.3.3 (Continued)

Table 3.7 Fourth experiment: summary of ANOVA

Source	SS	df	MS	F
S (subj.)	2,653,589	4	663,397.25	
A (task)	3,994,791	4	998,697.69	13.76**
SxA	1,160,960	16	72,560.00	
B (cont. exp.)	4,322,284	1	4,322,284	21.28***
SxB	815.561	4	203,140.25	
CwB	184,886	3	61,628.61	<1
CwB_1	141.29	1	141.29	<1
CwB_2	184,744.51	2	92,372.26	<1
SxCwB	992,064	12	82,672.33	
$SxCwB_1$	23,493	4	5,873.25	
$SxCwB_2$	968,575	8	121,071.87	
AxB	1,107,123	4	276,781.00	4.96*
SxAxB	892,042	16	55,752.62	
AxCwB	279,800	12	23,316.66	1.77
SxAxCwB	632,614	48	13,179.45	

* $p < .05$ ** $p < .01$ *** $p < .001$

Even a combined factor (cwB) yielded an F ratio which is smaller than unity.

Comparison E (control - experiment, of Table 3.4) did produce a significant F ratio (Table 3.7). This means that in general, the performance of a RT task simultaneously with a shadowing task, differs significantly from the performance of the RT task alone.

3.3.3 (Continued)

From Table 3.7 it can also be seen that the performance of the five CRT tasks - when both control and experimental conditions are pooled together (factor A), differ significantly. However, there is also an interacting effect of tasks and condition (factor AxB) which hints that a further examination of these two factors might be beneficial. Indeed, this further examination is carried out through the planned comparisons (comparison F, in Table 3.4).

Table 3.8 Fourth experiment: planned comparisons within tasks

Source	SS	df	MS	F	$\hat{\omega}^2$***
B at A vis. w.	279,564.61	1	279,564.61	3.28	0.04
B at A numbers	266,131.81	1	266,131.81	3.12	0.04
B at A lines	397,420.65	1	397,420.65	4.66	0.06
B at A aud. w.	1,708,225.34	1	1,708,225.34	20.04**	0.32
B at A pips	2,777,972.07	1	2,777,972.07	32.59**	0.53
error		* upper lim. 100 lower lim. 20	85,230.14		

*see Winer (1971 p.545) ** $p < .001$ *** the estimations were rounded

For the calculations needed for the comparisons and their validation, see Appendix IVF. For the estimation of the magnitude of the experimental effects see Appendix IVG.

As it can be seen from Table 3.8, the comparisons between the control and experimental conditions yield significant results only at the auditory words task and the pips task. In the three other CRT tasks the F ratio

3.3.3 (Continued)

was not found significant. The rough estimation of their relative effects shows that these effects are large in the auditory words task and the pips task, but quite small in the other three tasks.

The last two comparisons, G and H (Table 3.4) appear in Appendix IVH. It was already argued that in a way these two comparisons are redundant and non-orthogonal. However, they are carried out because comparisons A, B, F_1 and F_4 (Table 3.4) propose to demonstrate 'no significant difference'. This 'lack of difference' is not a demonstration of equality. Therefore comparisons G and H enhance the argument that while visual and auditory words task were not found to be different in the control condition, they are found to be different in the experimental condition. The same applies to pips and lines tasks.

3.3.4 Error analysis

The hierarchical functional model predicts that the greater the load imposed by time-sharing performance the greater the number of errors made during that performance.

Table 3.5 contains the summary of errors-frequencies made in this experiment. It can be seen from this table that in a control condition, where each of the RT tasks performed alone, more errors were made on the more diffucult tasks (i.e. words or numbers tasks) than on the easier tasks (lines and pips tasks). Furthermore, the simultaneous performance (experimental condition) is more difficult than the single performance (control condition) and therefore more errors were made in the former condition than in the latter one.

The various RT analyses carried out in the previous section have already indicated that in this experiment sense modality is the most influential independent variable. If this variable influences one dependent variable (RT), it is reasonable to assume that it influences the others. The speed accuracy trade-off is a well known phenomena in CRT experiments (Hick (1952); Fitts (1966)).

The main hypothesis in regard to sense modality is that the variable control experiment causes a relatively small variation in the error rates in visual tasks, but it causes a large variation in auditory tasks. It is also expected that the error rate in the control condition between similar tasks will also be similar, but in the experimental situation the error rate in those tasks will differ according to the sense which they stimulate.

3.3.4 (Continued)

Table 3.9 a), b) contains the means of errors made in the experiment. In the first stage (part a) the means were calculated according to task and condition, while in the second stage (part b) all the visual tasks and all the auditory tasks were combined.

Table 3.9 Fourth experiment: mean error matrices

a) Mean errors according to task

	Vis. w.	Numbers	Lines	Total	Aud. w.	Pips	Total
control	3.5	2.5	0.5	6.5	2	1	3
experimental	2	5	0.66	7.66	6.66	5.66	12.33

b) Mean errors according to sense modality

	Visual		Auditory	
	mean	per cent	mean	per cent
Control	2.17	3.611	1.5	2.500
Experimental	2.56	4.259	6.17	10.277

From Table 3.9 it can be seen that there is only a slight increase in the error rate between the control and experimental conditions in visual tasks, while in auditory tasks the increase is more than four times.

Two independent binominal tests were carried out within the visual tasks and within the auditory tasks, between the control and experimental conditions using the actual error rate (Table 3.5). In the visual tasks no significant difference was found between the control and experimental

3.3.4 (Continued)

situation ($z = -1.5$, $p = .0668$). In the auditory tasks the test did yield significant results ($z = -4.575$, $p < .000003$) (from Siegel (1956 pp.36 - 42) and Winer (1971 Table C1)).

The percentages in Table 3.9 part b are calculated from the total number of stimuli in the various categories.

The total number of human errors is 79 (5.266%), the total number of machine errors is 59 (3.933%), and the total number of expected response is 1500. The machine errors were not analysed, but expected to be randomly distributed. As in the previous experiment, these errors were due to the print-out unit failing to register the subjects' RTs.

3.4 Discussion

The analysis of the experimental results was carried out using the 'unweighted means method' (Appendix IVC, Table IVC7). In order to facilitate the discussion of these results a new summary table (3.10) is constructed, based on the above mentioned summary means matrix and on the planned comparisons (Table 3.8).

Table 3.10 Planned comparisons: summary of results

	visual words	numbers	lines	auditory words	pips	TOTAL
control	513.66	479.60	391.64	508.16	386.74	455.96
experimental	579.86	544.19	470.57	671.80	595.42	572.37
$\Delta\bar{X}$	66.20	64.59	78.93	163.64	208.68	116.41
F	3.28	3.12	4.66	20.04	32.59	21.28
p	not signft.	not signft.	not signft.	$<.001$	$<.001$	$<.001$
$\hat{\omega}^2$	0.04	0.04	0.06	0.32	0.53	----

The table contains two of the main factors in this experiment:

Factor A - the five CRT tasks (+ total)

Factor B - control and experimental conditions

The intersections of the two factors contain the various mean RTs in m.sec. (identical to Table IVC8 of Appendix IVC). The table also contains:

$\Delta\bar{X}$ - the differences between experimental and control conditions (in m.sec.)

F - the F tests which were carried out on these differences

3.4 (Continued)

α - the level of significance of these tests

$\hat{\omega}^2$- the estimation of the magnitude of the tested effects

The total column on the right-hand side of Table 3.10, contains the total effect to factor B (the F ratio and level of significance were extracted from overall ANOVA (Table 3.7).

The discussion of the outcome of this experiment will also be facilitated by graphical presentations. Figure 3.3 presents the various RTs (in m.sec.) according to task and condition. Figure 3.4 presents the difference in RTs - between experimental and control - according to task. The two figures are based on the raw data (i.e. on weighted means, Table 3.5).

Figure 3.3 contains also various comparisons (according to Table 3.4) between the tasks at different conditions. Figure 3.4 is a visual presentation of the planned comparisons (Table 3.10). The planned comparisons are based on the unweighted means method, while Figure 3.4 is based on the weighted means. Therefore, there are slight differences in the averages obtained using the two methods.

The discussion of the RTs results cannot be meaningful unless it also takes into consideration the other simultaneous tasks (i.e. the shadowing task) and the error in performing the CRT tasks.

Figure 3.3 RTs according to task and condition

(1) Matched words tasks - comparison A

(2) Matched physical tasks - comparison B

(3) Visual tasks

(4) Auditory tasks

(5) Control - experimental within each task - comparison F

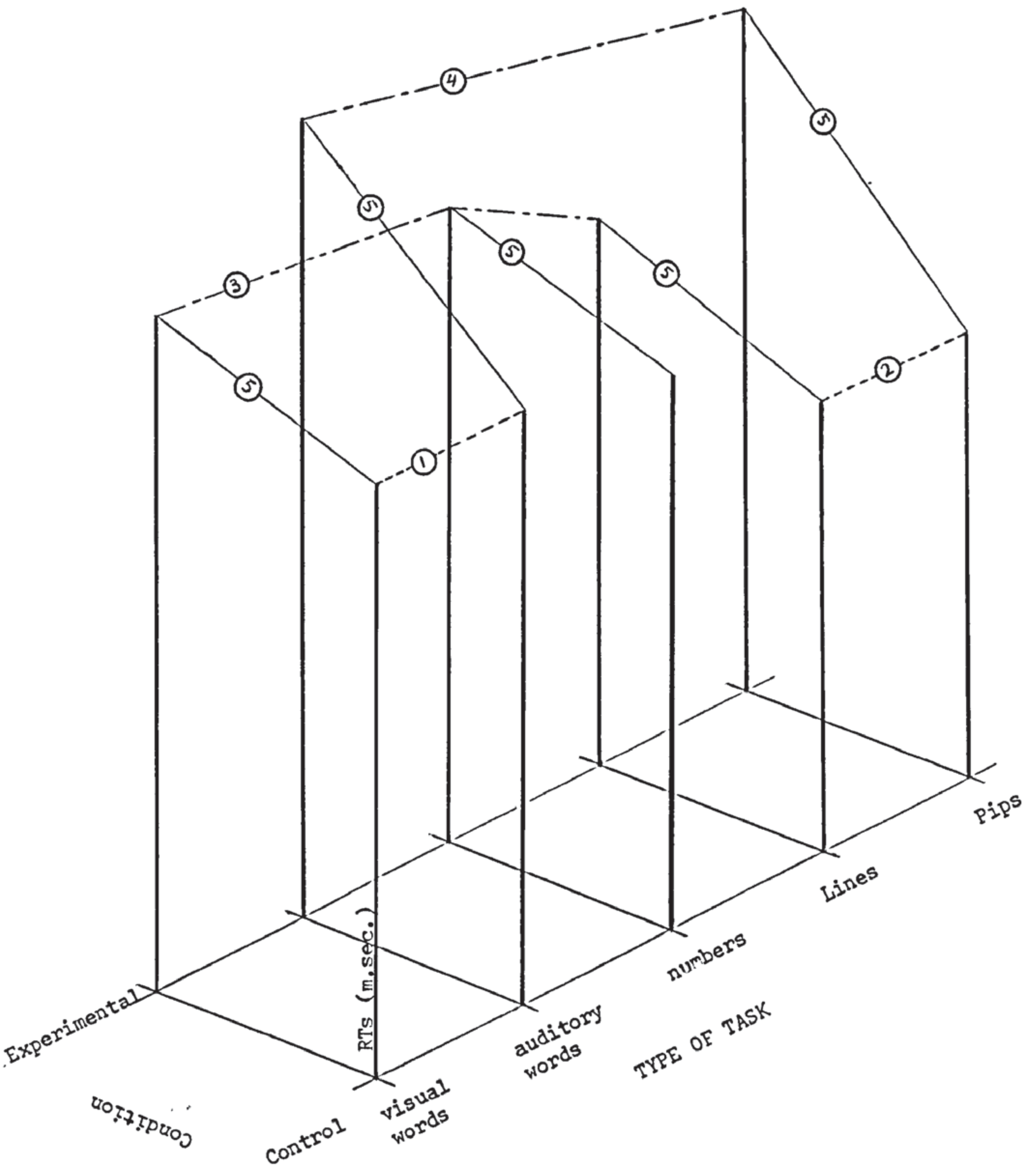
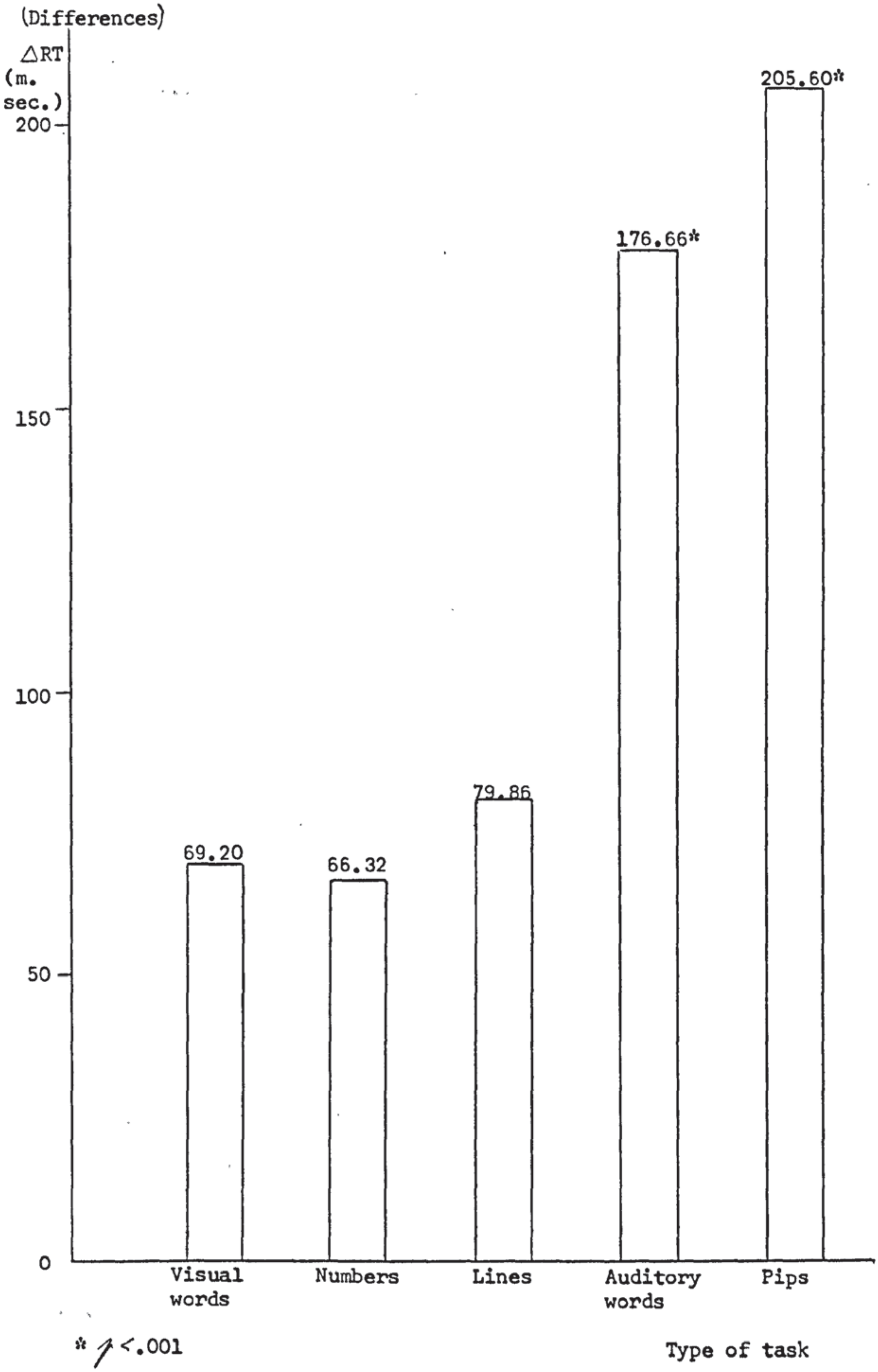


Figure 3.4 Differences between control and experimental conditions within each task



3.4.1 The shadowing task

According to the hierarchical functional model, in a simultaneous time-sharing situation both shared tasks suffer a decrement in the performance. However, it is possible to give priority to one of the tasks, so that in a simultaneous situation, the performance of this particular task would only suffer a minor deterioration.

This technique, of stressing the importance of one task over the other, is well known and is mainly used in estimating mental load through the use of secondary tasks technique (for review see Welford (1968); Rolfe (1971a)). However, the technique was also used in studying attention. For example Flaherty and Coren (1974) trained their subjects to shadow while responding to target words task, stressing to them that shadowing was the main task and key press was the secondary task. The procedure described by Flaherty and Coren and the procedure of this experiment are very similar. The fact that the shadowing task was not studied in any way is a serious fault in Flaherty and Coren's experiment (although they report examining the shadowing responses).

In this experiment, the rather long practice was mainly aimed at achieving good shadowing performance in all the conditions.

Shadowing is a very difficult task to perform and it is also difficult to evaluate. A slight hesitation in the voice of the shadower, a random stutter, a change in the rate of speech, are all easy to detect qualitatively, but difficult to evaluate quantitatively. That is why the writer employed five students to judge the quality of shadowing in the various situations.

3.4.1 (Continued)

As it can be seen from Table 3.3 the 'judges' could not differentiate among the shadowed passages, according to the various CRT tasks. In other words, the quality of the shadowing performance was the same regardless of the type of CRT task with which it was simultaneously performed.

It should be noted that the subjects only shadowed in a simultaneous time-sharing situation, so that a comparison between shadowing alone and shadowing while performing a CRT task was never carried out. This should not make any difference to the conclusions reached in this experiment, since the shadowing performances were judged in the experimental condition.

Even if some differences between shadowing alone and shadowing while time-sharing could be detected this would not alter any of the conclusions reached in this experiment. It is only worth mentioning that distinctive background noises made the shadowing in the experimental condition unmistakably different from any of the normal control shadowings.

3.4.2 Errors in CRT

The hierarchical model argues that simultaneous performance is more loading than individual performance. Such a loading situation may cause the operator to make more mistakes than otherwise. Therefore it was expected to find more errors in the CRT tasks in the experimental condition than in the control condition. From Table 3.9 it is possible to calculate the total mean error for the control and the experimental conditions (1.835 and 4.365 respectively). Thus, on average, there are more errors in the simultaneous performance than in the individual performance.

The increase in error rate between the control and the experimental conditions should be relatively small in visual CRT tasks and relatively large in auditory CRT tasks. As it can be seen from Table 3.9 the mean increase in the visual tasks is very small and not significant (p =.0668), while the increase in the errors means in auditory tasks is relatively large (over four times) and highly significant (p <.000003).

The findings of the error analysis are compatible with the findings of the RT analyses. Part of the difficulty to perform two simultaneous tasks was expressed in the error rate and part in the speed of the RTs.

The speed accuracy trade-off in CRT is well known. Subjects are capable of trading off speed and accuracy (Fitts (1966); Hick (1952)) so that the increase in one brings about a decrease in the other. Therefore, the fact that there is a sharp increase in the error rate on auditory CRT tasks in the experimental condition only conceals the full impact of such a simultaneous performance. In other words, if the error rate

3.4.2 (Continued)

would have been kept constant throughout the whole experiment, the increase in RT found between control and experimental conditions in the auditory tasks would have been much greater. As it is, part of this manipulation effect was absorbed by the increase in the error rate.

It should be noted that the errors ratio found in this experiment are compatible with other findings. The error rate in the control condition is consistent with the error rates of the previous experiments in this study, and also with other known rates in similar tasks (see Smith (1969) for review).

The errors made in the auditory CRT tasks in the simultaneous performance (10.277%) are compatible with the finding of Tune (1964). His subjects made 9% errors in simultaneous auditory tasks, but his tasks were slightly easier than the ones used in this experiment.

3.4.3 CRT - preliminary examinations

Before analysing the data of this experiment a number of preliminary examinations are carried out.

3.4.3.1 Matched tasks

Table 3.1 showed logical connections between the various tasks in this experiment. Two sets of matched tasks were used in the experimentation:

1) The visual words task was matched with the auditory words task, and

2) The lines task was matched with the pips task.

The first pair of tasks were matched in the sense that both tasks demanded an identical transformation: sorting out numbers (in words form) to odd and even categories. Both tasks presented the numbers in the form of words, the only difference being that one stimulated the visual sense, and the other the auditory sense.

The lines and the pips tasks were matched in so far as both tasks demanded some comparisons along physical scales.

It was expected that in the control condition the RTs within each pair of matched tasks would not differ significantly.

Indeed the raw data of Table 3.5 shows that the means RTs within each pair were almost identical. A test for differences - comparison A and comparison B in Table 3.4 - based on unweighted means (from Appendix IVC, Table IVC8) did not yield any significant results

3.4.3.1 (Continued)

(Table 3.6). This preliminary test enhances the argument that the tasks are matched within each of the two sets.

If the performance of the two words tasks would have deteriorated in the experimental condition it would not have been possible to trace the reason for this deterioration. It could have been the particular transformation demanded by the two tasks, but it could also have been the fact that both tasks used words as their stimulation. The latter argument was put forward by Rollins and Thibadeau (1973) and is discussed later in the study.

In order to solve this problem, the numbers task was also introduced. This task demanded the same transformation as the two words tasks, but it did not use words as stimuli.

According to Table 3.1, there are three possible reasons for a deteriorated performance in simultaneous time-sharing:

a) The use of words as stimuli.

b) A particular demanded transformation.

c) A particular stimulated sense modality.

Before examining these possible reasons, it is necessary to look at the effects of practice on simultaneous time-sharing.

3.4.3.2 The effect of practice

The hierarchical model argues that any performance, even a simultaneous

3.4.3.2 (Continued)

performance, improves with practice. On the other hand this experiment was not designed in order to demonstrate learning or practice effects. On the contrary, the subjects went through a long period of training in order to test the various hypotheses with well practised operators.

Each of the five CRT tasks was tested before and after the simultaneous performance. A comparison between the before - after performance (comparison C in Table 3.4), is designed to test whether any improvement in performance takes place throughout the experiment.

There is a possibility that the experimental condition has an after-effect on the 'normal' performance of the CRT tasks (the after condition). If there is such an after-effect its influence is not yet known. Therefore, the three experimental levels (exp.1, 2 and 3) should also be compared.

A careful examination of the mean RTs of before and after conditions (454.89 m.sec. and 453.95 m.sec. respectively, from Table 3.5) or of the three experimental levels (563.64 m.sec., 592.54 m.sec. and 568.23 m.sec.) reveals that the means to be compared are very similar.

With such similar means there is little wonder that neither the before - after comparison (C within B_1, in Table 3.7) nor the exp. 1 - 2 - 3 comparison (C within B_2) yield any significant effect. This may lead to the conclusion that no significant improvement in performance takes place during the experiment. Probably there also is no after-effect due to the simultaneous time-sharing. The fact that factor C (CwB in Table 3.7) did not have an overall significant effect enhances these conclusions.

3.4.4 The overall ANOVA

Three main factors are examined in the overall ANOVA (Table 3.7) A - tasks, B - control experiment and C - which was discussed in the last section (3.4.3.2).

As it can be seen from the summary table, factors A and B and their interaction yield significant results.

A significant tasks effect means that there is a significant difference in the performance of the five CRT tasks. This is an expected effect, because the tasks which demanded sorting out numbers to odds and evens (i.e. the numbers task and the two words task) were more difficult to perform than the two tasks which demanded physical transformations (the lines and pips tasks).

The results in Table 3.5, show that there are marked differences in RT among the various tasks. While the words and numbers tasks require RTs within the region of 517 to 617 m.sec., the lines and pips tasks only require RTs of 439 to 504 m.sec.

A significant control experimental effect means that there is a significant difference between performing a CRT task simultaneously with a shadowing one and between performing the same task alone.

The results in Table 3.5 show that the mean RT in the control condition was 454.43 m.sec. while in the experimental condition it was 574.59 m.sec., a difference of 120 m.sec.

3.4.4 (Continued)

This overall effect was predicted by the hierarchical model which argues that simultaneous time-sharing is a more loading situation than the two individual performances. Therefore, such performances are impaired in comparison with the individual performances. This effect was demonstrated before by numerous experiments (e.g. Gerver (1974); Ninio and Kahneman (1974); Treisman and Davies (1973); Treisman and Fearnley (1971); Treisman and Riley (1969); Underwood (1974); Wright, Holloway and Aldrich (1974)).

The last effect which was found significant is the interaction between task and condition. This means that the performance of the various tasks is affected differently by the control or experimental conditions. In other words, the performance of some tasks deteriorates more than the performance of others in the experimental situation.

The next stage is a more thorough examination of the degree to which the various performances did deteriorate in the experimental condition.

3.4.5 Planned comparisons

The performance at the control level was compared to the performance at the experimental level within each of the five CRT tasks. The results of these planned comparisons are summarized in Table 3.10. Figure 3.3 is a visual presentation of the mean RTs according to the different tasks and the two experimental conditions. The differences (in RTs) between the control and experimental conditions within each task is plotted in Figure 3.4. As it can be seen from Table 3.10, these differences were not found significant in the visual words task, the numbers task, and the lines task. According to Table 3.1 the logical connection - or common denominator - among these tasks is the fact that they all involve visual stimulation. On the other hand the performances on all the auditory tasks have deteriorated when they were simultaneously performed with another auditory task.

Other experimenters have found similar results. Treisman and Fearnley (1971) measured RTs to a single item, or pair of items, in a classification task. They found that RT to simultaneous items was longer by about 80 m.sec. than RT to single stimuli. Ninio and Kahneman (1974) exposed subjects to brief dichotic word lists. The subjects had to press a key whenever they heard an animal name. RTs were measured in divided and in focused attention. The difference between the mean RT in the two conditions was about 140 m.sec.

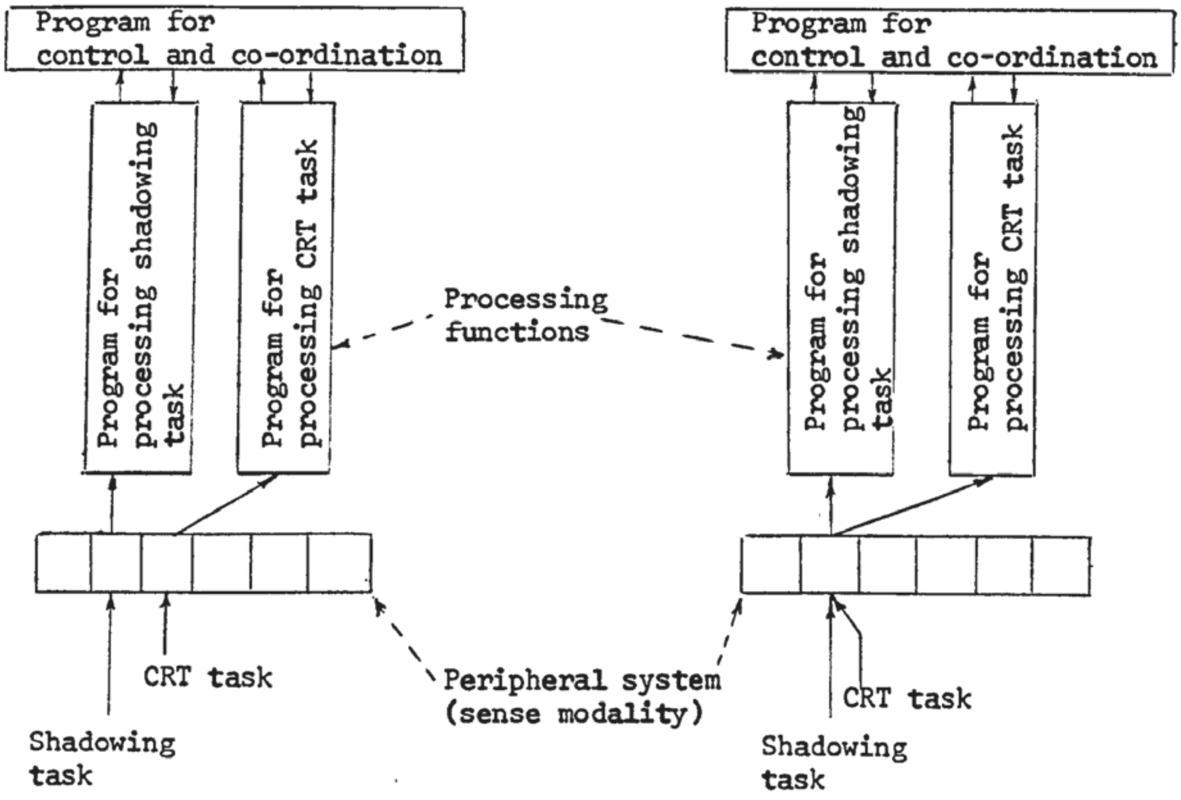
The results of the experiment are in full agreement with the predictions of the hierarchical model. The model argues that in simultaneous time-sharing, the performance of the task would deteriorate due to the processing load. If the two simultaneous time-shared tasks also

3.4.5 (Continued)

stimulate a common sense modality, a further deterioration in the performance would occur due to sense load.

It is possible to argue that the deteriorations of the visual tasks - performances are due to the processing load (of a multi-functions type) while the deterioration of the auditory tasks performances are due to the processing load plus the sense load (Figure 3.5).

Figure 3.5 Same and different sense modality in simultaneous time-sharing



The hierarchical model predicts that tasks which demand the same transformation require the same amount of control and co-ordination when each of them is time-shared with a third task. Therefore, the amount of deterioration in performance due to processing load in both tasks

3.4.5 (Continued)

would be the same. This is so, provided that none of them causes an additional load, such as sense load.

These conditions apply to the visual words tasks and the numbers tasks in this experiment. Both tasks demand the same transformation and none of them would cause sense load when performed simultaneously with a shadowing task.

The amount of deterioration in the performance due to processing load can be measured by subtracting the RT in the control condition from the RT in the experimental condition within each task.

From Figure 3.4 it can be seen that for both tasks the difference in RT was almost identical (69.20 m.sec. and 66.32 m.sec.).

This is true despite the fact that the numbers task is an easier task to perform. It is easier probably because the stimuli in the numbers task are composed of single digits and therefore are quicker to encode than the words which are composed of several letters. Probably also because we have more experience in using numbers in the form of digits than in the form of words.

It is further argued that the deterioration in performance due to the processing load is equal in each matched pair of tasks (i.e. visual and auditory tasks and pips and lines tasks), because each pair of tasks demand the same transformations.

3.4.5 (Continued)

In the case of the two words tasks there is no doubt that the two tasks demand the same transformation. The auditory words task suffered a greater deterioration than the visual words task, because in the time-sharing situation it brings additional sense load.

In the case of the lines and pips tasks, the two demanded transformations cannot be said to be identical. However, it can be argued that when each of them is simultaneously performed with a shadowing task, the higher level programs which need to control and co-ordinate their activities are, for practical purposes, the same. In other words, the lines task and the pips task cause similar processing load when time-shared with a shadowing task. The pips task further deteriorated due to the sense load.

If all the above is correct the following formula applies:

(RT aud. word exp. - RT aud. word cont.) - (RT vis. word exp. - RT vis. word cont) $\stackrel{?}{=}$ (RT pips exp. - RT pips cont.) - (RT lines exp. - RT lines cont.).

In theoretical terms the above can be expressed in terms of the differences in load between the control and experimental conditions:

auditory words task = processing load (words) + sense load
\-
visual words task = processing load (words)
____
= sense load

pips task = processing load (pips) + sense load
\-
lines task = processing load (lines)
____
= sense load

3.4.5 (Continued)

where processing load (pips) $\approx$ processing load (lines).

The justification of this argument lies within the predictions of the hierarchical model. According to the model the peripheral system operates in a fairly fixed and pre-programed manner with very few degrees of freedom. Because of this very mechanical manner of operation, it is possible to argue that the sense load is uniform. In other words, the sense load is independent of the particular stimuli used. This is analogue to a computing system which has to read paper tapes or punched cards. The tapes or cards are read at a steady rate regardless of what is punched on them. If the message is complicated it will require more processing time, but not more reading time.

Therefore, when each of the tasks is time-shared with a shadowing task, the difference in performance deterioration between visual words and auditory words is equal to the difference in performance deterioration between lines and pips.

The data for the calculation is extracted from Table 3.5 or Figure 3.4. The differences between the words tasks is 107.46 m.sec., while the differences between the pips - lines tasks are 125.74 m.sec. (176.66 - 69.20 = 107.46 m.sec.; 205.60 - 79.86 = 125.74 m.sec.). This is a very good fit considering the fact that pips and lines are not <u>identical</u> tasks but only <u>similar</u> tasks, and taking into account the fact that the RT is widely recognized as a 'noisy' measurement (the overall mean RT of 525.01 m.sec. has a standard deviation of 179.68 m.sec.).

3.4.5 (Continued)

Another possible mathematical deviation from the above argument can be carried out not by subtracting the two sets of differences, but by finding a ratio between them. In other words:

$$\frac{\text{(RT aud. word. exp. - RT aud. word. cont.)}}{\text{(RT vis. word exp. - RT vis. word cont.)}} \stackrel{?}{=} \frac{\text{(RT pips exp. - RT pips cont.)}}{\text{(RT lines exp. - RT lines cont.)}}$$

As a result of the calculation it is found that:

$$2.553 \approx 2.574$$

This is also a very good fit (the difference is less than 1%).

From Figure 3.4 it can also be seen that the differences between control and experimental conditions for the lines task is slightly bigger than the difference for the visual words task or for the numbers task. It can also be seen that similar results are found for the auditory tasks. This means that probably the lines and pips tasks are slightly more difficult to control and co-ordinate, than the words tasks when each of them is time-shared with a shadowing task.

It is important to bear in mind that the amount of control and co-ordination in a simultaneous time-sharing situation is independent from the amount of processing required by the individual tasks. In other words, the question how difficult it is to control and co-ordinate two simultaneous tasks, is not connected to the question how complicated is each of these tasks.

Therefore, it is quite possible that to co-ordinate between a shadowing task and any of the words or numbers task is slightly easier (i.e. less time-consuming) than to co-ordinate between a shadowing task and the lines or pips tasks.

3.4.5 (Continued)

The reduction of the difference ($\Delta\bar{X}$) in the visual words task from the difference in the auditory words task (i.e. $\Delta\bar{X}$ aud. word - $\Delta\bar{X}$ vis. word) yields a very close result to a similar manipulation with pips and lines tasks ($\Delta\bar{X}$ pips - $\Delta\bar{X}$ lines). These results of 107.46 m.sec. and 125.74 m.sec. calculated above, give an indication of how much additional time is consumed by the sense load.

As it can be seen from these results the sense load is much bigger in this experiment than the multi-functional processing load. The ratio between sense load and processing load can be calculated in the following manner:

$$\frac{(\Delta\bar{X}\text{ aud. word} - \Delta\bar{X}\text{ vis. word})}{\Delta\bar{X}\text{ vis. word}} \approx \frac{(\Delta\bar{X}\text{ pips} - \Delta\bar{X}\text{ lines})}{\Delta\bar{X}\text{ lines}}$$

$$1.553 \approx 1.574$$

$\Delta\bar{X}$ auditory words contain processing load + sense load

$\Delta\bar{X}$ visual words contain only processing load

The same logic applies to pips and lines tasks. Therefore, the sense load is about 1.5 times bigger than the processing load in this experiment. The interesting question of course is whether this ratio applies to other situations. At present it is very difficult to give a decisive answer to this question due to the lack of experiments and data in this subject. However, it is very likely that the answer is negative. The sense load varies probably only slightly in terms of time-consumption, while the dynamics of the processing load is quite different. It mainly depends on the control and co-ordination between the two transformations, and therefore it has many more possible variations. Thus, the ratio between sense load and processing load

3.4.5 (Continued)

found in this experiment is not uniform and is expected to vary from one situation to another. It did not vary much in this experiment, probably because of the fact that the processing loads of words, pips and lines tasks were very similar.

3.4.6 Comparison with and evaluation of other experiments

The results of this experiment are in a way similar to the results obtained by Glucksberg (1963). He used a two task situation in which a secondary task could be presented via the same sense modality as the primary task, or via one of two different sense modalities. The primary task was a visual pursuit task, the secondary was a simple or choice response presented either visually, auditorily or cutaneously. The performance of the primary task was deteriorated in comparison to a control condition - when time-shared with the visual secondary task. The secondary task was also deteriorated as compared to a control condition. However, the strongest deterioration occurred when it stimulated the visual sense.

The results of this experiment are also compatible with the finding of two recent experiments carried out by Rollins and Thibadeau (1973) and Flaherty and Coren (1974).

In their experiment, Rollins and Thibadeau, used four types of tasks:

1) Auditory words
2) Visual words
3) Pictures of these printed words and
4) Pictures of fictitious objects which were difficult to label.

They found a significant deterioration in the first three tasks when each of them was performed simultaneously with a shadowing task, as compared with a non-shadowing condition.

3.4.6 (Continued)

They did not employ a control condition in which the subjects performed each of the RT tasks individually. Instead they had a non-shadowing condition in which the subjects had to 'listen to the message'. There is obviously no way to tell whether the subjects did or did not really listen. The writer is of the opinion that they should have used an additional control with individual performances, for controlling their non-shadowing condition.

Rollins and Thibadeau found that under non-shadowing conditions, subjects receiving words auditorily recognized as many items as did subjects receiving words visually. This in a way corresponds with the finding of this experiment that the RTs for visual and auditory words tasks were almost identical in the control condition (Table 3.5).

They also found that the interfering effects of the shadowing task were much larger for words presented auditorily than for words presented visually. This is again compatible with the findings of this experiment.

They conclude that when subjects attend to one auditory message, they have no permanent memory for a second message received simultaneously. This is not true even according to their own findings! They also found some processing of two simultaneous auditory messages. The difficulty in processing two simultaneous auditory messages, in their experiment, is due to the type of load imposed by the tasks and not to a general human inability as they claim. Rollins and Thibadeau have difficulties in interpreting the results of their experiment and they rely in their explanations mainly on a model developed by Atwood (1971). This model will be referred to later in this thesis.

3.4.6 (Continued)

In terms of the hierarchical model their findings are easily explained. The greatest deterioration, in the shadowing condition, occurred with auditory words. They measured the deterioration in differences in d' (i.e. changes in sensitivity according to signal detection theory). They found a difference in d' of 2.03. This great deterioration is due to sense load + single function and multi-functions processing loads.

According to this model the deterioration in both the visual words and the pictures of these words is due to single function and multi-function processing load. In this case the deterioration should be much smaller than that of auditory words. Furthermore, both the visual words and their pictures should deteriorate by the same degree. Indeed the former deteriorated by 1.23 (d') and the latter by 1.15 (d').

The least deteriorated task should be the 'fictitious characters task' which together with the shadowing task causes only multi-function processing load. The results show only a slight deterioration of 0.38 (d').

The findings of this experiment are also consistent with the findings of Flaherty and Coren (1974). They found that the RT for tones are shorter than the RT for auditory words when each of these tasks is simultaneously performed with a shadowing task. Similar results were found in this experiment.

Two main conditions were employed in their experiment. A 'divided attention' condition in which the subjects had to detect target words or tones simultaneously in both ears, and an 'attention' condition, in which the subjects had to shadow one ear and still carry out the two

3.4.6 (Continued)

simultaneous detection tasks. The two investigators hypothesized that "there should be no difference between the shadowed (attended) condition and the divided attention". This odd hypothesis was not sustained by their results (in m.sec.):

Condition	Stimulus	
	Tones	Words
Divided attention	462	718
Attention	561	790

They did not find a significant difference between 'divided attention' and 'attention' for each of the stimuli. However, according to the hierarchical model the load due to the attention condition is greater than the load due to divided attention. The former is composed of the latter plus a shadowing task. Therefore, the performance in the attention condition should be worse than the performance in the divided condition. Indeed their results suggest so. The lack of significant results does not demonstrate equality. Probably if the results of the tones and words were pooled, the test would have yielded significant results. The experimental effect may be quite weak, but it cannot be zero as Flaherty and Coren argued, and certainly not reversed as they have indirectly hinted.

The writer does agree with their final point about the usefulness of RT as a measure of selective attention and the importance of stimulus type as a possible factor which influences the performance.

3.4.7 Summary

To summarize, the outcome of this experiment suggests that:

1) There is a deterioration in the speed of performance in simultaneous time-sharing.

2) The performance of two tasks which stimulate the same sense modality deteriorate more than the performance of two tasks which stimulate different sense modalities.

3) This deterioration occurs both in speed of performance and in number of errors.

4) The sense load is uniform and causes the same amount of speed deterioration regardless of the type of transformation demanded by the tasks.

5) In this experiment sense load is estimated to cause 1.5 times more deterioration in the speed of the performance, than multi-function processing loads.

6) The results indicate that the use of words as stimuli in simultaneous tasks does not cause deterioration in the performance.

4.0 DISCUSSION

The aim of this study is to gain further understanding of the way in which the human information processing system operates in general and in time-sharing situations in particular.

The proposed model for information processing has two main features: specializing functions (programs) and a hierarchical structure. In order to test the model in any time-sharing situation it is necessary to manipulate these two main features.

The representation of the theoretical notions in operational terms divides the hierarchy into two levels, a lower and a higher one. Each of these two levels is in turn composed of other levels.

The lower levels are determined by the sense modality which is stimulated by the task. The higher levels functions are determined by the transformation demanded by the task. In other words, the higher levels are determined by what has to be done in the task, or in information processing terms, by the particular processing which is needed.

In operational terms, the model can be studied in four different combinations of time-shared tasks:

1) The sharing takes place between two different sense modalities and two different transformations (i.e. both lower and higher levels are different).

2) The sharing takes place between the same sense modality and the same transformation.

4.0 (Continued)

3 & 4) The sharing takes place either between the same sense modality and different transformations, or vice versa.

Time-sharing itself is not a specific situation, but a continuum of possibilities ranging from the need to share simultaneously a given period of time, to the need to share it successively.

It can be argued that by studying the two extreme situations it is also possible to gain some knowledge about the intermediate situations. These situations are probably composed of varying degrees of the two extremes. However, the writer thinks that these intermediary time-sharing situations should also be studied on their own.

The above four types of time-shared tasks can be studied in both simultaneous and successive time-sharing. The simultaneous situation is a classical way of studying time-sharing, the successive tasks which were never used before. Therefore, in this study, more experiments were devoted to the investigation of successive time-sharing.

This discussion contains a brief review of the main findings in this study. Since in simultaneous time-sharing not all four possibilities were studied, the discussion includes a section which reviews the typical findings of other investigators, classified according to the four different groups. The classification, however, is made according to the various types of load derived from the model.

4.1 The model and supportive experimental evidence

Figure 4.1 sums up the various conditions under which time-sharing took place and the various factors which influenced the human performance in these conditions.

As it can be seen from Figure 4.1, the two main types of time-sharing were successive and simultaneous. According to the proposed hierarchical model, successive time-sharing is easier to perform than the simultaneous one. In a successive situation the operator performs only a single task at each given moment, while in a simultaneous situation there is more than one task to be performed.

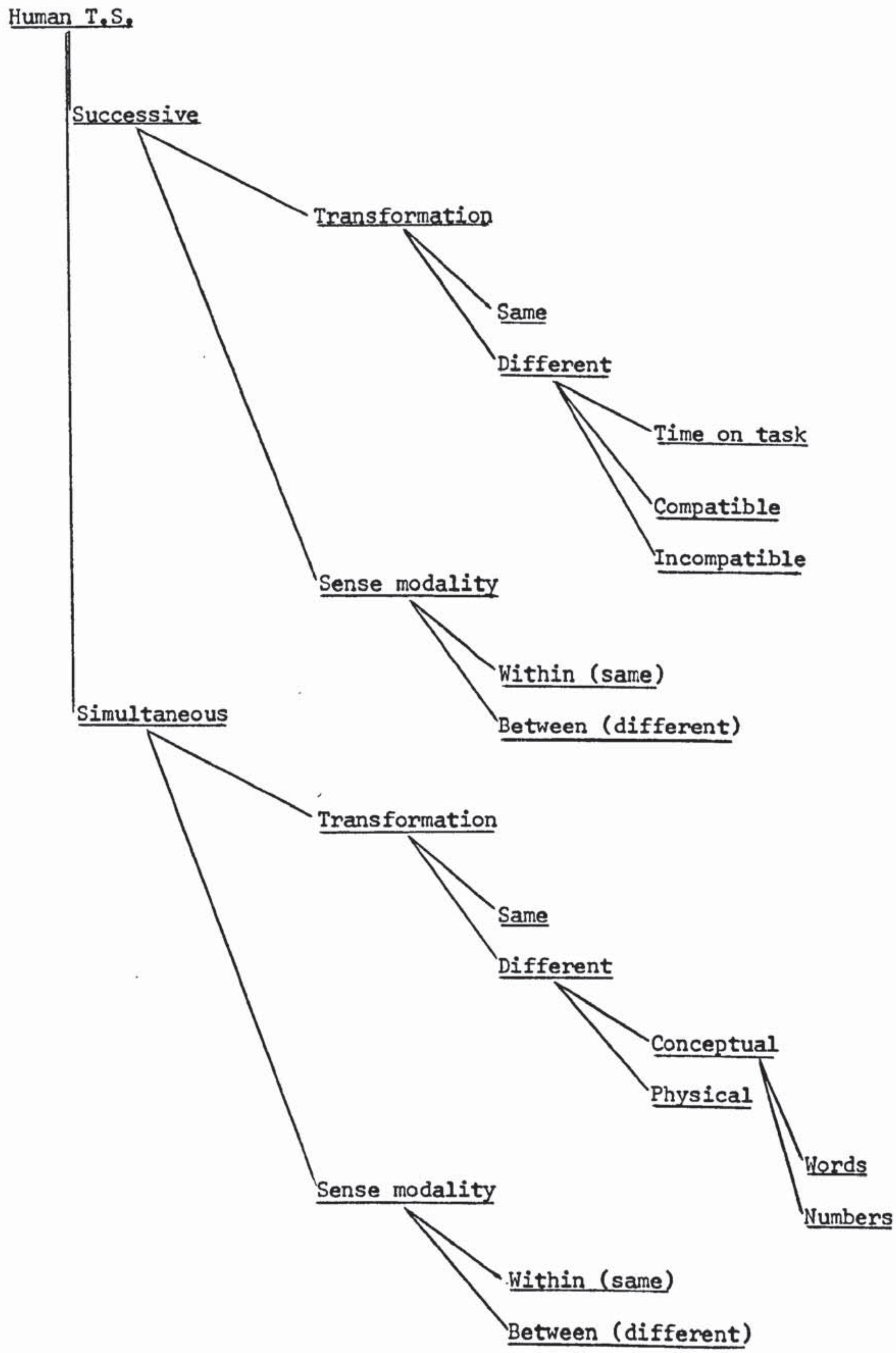
Both types of time-sharing are influenced by the two main factors employed in this study - transformation and sense modality.

According to the model, transformation has a stronger impact that sense modality, on both types of time-sharing, because it activates the higher levels of processing.

Setting up the higher levels takes longer than setting up the lower levels. Therefore, it can be argued that in successive time-sharing the need to switch between different transformations rather than between the same transformation, consumes more time than the need to switch between (different) sense modalities, rather than within a sense modality.

This argument is demonstrated in the experiment described in section 2.3.

Figure 4.1 Plan of experimentation



4.1 (Continued)

In analysing the data of the experiment the common task of visual words was separated from all the other tasks and thus provided a common ground for comparison. Table 2.3.15 (section 2.3) shows that the difference between RT to the first stimulus in a series, and RT to the rest of the stimuli in that series (i.e. $\Delta\overline{X}$ diff.) for same transformation, was 93.594 m.sec., while for different transformations it was 136.973 m.sec. Each of the differences provides some measurement of the amount of time consumed by the need to successively time-share (at a later stage it will be explained why the differences are only 'some measurement' of time-sharing).

The difference between the two results (136.973 - 93.594 = 43.379 m.sec.) provides some measurement of the difference between same and different time-shared transformations.

A similar calculation can be carried out for sense modality (124.135 - 106.432 = 17.703 m.sec.). The ratio between the two sets of calculations ($\frac{43.379}{17.703}$) is almost 2.5. In theoretical terms this ratio indicates that switching between higher levels is much more time-consuming than switching between lower levels. In operational terms this ratio means that setting up the higher level programs for a visual words task will probably take 2.5 times longer than setting up the lower level programs.

This ratio is not uniform. Setting up higher level programs is a function of the complexity of the demanded transformation. If the transformation is difficult, then there are more complex programs to

4.1 (Continued)

be set-up and this consumes more time than setting up simple programs. The lower level programs are mainly simple, and presumably setting up one type of program or another consumes almost the same amount of time.

Although the above ratio is not uniform, the model predicts that it will always be longer than unity. In other words, the ratio between switching higher level programs and low level ones will always be greater than 1.00. Quite likely, in very simple tasks it will approach unity.

This ratio, calculated for 'all the other tasks' (data from Table 2.3.16) is found to be slightly over 3.00. It should be remembered that in this case there are four completely different tasks, which demand different transformations and stimulate different sense modalities.

Transformation was also found to carry a greater weight than sense modality in the intersecting situation, when both factors can be manipulated together as well as individually.

The question as to which factor is more influential, transformation or sense modality, can also be asked with respect to simultaneous time-sharing. The hierarchical model predicts that transformation is the more influential of the two.

This aspect was not tested in the experiments carried out in this study. In fact the two simultaneously time-shared tasks always demanded different transformations. However, it can be studied by

4.1 (Continued)

using the findings of other investigators.

The fact that man cannot handle two simultaneous messages was studied when both messages stimulated the same sense modality (e.g. Cherry (1953); Kahneman (1973); Moray (1959, 1969b); Moray and O'Brien (1967); Mowbray (1964); Peterson and Kroener (1964); Shaffer and Hardwick (1969); Treisman and Geffen (1967, 1968)), or different sense modalities (e.g. Mowbray (1953, 1954, 1962)). In both cases the simultaneous performance was not successful. In the former case, both time-shared tasks stimulated the same sense and demanded the same transformation, but in the latter case they still demanded the same transformation only through different sense modalities.

Finally most investigators who succeeded in demonstrating simultaneous performance, did so by employing tasks which demanded different transformations, whether stimulating the same (e.g. Broadbent (1956); Herman (1965); Ninio and Kahneman (1974); Treisman (1970); Treisman and Fearnley (1971), or different (e.g. Lindsay (1970) for review; Lindsay, Duddy and Tulving (1965); Tulving and Lindsay (1967)) sense modality.

This is a further demonstration that transformation mainly determines the ability to time-share, while sense modality plays only a secondary role.

Transformation is also the influential factor in determinating whether two tasks are similar or different from each other.

4.1 (Continued)

According to the hierarchical model different tasks are relatively easy to simultaneously time-share between, but relatively difficult to successively time-share between; while similar tasks are relatively difficult to simultaneously time-share but relatively easy to successive time-share. This is so because in successive time-sharing there is a need to set-up all the necessary programs for the new task. If part of these programs were used in the previous task then there are less programs to set-up, and less time is consumed on sharing. In simultaneous time-sharing two very similar tasks require to be processed by common programs and their signals have to travel along many common pathways. These programs or pathways behave as a single channel. In other words, each program can process only one signal at a time, and through a particular pathway signals have to travel in succession.

Therefore the more identical the tasks, the easier (quicker) is the successive time-sharing, but the more difficult is the simultaneous time-sharing. From a theoretical point of view, identical tasks consume zero time in successive sharing, and infinite time in simultaneous sharing. In practice, successive sharing is very easy while simultaneous time-sharing is very difficult.

In both simultaneous and successive time-sharing the similarity between the shared tasks is mainly determined by the type of transformations they demand while the stimulated sense modality plays only a small part.

From a theoretical point of view, sense modality - the lesser influential factor - is less interesting to manipulate than transformation. Therefore sense modality undergoes only two levels of manipulation - 'within' and 'between' (Figure 4.1) while the influence of transformation is

4.1 (Continued)

investigated further.

The condition 'different transformation' enables a range of possible investigations of both types of time-sharing.

In successive time-sharing it is possible to investigate the degree to which the compatibility between two different transformations influences the consumption of time in the sharing process.

This experimental manipulation is a very fine one, since whenever the successive transformations are time-shared, the previous programs have to be stored away while the following ones are being set-up. This operation takes place regardless of the degree of compatibility between the two transformations. However, compatibility is hypothesized to have a limited influence on the time consumed by the above operation. The difference between the compatible and incompatible conditions was found to be significant (Table 2.2.1). As hypothesized, the overall estimated experimental effect was found to be very low (less than 2%). The difference in time-consumption was found to be about 47 m.sec. for the lines task and 40 m.sec. for the numbers task.

It should be mentioned that the study of compatibility was initially meant to investigate the relationship between stimulus and response (Fitts and Seeger (1953); Fitts and Simon (1952); Fitts and Deininger (1954)). In other words, it was, and still is, the study of relationship <u>within</u> tasks. In this study the concept was broadened so as to include the relationship <u>between</u> tasks.

4.1 (Continued)

It is possible to generalize by arguing, that the outcome in both cases is similar, in so far as whenever an operator is faced with a compatible situation his performance is better than otherwise.

The last experiment to be discussed in the context of successive time-sharing is concerned with the duration of performance before the sharing takes place (Figure 4.1). The more we perform a particular task, the more skill we gain in performing that task, so that the internal programs needed for it become more efficient. At the same time they are also reinforced and become habits, so that switching away from such a task becomes more difficult, or more time-consuming (Figure 2.1.6). Indeed the very first experiment carried out in this thesis (section 2.1) studied the influence of time spent on previous tasks (measured as the number of trials) on the time consumed on the sharing process. It was found that the longer the series the longer is the time consumed by the sharing process, and the longer is the magnitude of the experimental effect - as it can be seen from Table 2.1.1.

The consumption of time and thus the experimental effect was always slightly larger for the lines task than for the numbers task. This is so because the lines task is easier than the numbers (the 'rest' - in lines is always shorter than the 'rest' in numbers). Being an easier task, its programs are less complex and thus they require less time to become habits. A complex task takes longer to learn and longer to become a habit.

4.1 (Continued)

The next step, after having looked at the findings concerning different transformations in successive time-sharing is to look at the findings of different transformations in simultaneous time-sharing.

Two main transformations were used (section 3): a conceptual one (i.e. the various numbers tasks) and a physical one (i.e. lines and pips tasks). Each of these transformations (tasks) was shared with a third task.

From Figure 3.4 it can be seen that the physical transformation tasks deteriorated slightly more than the conceptual transformation tasks. Accordingly, the magnitude of the experimental effect in the physical transformation tasks is larger by about 50% - 65% than the effect in the conceptual transformation tasks (Table 3.10). This means that the physical transformation tasks are slightly more difficult to control and co-ordinate when time-shared with a shadowing task.

A further hypothesis which was tested regarded the choice of stimuli. The theoretical question was whether the use of the same type of stimuli for both tasks caused a further deterioration in the simultaneous performance.

The hierarchical model predicts that the important factor in deterioration of performance is the demanded transformations, not the choice of stimuli.

In order to test this hypothesis, the conceptual transformation was divided into a numbers task - which used visual digits as stimuli, and

4.1 (Continued)

a words task - which used visual words as stimuli. Words were also used in the shadowing task.

The numbers and visual words tasks deteriorated to almost an identical degree (Figure 3.4) when simultaneously performed with the shadowing task. This was expected, since both demanded an identical transformation. The fact that the words task did not deteriorate further means that the common type of stimuli (i.e. use of words) does not have any impact.

One of the major outcomes of the fourth experiment (section 3) is connected with sense modality. In recent years several experimenters have found that detecting and processing simultaneous targets or messages on the same modality is more difficult that processing simultaneous targets or messages on different modalities (see Kahneman (1973) for review). These were also the conclusions of the fourth experiment. However, the outcomes of this study are more far-reaching. In principle the sense load in a simultaneous presentation is the same, regardless of the particular stimuli used. In other words, the deterioration of performance due to the fact that two simultaneous tasks stimulate the same, rather than different sense modalities, is theoretically the same, whatever the stimuli used. In practice we should expect to find small variation in the sense load.

Unfortunately, it is impossible to bring substantiated evidence from other studies mainly because they were not designed to test this hypothesis, or did not use RTs as the dependent variable.

4.2 Typology of load in the light of existing literature and the present study

The typology of load is an important link between the proposed model and its predictions with regard to simultaneous time-shared performance. Two types of load are of particular interest: processing load and sense load. The processing load is always present in simultaneous performance, either in its relatively less loading version (of multi-functions) or in its more loading version (of single function). The sense load is present only when both tasks stimulate the same sense modality (Table 4.1).

The numbers in Table 4.1 are arranged according to the amount of deterioration expected in simultaneous performance due to the combination of loads. Most of the deterioration is expected to occur in no. I while no. IV is expected to deteriorate least.

Table 4.1 Load and simultaneous time-sharing

		Sense load	
		Yes	No
Processing	Single	I	II
Load	Multi	III	IV

The model gives a wide span of predictions, some of which have been tested in this study. Others can be tested through the findings of other experimenters.

4.2 (Continued)

The findings of this study cover only the area of multi-function processing load either with or without sense load. However, all the four categories will be looked at in this discussion. Examples of typical experiments in each category are given and explained in terms of the functional hierarchical model.

I Single function - sense load

This is a very effective combination of load which causes the greatest degree of performance deterioration. In such situations the operator is expected to simultaneously perform two identical or very similar tasks.

Most of the investigators who applied this combination of loads accepted the single channel hypothesis. Their typical experimental design usually required the subject to shadow one message while simultaneously being exposed to another 'irrelevant' message (e.g. Cherry (1953); Broadbent (1952, 1958); Moray (1959, 1969a, b); Mowbray (1964); Treisman (1960, 1964a, d)), or he is expected to detect target words in both messages usually while monitoring one of the messages (e.g. Bloomfield (1972); Broadbent and Gregory (1964); Kahneman (1973); Ninio and Kahneman (1974); Moray and O'Brien (1967); Treisman (1970); Treisman and Fearnley (1971); Treisman and Geffen (1967); Treisman, Squire and Green (1974)). The detection of pure tones in both ears was also used in studying attention (e.g. Moray (1970a, b)) and so was the simultaneous visual stimulation (e.g. Sampson (1964); Sampson and Spong (1961a, b)).

4.2 (Continued)

The typical trend of their findings is the inability to process both messages simultaneously. Usually the irrelevant message was completely, or almost completely ignored. The detection of targets (words or tones) in the message was very poor.

These findings are predicted by the hierarchical model: a combination of single function and sense loads causes the two messages to be processed in serial order. This is according to the hypothesis put forward by the model that only one signal at a time can pass through a particular pathway or processed by a particular program. Since one of the messages is irrelevant or perceived by the subjects as less important, its processing is greatly impaired. It is only partially processed, at opportune times.

II Single function load

In this situation there is only a processing load without a sense load. Although this is a less loading situation than the previous one, a massive deterioration in the performance should still be expected.

There are very few experiments which qualify to be included in this section. The experiment should involve the performance of two very similar tasks which stimulate two different sense modalities. Receiving two messages divided between two sense modalities (e.g. Greenwald (1970a, b); Mowbray (1953, 1954); Treisman and Davies (1972)) usually falls in this category.

4.2 (Continued)

The typical findings on these experiments are that the performance of two identical tasks stimulating different sense modalities is greatly impaired, although it is less impaired than when the two tasks stimulate the same sense modality. This last conclusion was also confirmed in other experiments, using not identical but very similar tasks (Kroll et al. (1970); Mowbray (1964); Parkinson (1972)).

These findings are consistent with the predictions of the hierarchical model. Whenever two simultaneous tasks demand the same transformation there should be a great deterioration in performance. This deterioration should be smaller if the tasks stimulate different senses, than when they stimulate the same sense and cause an additional sense load.

III Multi-functions - sense load

In this situation two different tasks stimulate the same sense modality. In theory this is a less loading situation than the previous one. The processing load, which is the more dominant type of load is reduced from single to multi-load. This should make time-sharing easier, even though there is an addition of sense load which was absent previously. In practice there may be variations from this prediction. For example, two very complex tasks which stimulate the same sense modality and also need a complicated higher level program for control and co-ordination, may be as difficult to perform simultaneously as two identical but very simple tasks which stimulate different sense modalities.

4.2 (Continued)

This combination of load was used in studying attention (e.g. Wright, Holloway and Aldrich (1974)) but it was mainly used in estimating the mental load by using the secondary task technique (Bahrick and Shelly (1958); Benson, Huddleston and Rolfe (1965); Day (1953); Olson (1963); Poulton (1958); Schori (1973); for review see Rolfe (1971a)).

The typical findings of these experiments include the deterioration in the performance of one of the tasks, usually the secondary task, which is presented as the less important of the two. In most experiments belonging to this category, it is possible to argue that both tasks, although deteriorated, were actually performed, while in the previous categories one of the tasks was rarely performed at all.

These results, according to the predictions of the hierarchical model, which claims that two tasks which demand different transformations, can be processed in parallel. However, the need to control and co-ordinate the two processing functions will cause deterioration in the performance. The fact that the two tasks stimulate the same sense modality causes a further deterioration in the performance. Although usually the single function load caused by two identical tasks is far greater than the multi function load.

IV Multi-functions load

Out of the four possible combinations of load discussed here, this is the easiest combination. Theoretically, simple tasks which need very little control and co-ordination can be time-shared with very little, or even no impairment in a simultaneous performance. However, in most experiments simultaneous performance does not seem to be as good

4.2 (Continued)

the individual, even when the investigators cannot find a significant difference between them (Allport, Antonis and Reynolds (1972); Rollins and Thibadeau (1973)).

This type of load has been widely used in the study of attention, especially by investigators who oppose the single channel hypothesis (e.g. Allport, Antonis and Reynolds (1972); Peterson (1969); Tune (1964); Wright, Holloway and Aldrich (1974)).

The typical findings of these experiments show that the two simultaneous tasks can be carried out simultaneously with very little or almost no deterioration in either performance.

These results are consistent with the predictions of the hierarchical model. The multi-function processing load makes it feasible to carry the two transformations in parallel. In cases where the two transformations are not very complex and the co-ordination between them is quite simple, there is almost no deterioration in the simultaneous performance (Allport et al. (1972); Tune (1964)). In more complex cases the deterioration, in simultaneous as compared to the individual condition, is marked (Peterson (1969)).

In some cases, simultaneous performance is superior to individual performance. For example Adams and Chambers (1962) found that the response to certain visual events in their bisensory task was actually superior to their unisensory visual control group. This was because the RTs to the visual stimuli were shortened to the length of the

4.2 (Continued)

faster response made to the accompanying auditory stimuli. When events were uncertain, the RTs were reduced in speed and synchronized with the slower visual response time. Similar findings were reported by Morrel (1968) and Bernstein, Clark and Edelstein (1969a, b).

In terms of the hierarchical model the two transformations were carried out in parallel. In this specific condition, once the processing of the auditory stimulus was completed, the responses followed. The fact that auditory stimuli takes less time to respond to than visual stimuli is well-known (see Woodworth and Schlosberg (1954), for review). Therefore, it appears as if the processing of the visual stimuli was shortened. In the uncertain condition it appears as if the processing of the auditory stimuli was lengthened. According to the hierarchical model, both processing times did not alter, only the simultaneous responses were synchronized.

The multi-function load was also widely used in the study of mental load (e.g. Bahrick, Noble and Fitts (1954); Brown (1965, 1966); Brown and Poulton (1961); Brown, Simmonds and Tickner (1967); Garvey and Knowles (1954); Garvey and Taylor (1959)).

The investigators employing the secondary task technique usually argue that variations in the difficulty or complexity to process one task directly, cause variations in the spare capacity available for processing the other task. In other words, the multi-functions load is caused only by the two programs which are needed to process the two transformations.

4.2 (Continued)

This is not the case according to the hierarchical model. Varying the complexity of one of the transformations also varies the complexity of the higher level program which controls and co-ordinates the activity of the two processing programs. The variations in the higher level program were neither known nor estimated in the above experiments. Thus the variations in the performance of the secondary task are not good estimations of the so-called mental load imposed by the primary task.

If only slight variations are made in the complexity of the primary task, then probably only minor variations are caused in the higher level program. If this is so, then the variations in the performance of the secondary task might give some indication to the load imposed by the change in the complexity of the primary task.

4.3 The model and its compatibility with other theoretical approaches

This section reviews a number of theories which cannot be called attentional in the classical sense. Yet they may have an impact on the study of attention in general and this thesis in particular.

The writer has preferred to present them in this context, so that they would be appraised in the light of the hierarchical model and experiments described in this study.

4.3.1 The first theories to be reviewed represent what the writer calls the 'multi-memory approach'.

1) Brooks (1968) offers an interesting presentation of the interference between the modality of the response and the modality of the input that controls the response. His research has, for example, shown that when a person is recalling a sentence he is restricted in the type of articulate output he can use concurrently in order to signal information about that sentence. Or, for example, when a person is recalling a diagram, he is restricted in the type of spatially monitored output he can concurrently use. So that recall of verbal information is readily disrupted by concurrent vocal activity but not by spatial-visual activity, while recall of spatial-visual information is disrupted more by spatial activity than by vocal activity.

Brooks (1967, 1970) also shows that reading and visualization are mutually interfering.

4.3.1 (Continued)

Even though the hierarchical model is mainly concerned with the part of the system which receives information, it also recognizes the importance of the part which is involved in executing the decision taken by the central processor. What Brooks has so elegantly demonstrated is the existence of load throughout the system. As a conclusion from his study, as well as from others, it can be argued that various types of load exist between any concurrent activities, whether externally generated (simultaneous time-sharing between two external tasks) or internally-externally generated (simultaneous time-sharing between a recall task and a concurrent task).

Following this logic one step further, it is probably fair to argue that two simultaneous internally generated tasks - such as recall - also cause load and thus mutual disruption.

Bower (1970) and Atwood (1971) have pursued Brooks' line of research assuming independent and parallel processing of visual and verbal inputs with modality - specific but interacting memories.

2) Atwood (1971) suggests a model in which an independent visual system controls visual perception and visual imagination, while a verbal-auditory system controls auditory perception, auditory imagination, internal verbal representation, and speech. The two systems are functionally linked so that a word presented auditorily may be transformed for storage in the visual system, and a word presented visually may be transformed for storage in the verbal-auditory system.

4.3.1 (Continued)

Under normal conditions, a particular word or phrase could be stored in both systems regardless of input modality. However, if the verbal-auditory system is occupied by the simultaneously performed task then the storing and the recall of that word would be impaired. This is due to the fact that only the visual system is in operation, and therefore the information is only stored in one system rather than the two.

This theory explains very well some of the findings of simultaneous time-sharing studies. In particular those which are results of stimulating same or different sense modalities. Its predictions are qualitative with no attempt of quantification. Even so it has the ability to provide explanations in an area in which most of the traditional attentional theories have no hypotheses or suggestions to offer.

However, the process suggested by Atwood is uneconomical since it advocates the storage of every signal in two duplicates, one in each memory. The theory only deals with two sense modalities, but what happens to the others is not known. The auditory storage of purely visual experiences and vice versa is quite dubious.

The main fallacy of his model lays in its predictions of simultaneous time-sharing with no sense load. The model predicts that when one of the systems is occupied by one task, the memories of the first task can only be recollected by one system, rather than the two. If this is so, then tasks shared by cross modalities should create the same impairment as tasks shared when the same sense modality and this is

4.3.1 (Continued)

clearly not the case. Atwood could have argued that the duplicate complimentary memory is not as good as the original, but then it would have to be an extremely bad duplication to be able to explain the various findings.

The writer thinks that the hierarchical model enables all the predictions which Atwood's theory makes, but more precisely and without postulating duplicate memories. The term sense load enables to make various quantitative estimations about the performance. As it was demonstrated in this study these estimations were very accurate.

4.3.2 Information processing theories discussed in this thesis were mainly originated by researchers whose prime interest was in perception. However, attention is by no means the only area from which such theories were derived. The writer would like to give a short description of two other theories which resemble his own views in some aspects.

Models for cognitive abilities

1) Luria, who based his model on clinical examinations, (Luria (1966a, b, 1970); Luria and Tzvetkova (1967)) proposes that the processing of the cognitive content by the brain is accomplished through the employment of series on analysers. They seldom work in isolation but rather collectively synthesize input into various forms. Luria claims that this synthesis can be of two sorts, simultaneous and successive.

4.3.2 (Continued)

The simultaneous synthesis is of three varieties:

a) Direct perception where the organism is selectively attentive to the stimulus field. This type of formation is primarily spatial even in the case of the accoustic analyser.

b) Mnestic processes. This refers to the organization of stimulus traces for earlier experience. The stimulus traces can be either short-term or long-term, and the integration of the traces is performed on the basis of criteria which can be specified either by the organism or by an external source.

c) Complex intellectual processes.

Successive information processing refers to processing of information in a serial order. Here the system is not totally surveyable at any point in time. Successive synthesis has also three varieties: perceptual, mnestic and complex intellectual.

The writer agrees with the main points of Luria's model of serial and parallel synthesis and the three types of processing possible under them. Although Luria's model is based on psychophysiology, while the present model is based on attentional research, there are some similar aspects between the two. The programs in the present model resemble the analysers in Luria's model; the need to synthesize and the need to integrate are also similar. However, the present model refers to successive and simultaneous processing as the relationship <u>between</u> sets of signals, while Luria's model refer to them as relationship <u>within</u> the same set. Furthermore, Luria's approach to information processing is based on physiology with no reference to the integrated

4.3.2 (Continued)

human as reflected in attention and perception.

2) There is a variation of Luria's model, proposed by Das, Kirby and Jarman (1975), which is less acceptable to the writer than his approach. They propose a model in which the input can be presented in a parallel or in a serial manner. The information is registered and passed on for central processing. This registration is a buffer and works in parallel. It is then 'read out' serially into the central processing unit. Inconsistent with their proposals on the ways in which the central processor operaties, they proceed to propose a similar model to Broadbent's 'Filter Theory' (1958). There is a clear conversion from parallel to serial processing assisted by a short-term memory (S - system - according to Broadbent, and a buffer - according to Das, Kirby and Jarman), without the detailed account of capacity, switching time etc. They do, however, support the model, which is basically Luria's, with a number of factor analytic studies of cognitive abilities and related data from memory, imaginary and language studies.

Their model is based on Luria's and thus it bears some resemblance to the hierarchical model with a clear difference: their model is basically a single channel model while the present model is not.

4.3.3 'Perceptual readiness' theory

The term 'perceptual readiness' coined by Bruner (1957) hints to the dynamic process of perception advocated by him. He rejects the model based on template matching in favour of one that is more properly constructive. Perception depends upon the construction of a set of organized categories in terms of which stimulus inputs may be sorted, given identity, and given more elaborated connotated meaning.

Perceptual readiness refers to the relative accessibility of categories to different stimulus inputs. At any one time we are more ready to recognize some events than others. The main determinants of the perceptual readiness for a particular stimulus are the past frequency of its occurrence, its probability of occurrence in the momentary context, and its present significance to the individual.

The processes involved in sorting sensory inputs into appropriate categories involve the utilization of discriminatory cues. This varies from sensorially open cues searching under relative uncertainty to selective search for confirming cues under partial certainty, to sensory gating and distortion when an input has been categorized beyond certain levels of certainty.

Four general types of mechanisms are proposed to deal with the phenomena of perceptual categorization and differential perceptual readiness:

1) Grouping and integration - according to this theory, there are neural integrators whose operation is based on learned expectancies.

4.3.3 (Continued)

The moment-to-moment programming of perceptual readiness depends upon these integrators.

2) Access ordering - this denotes the ease or speed with which a given stimulus input is coded in terms of a given category under varying conditions of instruction, past learning and motivation.

3) Match-mismatch processes - the system operates in two modes, either all-or-none, in which the input fits or does not fit the required specifications; or in graded match-mismatch in which the system checks how good the fit between the input and the required specification is.

4) Gating processes - one of the mechanisms, operative in regulating search behaviour is some sort of gating or filtering system. The degree of openness or closedness to sensory input during different phases of cue utilization is effected by the gating processes.

The main points in Bruner's theory (1973) are an expectancy or hypothesis, information processing and checking. His approach is functional, concerned principally with the operation of perception and its manner of organization and selectivity.

His functional approach and his suggestion of flexible programs which can be replaced according to the various conditions are in a way comparable to the flexible programs which are part of this model. His ideas about grouping and integration are probably similar to the need to control, co-ordinate and integrate the activities of the programs, as advocated by the hierarchical model.

4.3.3 (Continued)

Bruner's model, although in some aspects quite detailed, does not always allow direct predictions. It also tends to lend itself to the fields of personality, developmental and social psychology, while the present model is basically a model of human information processing.

4.3.4 It is difficult to trace all the theories and the various concepts which helped in formulating the hierarchical theory. It seems that quite a considerable amount of effort has been invested in the field of attention since Broadbent presented his somewhat simplified but most elegant filter theory almost twenty years ago. Independently, Bruner (1957) had conceptualized his theory of perceptual readiness. His 'NEW LOOK' adopted the concept of programs and transformation of inputs (see Bruner (1973) for a collection of his major publications). In a parallel way Hochberg (1970) described perception as a confirmation of expectations.

The hierarchical model was also influenced by Miller, Galanter and Pribram (1960), especially from their analytical approach to behaviour as a set of objectives defined for each operation, tested and confirmed.

Neisser (1967, 1969) presented a very interesting theory which advocates that perception is an active process of analysis by synthesis. The present theory advocates that the higher programs have the task of controlling, co-ordinating, and integrating the activities of the lower programs.

Kahneman (1973) proposes an effort theory which postulates that the amount of capacity invested in a response varies with the change in the demands of the task. In terms of the present theory Kahneman postualtes a varying load due to the need to carry out transformations. It is a processing load imposed by a single transformation.

The comparison of man and machine had its philosophical roots long before the beginning of modern psychology. Many generations have

4.3.4 (Continued)

compared man to the most advanced machine at that time. Therefore, there is little wonder that the contemporary man is compared to the contemporary computer. Moray (1967) argued that man acts as a limited capacity processor in whom the programs occupy processing capacity. Hunt (1971) went one step further by claiming that the architecture and components of a computing system simulate the human information processing. The present author has also forwarded a few similar analogies between man and computing systems. He agrees with Moray that man acts as a limited capacity processor. Thus the hierarchical model is partially based on this idea. The multi-functions processing load can be viewed as the load on the central processor due to the fact that the programs occupy space.

The writer also agrees with some of the mechanical ideas of Hunt, such as the ability to monitor simultaneously several sensory paths, the allowance for interruption of data processing by a higher priority and the returns to orderly routine (successive time-sharing), or to his suggestion of program structure.

Treisman's filter-attenuation theory has quite a different approach from the hierarchical model. Even so, the writer would like to point at some similar aspects. The following passage is extracted from Treisman and Geffen (1967 p.3): "If we assume that speech perception is a hierarchical process, in which categorizations may be made at a number of different levels, such as the physical sound, ..., it may be possible for different responses to be selected and programed at different stages in the sequence rather than all being dependent on

4.3.4 (Continued)

its completion". This sentence shows some of the main points in the present model: the hierarchical structure, the various types of processing at each level, and the ability to carry out the processing simultaneously in all the levels.

4.4 Criticism and further research

It was mentioned earlier that the hierarchical model developed in this thesis tries to draw a complete picture of the human information processor in general and in time-shared situations in particular. Such a model rests not only on existing evidence but it also gives much room for many more studies to come.

Like all newly developed models, it is more qualitative than quantitative. Therefore, future research will have to make more explicit predictions and provide more numerical data.

It also needs more understanding of the influence of other factors, especially in time-sharing situations.

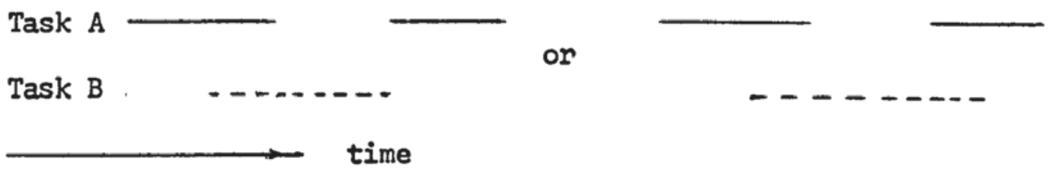
This section will only concentrate on a relatively small area of study of various time-sharing situations.

Time-sharing does not necessarily have to be either successive or simultaneous as it was categorized in this study. In practical situations it can be combined (Figure 4.2).

The operator performs task A while his attention is drawn to task B, so that he carries out both tasks simultaneously. When task B becomes very demanding he concentrates only on task B. Finally he either finishes task B and returns to A, or returns to A while still continuing with B for sometime.

4.4 (Continued)

Figure 4.2 Combined time-sharing



This combination of successive and simultaneous time-sharing ought to be studied on its own. The factors which influence this situation ought to be identified and thus relative influence on the ability to time-share studied.

The study of practice in time-sharing can be extended. It can be hypothesized that:

1) In successive time-sharing:

well practiced tasks are: - easy to start
- difficult to switch away from

not practiced tasks are : - difficult to start
- easy to switch away from

2) In simultaneous time-sharing:

well practiced tasks are: - easy to time-share between

not practiced tasks are : - difficult to time-share between.

Tasks can be categorized into easy and difficult tasks. The former has simple transformations while the latter has complicated ones. Therefore, successive time-sharing between difficult tasks consumes more time than between easy tasks. In simultaneous time-sharing, the difficult tasks are not easily time-shared, while easy tasks are.

4.4 (Continued)

It is also interesting to find out what happens in a mixed situation of easy and difficult tasks.

The study of easy and difficult tasks can also provide further understanding of the time-sharing process. For example it can provide information as to which operation consumes more time in successive time-sharing: the storage of old programs or the construction of new ones.

Compatibility can also be studied in simultaneous time-sharing. This may provide a comparison between compatible and incompatible conditions and thus provide more information about the higher level programs which control and co-ordinate the two tasks.

Prior knowledge as to when the switching from one task to another is about to occur may prove to be an important factor in successive time-sharing. Another important factor is the operator's ability to control the time of switching. In other words, whether the moment at which the time-sharing takes place is internally or externally controlled may determine the consumption of time in the sharing process.

If the operator controls the time, then he also has prior knowledge of the moment at which the switching takes place. If the timing is is externally controlled then:

a) The operator may know the exact moment.

b) The operator may not know it.

c) The operator may know that time-sharing will take place in the future, but he does not know when (which is the situation studied in

4.4 (Continued)

this research).

All these various conditions can prove to be influential and they are worth investigating.

Another theoretical problem which is worth pursuing with regard to successive time-sharing is the whole versus part programs set-up problem.

The hierarchical model assumes that the setting up of programs takes place prior to the processing of the information. The model also states that the processing of information takes place in 'n' stages - depending on the complexity of the information, the demanded transformation, its importance or centrality, the amount of practice in the task, and so on.

There are several ways in which setting up and processing can be combined:

1) All the stages are set prior to any processing operation.

2) The upper stages are set while the signals are being processed at a given stage.

3) Various combinations of these two possibilities.

According to the first possibility the RT to the first stimuli is composed of the 'normal' RT to the stimulus (RT to rest) plus time-sharing (the set-up time). If this is so, then:

4.4 (Continued)

Time-sharing = RT to first - RT to rest.

According to the second and the third possibilities the RT to first contains the RT to rest plus a part of the time-sharing. Therefore:

Time-sharing $>$ RT to first - RT to rest.

The present study did not attempt to answer this difficult theoretical problem. The answer probably does not lie with one 'crucial experiment', but requires a number of experiments with varying factors such as the degrees of practice in time-sharing, or the degrees of tasks complexities.

It should be stated that the first processing stage must be set before any processing activity can take place, regardless of whether the rest of the stages are set before or during the information processing. This means that RT to first is always longer than RT to rest.

The theoretical question about the combination of set-up and processing, does not affect any of the conclusions reached in this study. The question which remains unanswered is whether the notion 'first - rest' is the correct measurement of time-consumption in time-sharing, or whether it is only a partial measurement of it. At any rate, regardless of the answer to the above question the notion 'first - rest' is an unbiased estimation of the difficulty in successive time-sharing.

This account of possible further studies covers only some of the possibilities and not necessarily the most important ones.

4.4 (Continued)

This section cannot be expected to cover all the possible suggestions for further research connected with the hierarchical model. The suggestions mentioned here are only few in number and they are very much the writer's personal choice.

4.5 Final words

Finally, there are in principle two approaches to conduct research:

1) The development of ad hoc theories, which usually have a narrow basis for prediction, but are backed by experiments carried out in the research context and by the data provided by literatures.

2) The development of more complete and elaborate theories which are only partially backed by experimentation. Such theories aim to bring about more complete understanding of the area and to suggest far more hypotheses to study.

The writer has preferred the latter approach. This approach is less defendable than the former one, due to lack of data and findings to back it. It will take years before the writer, and hopefully others, will provide more substantial evidence which agrees, or otherwise challenges, the predictions of the model.

It should, however, be remembered that most of the main points have been demonstrated and the rest are at least in agreement with the general consensus in the area.

Theories and models are difficult to compare and evaluate. One of the criteria for doing so is to compare the number of postulations and the number of predictions which can be derived from the model.

This model mainly postulates a hierarchical structure of specializing functions. The rest of the assumptions are not crucial to the existence of the model, or else they are logical derivations from the main postulation.

4.5 (Continued)

On the other hand, the model has very good predictions for future research (as demonstrated in the experiments of this study), or the past (by explaining the findings of others).

Whether the model has a heuristic value, only the future can tell.

APPENDICES

APPENDIX IA   First experiment: stimuli

Lines stimulation - examples:

Numbers stimulation - examples:

8   5   2   3

APPENDIX IB First experiment: subject's instructions

Are you right-handed?

Do you see well?

You are participating in a reaction time experiment. The purpose of this experiment is to measure the required time for reacting to various stimuli. The stimuli will be presented to you in the device which is in front of you. While looking into the device you will keep your index fingers of both hands on each of the push buttons. In the device you will see an illuminated window and in its centre a print. This point is a fixation point and you should keep you eyes on it. After, the experimenter will give you a warning signal by saying "ready", the fixation point will disappear and instead you will see the stimulus.

In general all the stimuli are composed of either two digits or two lines. Your task is to react to the larger of the two, i.e. if the bigger number or the longer line appears on the right side you should react by pressing the right button, if on the other hand the bigger number or the longer line appears on the left side you should press the left button.

You are required to react correctly but you must at the same time try to react as fast as you can.

Now you will have some examples so you can practice. If you have any questions do not hesitate to ask.

APPENDIX IC First experiment: data form

NAME ______________________________

GROUP ______________________________

	TYPE	STI	HAND	ERR	RT

	TYPE	STI	HAND	ER	RT

APPENDIX ID Training effect: ANOVA

Table ID 1 Training effect analysis: computational formulae

Source	SS: Computational formulae*	df	MS	F
S	$\frac{\Sigma(S)^2}{abc} - \frac{T^2}{abcs}$	$s-1$	$\frac{SS_S}{df_S}$	
A	$\frac{\Sigma(A)^2}{bcs} - [T]$	$a-1$	$\frac{SS_A}{df_A}$	$\frac{MS_A}{MS_{AS}}$
AxS	$\frac{\Sigma(AS)^2}{bc} - [A] - [S] + [T]$	$(a-1)(s-1)$	$\frac{SS_{AS}}{df_{AS}}$	
B	$\frac{\Sigma(B)^2}{acs} - [T]$	$b-1$	$\frac{SS_B}{df_B}$	$\frac{MS_B}{MS_{BS}}$
BxS	$\frac{\Sigma(BS)^2}{ac} - [B] - [S] + [T]$	$(b-1)(s-1)$	$\frac{SS_{BS}}{df_{BS}}$	
~~C~~				
CxS				
AxB	$\frac{\Sigma(AB)^2}{cs} - [A] - [B] + [T]$	$(a-1)(b-1)$	$\frac{SS_{AB}}{df_{AB}}$	$\frac{MS_{AB}}{MS_{ABS}}$
AxBxS	$\frac{\Sigma(ABS)^2}{c} - [AB] - [AS] - [BS] + [A] + [B] + [S] - [T]$	$(a-1)(b-1)(s-1)$	$\frac{SS_{ABS}}{df_{ABS}}$	
~~AxC~~				
~~AxCxS~~				
~~BxC~~				
~~BxCxS~~				
~~AxBxC~~				
~~AxBxCxS~~				
TOTAL	$\Sigma(ABCS)^2 - [T]$	$abcs-1$		

*Bracketed letters represent complete terms in the computational formulae; a particular term is identified by the letter(s) appearing in the numerator.

APPENDIX IIA Second experiment: subject's instructions

(These instructions are only for condition II, for the instructions of condition I see Appendix IB).

Are you right-handed?

Do you see well?

You are participating in a reaction time experiment. The purpose of this experiment is to measure the required time for reacting to various stimuli. The stimuli will be presented to you in the device which is in front of you. While looking into the device you will keep your index fingers of both hands on each of the push buttons. In the device you will see an illuminated window and in its centre a point. This point is a fixation point and you should keep your eyes on it. After, the experimenter will give you a warning signal by saying "ready", the fixation point will disappear and instead you will see the stimulus.

In general all the stimuli are composed of either two digits or two lines. Your task is to react to the bigger (higher) number or the shorter line. If the bigger number or the shorter line appears on the right side you should react by pressing the right button, if on the other hand the bigger number or the shorter line appears on the left side you should press the left button.

You are required to react correctly but you must at the same time try to react as fast as you can.

Now you will have some examples so you can practice. If you have any questions do not hesitate to ask.

APPENDIX IIIA Third experiment: subjects instructions

Common to all subjects:

"You are participating in a reaction time experiment. As in all such experiments your task will be to react as fast as you can, but at the same time to react correctly. Please keep your index fingers of both hands on the two push buttons."

Only for the visual words - numbers group:

"Two types of stimuli will be presented to you in the experiment. Both types involve numbers. One type of stimuli consists of single digits, the other type consists of single words which represent numbers (you will see the word one, or five or eight).

For both types of stimuli your task is to press the right button when you see an even number and to press the left button when you see an odd number."

Only for the visual and auditory words group:

"Two types of stimuli will be presented to you in the experiment. Both types involve numbers. One type of stimuli consists of visual words which represent numbers (you will see the words one, or five or eight). The other type consists of audited numbers (you will hear the words, one, or five or eight).

Appendix IIIA (Continued)

Your task is to press the right button when you see or hear an even number and to press the left button when you see or hear an odd number."

Only for the visual words - lines group:

"Two types of stimuli will be presented to you in the experiment. One type of stimuli consists of visual words which represent numbers (you will see the word one, or five or eight).

Your task is to press the right button when you see an even number and to press the left button when you see an odd number.

The other type of stimuli consists of lines. On each presentation you will see a parallel pair of lines, one longer than the other. Your task is to react to the longer line. If the longer line appears on the right-hand side, press the right button, if it appears on the left-hand side press the left button."

Only for the visual words - pips group:

"Two types of stimuli will be presented to you in the experiment. One type of stimuli consists of visual words which represent numbers (you will see the word one, or five or eight).

Your task is to press the right button when you see an even number and to press the left button when you see an odd number.

Appendix IIIA (Continued)

The other type of stimuli consists of pips. There are two types of pips, a loud pip and a quiet pip. Your task is to press the right button when you hear the louder pip and to press the left button when you hear the quieter pip."

Common to all subjects:

"Please bear in mind that you are required to react correctly but at the same time to react as fast as you can.

You will now have some examples so that you can practice. If you have any questions do not hesitate to ask."

APPENDIX IIIB Third experiment: ANOVA

Table IIIB 1 Third experiment: computational formulae

1 Source	2 SS: Computational formulae*	3 df	4 S	5 F
A	$\bar{n}_h\left(\frac{\Sigma(A')^2}{bcS} - \frac{(T')^2}{abcS}\right)$	$a-1$	$\frac{SS_A}{df_A}$	$\frac{MS_A}{MS_{SWAB}}$
B	$\bar{n}_h\left(\frac{\Sigma(B')^2}{acS} - [T']\right)$	$b-1$	$\frac{SS_B}{df_B}$	$\frac{MS_B}{MS_{SWAB}}$
C	$\bar{n}_h\left(\frac{\Sigma(C')^2}{abS} - [T']\right)$	$c-1$	$\frac{SS_C}{df_C}$	$\frac{MS_C}{MS_{cSWAB}}$
~~D~~				
~~E~~				
AxB	$\bar{n}_h\left(\frac{\Sigma(AB')^2}{cS} - [A'] - [B'] + [T']\right)$	$(a-1)(b-1)$	$\frac{SS_{AB}}{df_{AB}}$	$\frac{MS_{AB}}{MS_{SWAB}}$
AxC	$\bar{n}_h\left(\frac{\Sigma(AC')^2}{bS} - [A'] - [C'] + [T']\right)$	$(a-1)(c-1)$	$\frac{SS_{AC}}{df_{AC}}$	$\frac{MS_{AC}}{MS_{cSWAB}}$
~~AxD~~				
~~AxE~~				
BxC	$\bar{n}_h\left(\frac{\Sigma(BC')^2}{aS} - [B'] - [C'] + [T']\right)$	$(b-1)(c-1)$	$\frac{SS_{BC}}{df_{BC}}$	$\frac{MS_{BC}}{MS_{cSWAB}}$
~~BxD~~				
~~BxE~~				
~~CxD~~				
~~CxE~~				
~~DxE~~				
AxBxC	$\bar{n}_h\left(\frac{\Sigma(ABC')^2}{S} - [AB'] - [AC'] - [BC'] + [A'] + [B'] + [C'] - [T']\right)$	$(a-1)(b-1)(c-1)$	$\frac{SS_{ABC}}{df_{ABC}}$	$\frac{MS_{ABC}}{MS_{cSWAB}}$
~~AxBxD~~				
•				
•				
S_{WAB}	$\Sigma\frac{(ABS)^2}{cde} - \Sigma\frac{(AB)^2}{cdeS}$	$a \cdot b(S-1)$	$\frac{SS_{SWAB}}{df_{SWAB}}$	—
CxS_{WAB}	$\Sigma\frac{(ABCS)^2}{de} - \Sigma\frac{(ABC)^2}{deS} - [ABS] + [AB]$	$a \cdot b(S-1)(c-1)$	$\frac{SS_{cSWAB}}{df_{cSWAB}}$	—
~~DxS_{WAB}~~				
•				
•				
•				
~~$CxDxExS_{WAB}$~~				
~~TOTAL~~				

* Bracketed letters represent complete terms in the computational formulae- a particular term is identified by the letter(s) appearing in the numerator.

Appendix IIIB (Continued)

Table IIIB1 requires some explanation:

1) The first column - Source - contains the factors of the experiment (also see section 2.3.2.1) and their possible interactions. As it was mentioned before, factors D and E and all the interactions containing these factors are excluded from the summary of the analysis. This does not affect the way in which the rest of the factors are computed.

2) The second column - SS: computational formulae - contains the 'working' formulae for computing the sums of squares.

The harmonic mean ($\bar{n}_h$) needed in the unweighted means method is calculated according to the following formula:

$$\bar{n}_h = \frac{\text{the total number of treatment means}}{\text{the sum of the various observations per cell}}$$

(for further discussion see Winer (1971), Keppel (1973)).

In this experiment $\bar{n}_h = \frac{AxBxCxS}{\Sigma\left(\frac{1}{n_i}\right)}$.

Here the harmonic mean is a function of factors D, E and the number of the correctly registered RTs, and not as usual, the function of the sample sizes (i.e. of the subjects).

Note that the harmonic mean is not needed in those sources of variance which are used as 'error terms' for calculating F. In other words, the 'within groups' are not adjusted by $\bar{n}_h$. Essentially these sums of squares are calculated in a very similar manner to those for equal sample size.

Appendix IIIB (Continued)

In this statistical model factor S does not contribute to the harmonic mean, but rather to the group means. On the other hand factors D and E, which 'help' in forming the harmonic mean, do not take part in the formation of the groups means.

3) The third and fourth columns of Table IIIB1 are calculated in the usual way.

4) The error terms for the F ratio were chosen according to Table IIIB2, based on a factorial design with repeated measures on one factor (C).

Table IIIB2 Third experiment: identification of error terms

Source	Error Term
No repeated factors	
A	
B	S/AB
AxB	
One repeated factor	
C	
AxC	CxS/AB
BxC	
AxBxC	

APPENDIX IIIC Magnitude of treatment effects in selected ANOVA designs

The need and importance of estimating strength of effects or magnitude of treatments in analysing the results of experiments, were expressed in numerous articles (for review see Hays (1963); Winer (1971); Keppel (1973); and also in this study, section 2.1.3.3). However, the concepts and the formulae which were adopted in this study until now were of uncomplicated experiments dealing with the difference between two population means, namely the application of a 't' test.

In this experiment the analysis of the data takes the form of a fairly complicated analysis of variance with nested, mixed (random and fixed) factors with repeated measures in unequal number of observations. The previous formula is unsuitable in this situation.

Fleiss (1969) claims that just as the statistics used in tests of significance must depend on the experimental design, so must the statistics used in measuring association. Little complication exists in the simple one-way layout, although an investigator has at least three formulae to choose from. Hays (1963 Formula 12.18.5) suggests to use the following formula:

$$\hat{\omega}^2 = \frac{(J - 1)\ (F - 1)}{(J - 1)\ (F - 1) + IJ} ;$$

where there are J levels of the experimental factor and I independent observations on each. F denotes the usual ratio of mean squares.

Cohen (1966 Formula 2) suggests to use a slightly different formula:

$$\hat{\varepsilon}^2 = \frac{(J - 1)\ (F - 1)}{(J - 1)\ (F - 1) + IJ - 1} ;$$

and Friedman (1968 Formula 2) suggests yet another version:

$$\hat{\eta}^2 = \frac{(J - 1)\ F}{(J - 1)\ F + J\ (I - 1)}$$

The statistics differ in the extent to which the numerators and denominators are unbiased. Although in practise their values will differ only slightly (especially when F and I are large), Fleiss (1969) prefers Hays' $\hat{\omega}^2$ and so do Vaughan and Corballis (1969).

Serious complications begin to emerge in designs more complicated than the one-way layout. Fleiss (1969) claims that the above formulae cannot be applied in more complicated designs. Hays (1963 Section 12.3.4), on the other hand, gives a formula for a modified version of his basic formula. He implies that his modification is appropriate. However, Fleiss (1969) opposes him and argues that Hays's implications are not only contradicting, but also that not one of them is uniformly correct. He goes on, saying that the uncritical following of advice given in the literature can result in serious over, or under,-estimation of the magnitude of experimental effects. He suggests that the proper measure for a complex design depends on whether other factors are fixed or random. He concludes that in complicated designs no simple formulae for estimating the magnitude of experimental effects seem possible.

Keppel (1973 pp.547 - 556) has a different suggestion for dealing with complicated designs. The general definition for estimating the magnitude of an experimental effect - $\hat{\omega}^2$ effect - suggested by Hays (1963 pp. 406 - 407) and others (e.g. Winer (1971 pp.428 - 430)) can be expressed as follows:

$$\hat{\omega}^2_{\text{effect}} = \frac{\hat{\sigma}^2_{\text{effect}}}{\hat{\sigma}^2_T}$$

Where $\hat{\sigma}^2$effect is the estimate of a treatment effect (for example:

$$\hat{\sigma}^2\text{effect} = \frac{(\text{df effect})\ (\text{MS effect} - \text{MSwg})}{N})$$

and where $\hat{\sigma}_T^2$ consists of the sum of the variance estimates for all factorial effects and error.

Keppel raises a serious objection concerning the appropriateness of this general formula. It relates the estimate of the population treatment component to the sum of all the components specified under the model. This means, according to Keppel that a particular omega squared, say $\hat{\omega}_A^2$, will be defined differently for each type of design. For instance:

$$\hat{\omega}_A^2 = \frac{\hat{\sigma}_A^2}{\hat{\sigma}_A^2 + \hat{\sigma}_{S/A}^2} \quad \text{and} \quad \frac{\hat{\sigma}_A^2}{\hat{\sigma}_A^2 + \hat{\sigma}_B^2 + \hat{\sigma}_{A\times B}^2 + \hat{\sigma}_{S/AB}^2}$$

in one and two factor designs respectively. Therefore, depending upon the nature of the design the same manipulation will result in different omega squares, even when the variance component estimated for that manipulation is identical in the designs.

Keppel suggests a different definition of omega squared, always relating the treatment component to the sum of only two components, the treatment component and the error component. In symbols,

$$\hat{\omega}^2\text{effect} = \frac{\hat{\sigma}^2\text{effect}}{\hat{\sigma}^2\text{effect} + \hat{\sigma}^2_{wg}}$$

for example,

$$\hat{\omega}_A^2 = \frac{\hat{\sigma}_A^2}{\hat{\sigma}_A^2 + \hat{\sigma}_{S/A}^2}, \quad \frac{\hat{\sigma}_A^2}{\hat{\sigma}_A^2 + \hat{\sigma}_{S/AB}^2}, \quad \frac{\hat{\sigma}_A^2}{\hat{\sigma}_A^2 + \hat{\sigma}_{S/ABC}^2}$$

as applied to one, two and three factor designs.

Vaughan and Corballis (1969) claim that when random factors are introduced or repeated measures are involved, the estimations become complex. These cases have to be considered separately, and Vaughan and Corballis (1969) present a readable discussion of these cases. However, they assume equal sample size.

Dwyer (1974) argues that Vaughan and Corballis and Fleiss do not multiply the variance components of interactions between fixed and random effects (which apply to our case) by the proper weights when they estimate variance explained. This problem according to Dwyer is especially serious for psychological applications, because fixed effect treatments often have only two levels (which apply to our design), and this results in at least a 100% over-estimation of variance explained by the interaction. In cases where the interaction is between several fixed effects and one random effect, the over-estimation may be even greater. Furthermore, Dwyer argues that this inflation is particularly misleading since, in psychological experimentation, the random effects are often subjects, while the fixed effects are a small number of treatment levels (which is exactly our case!).

Dwyer (1974) claims that his method of estimating explained variance can be applied to any design, but only as long as this design is balanced (which does not apply to our case - see section 2.3.3.1 at 2).
He warns the readers to be cautious because his estimates are not necessarily unbiased.

Vaughan and Corballis (1969) say that if there are unequal numbers of observations, further complications arise. For random effects models

Appendix IIIC (Continued)

there appears to be no satisfactory solutions (also Scheffé (1959 p. 224)). The situation for fixed effects designs is almost as bad. For the simple design of one-way fixed model, they do make some useful suggestions, but for our case, which is of a higher order and of mixed effects there is no apparent solution yet. They urge investigators to keep the number of observations per cell constant. This, of course, could not be applied in this type of study. Even if the original design does call for equal observations per cell, human errors in the experiment will yield unequality among cells.

It seems that complicated designs, especially with unequal cell frequencies, has no conclusive solution in terms of estimation of experimental effects. Even in the simpler cases, the proposed methods are controversial and the estimations might be biased one way or another. The writer thinks that attempting to develop a statistical association strength estimator, for experimental designs such as this one, is beyond the scope of this study.

However, one has to remember that the overall analysis of variance is only a small part, and not the most important one, in the general analysis of the data from this study. We are more interested in the planned comparisons (Table 2.3.5) (which enable us to assess the relative influence of each factor on time-sharing) than in the overall F.

The estimation of the strength of any factor ($\hat{\omega}^2$ effect), merely provides an estimate of the strength of the <u>average</u> or 'omnibus'

Appendix IIIC (Continued)

treatment effects - nothing is said about the relative contribution of orthogonal contrasts. A more revealing procedure than a calculation of an omnibus $\hat{\omega}^2$ effect would be to obtain an estimate of omega squared for meaningful comparisons. This is compatible with the writer's original intention to carry out planned comparisons.

Levin (1967) describes a single factor experiment with a = 6 levels in which $\hat{\omega}^2_A$ was found to equal .37. Of these 37% the variability accounted for by the experimental treatment, "over 85% of the total 'explained variation' resulted from the superiority of one of the experimental groups to all the others" (p. 676).

Vaughan and Corballis (1969 pp.210 - 211) indicate how a specific comparison is accomplished. Their discussion is restricted to one-way analysis of variance, fixed model. A ratio is obtained of the estimated population variance due to the comparison of interest relative to the estimated population variance due to experimental treatments:

$$\hat{\omega}^2_{Acomp.} = \frac{\hat{\sigma}^2_{Acomp.}}{\hat{\sigma}^2_A} = \frac{MS_{Acomp.} - MS_{WG}}{(a-1)(MS_A - MS_{WG})}$$

The procedures which are described in the literature for estimating the strength of comparisons are usually limited to the simple case of a single factor. Since this procedure could not be applied to this experiment design, the writer has decided to develop a more suitable model of estimating the strength of association in specific comparisons.

Vaughan and Corballis (1969 p.210) argue that in given significant linear (or quadratic, or cubic) trends among sample means, specific comparisons are generally meaningful only when the treatment levels are fixed rather than random. This is true in so far as the comparisons are made among levels of a fixed factor, however other treatments in the analysis could very well be random. In other words, the investigator must not restrict himself only to a fixed model in making meaningful comparisons. One could carry out such comparisons in a mixed model of random and fixed factors. The considerations of what levels have to be compared and how to carry out such comparisons must be separated from the considerations of how to estimate the strength of these comparisons.

This discussion is limited to comparisons among levels of a fixed factor. Whether the other factors are fixed or random will, of course, determine the way in which the compared mean squares are estimated. It will not, however, determine the way in which the estimation of the contribution - made by this specific comparison to the total treatment variance - is carried out.

The most satisfactory sub-sets of contrasts are those which are mutually orthogonal. Any treatment sum of squares having a - 1 degrees of freedom can be divided into a - 1 orthogonal components, there are many ways (for $a > 2$) in which this can be done. A treatment sum of squares can also be subdivided into a relatively large number of non-orthogonal components. However, orthogonal components are additive - each component covers a different portion of the total variation and the sum of the parts equals the whole. Non-orthogonal components are not additive in this sense (they are not independent of one another). Although it is possible to estimate how much given non-orthogonal contrasts contribute to the total treatment variance, the qualification concerning lack of independence would generally indicate that treatment variance be divided into components representing orthogonal contrasts. Therefore, the discussion is restricted to orthogonal components (which fit the design of this experiment).

The general definition of estimating the strength of any effect ($\hat{\omega}^2$effect) suggested by Hays (1963 pp.406 - 407) and others can be expressed as follows:

$$\hat{\omega}^2\text{effect} = \frac{\hat{\sigma}^2\text{effect}}{\hat{\sigma}^2_T}$$

where $\hat{\sigma}^2_T$ consists of the sum of the variance estimates for all factorial effects and error. In the case of estimating the strength of a comparison, a similar approach was adopted by Vaughan and Corballis (1969 pp.210 - 211). In the single factor case they substitute the 'effect' by 'comparison' or 'contrast', and the 'total' by a particular treatment in the experiment. Hence

$$\hat{\omega}^2_A \text{ comparison} = \frac{\hat{\sigma}^2_A \text{ comparison}}{\hat{\sigma}^2_A}$$

if the contrasts are orthogonal then:

$$\hat{\sigma}^2_A \text{ comp. 1} + \hat{\sigma}^2_A \text{ comp. 2} + \cdots + \hat{\sigma}^2_A \text{ comp.(a-2)} + \hat{\sigma}^2_A \text{ comp. (a-1)} = \hat{\sigma}^2_A$$

therefore

$$\hat{\omega}^2_A \text{ comp.1} + \hat{\omega}^2_A \text{ comp.2} + \cdots + \hat{\omega}^2_A \text{ comp.(a-2)} + \hat{\omega}^2_A \text{ comp. (a-1)} = 1.$$

In a higher order design this is no longer true. Assuming, for example, two fixed factors A and B. In terms of the general linear model, a simple main effect is actually a sum of an overall main effect and an interaction.

$\overline{AB}ab - \overline{B}b$ estimates $\alpha a - \alpha\beta ab = \alpha a$ for level Bb.

Appendix IIIC (Continued)

Hence

$\Sigma\ SS_A$ for Bb = $SS_A + SS_{AB}$ (Winer (1971 p.441)).

A test on the simple effect of factor A for level Bb is equivalent to a test that

$$\hat{\sigma}^2_\alpha \text{ for Bb} = 0$$

In a similar manner for a three factorial experiment, for example,

$\Sigma\ SS_A$ for Cc $= SS_A + SS_{AC}$

or $\Sigma\ SS_{AB}$ for Cc $= SS_{AB} + SS_{ABC}$

or $\Sigma\ SS_A$ for BCbc $= SS_A + SS_{AB} + SS_{AC} + SS_{ABC}$

The technique for estimating the strength of comparisons developed here, depends on the specific experimental design and the statistical method of each particular case.

In two factors for example,

$$\hat{\omega}^2 A \text{ at Bb} = \frac{\hat{\sigma}^2_A \text{ at Bb}}{\hat{\sigma}^2_A + \hat{\sigma}^2_{AB}}$$

Only then $\Sigma\ \hat{\omega}^2$ A at Bb = 1 because

$$\Sigma\ \hat{\omega}^2_A \text{ at Bb} = \Sigma\ \frac{\hat{\sigma}^2_A \text{ at Bb}}{\hat{\sigma}^2_A + \hat{\sigma}^2_{AB}} = \frac{\Sigma\ \hat{\sigma}^2_A \text{ at Bb}}{\hat{\sigma}^2_A + \hat{\sigma}^2_{AB}} = \frac{\hat{\sigma}^2_A + \hat{\sigma}^2_{AB}}{\hat{\sigma}^2_A + \hat{\sigma}^2_{AB}} = 1.$$

In a similar manner, for three factors

$$\hat{\omega}^2 A \text{ at Cc} = \frac{\hat{\sigma}^2_A \text{ at Cc}}{\hat{\sigma}^2_A + \hat{\sigma}^2_{AC}}$$

$$\hat{\omega}^2 AB \text{ at Cc} = \frac{\hat{\sigma}^2_{AB} \text{ at Cc}}{\hat{\sigma}^2_{AB} + \hat{\sigma}^2_{ABC}}$$

$$\hat{\omega}^2 A \text{ at BCbc} = \frac{\hat{\sigma}^2_A \text{ at BCbc}}{\hat{\sigma}^2_A + \hat{\sigma}^2_{AB} + \hat{\sigma}^2_{AC} + \hat{\sigma}^2_{ABC}}$$

Appendix IIIC (Continued)

The computational formulae could either contain MS or F. For example:

$$\hat{\omega}^2 A \text{ at } Cc = \frac{MS_A \text{ at } Cc - MS_{WG}}{(a-1)(MS_A - MS_{WG}) + (a-1)(c-1)(MS_{AC} - MS_{WG})}$$

$$\text{or } \hat{\omega}^2 A \text{ at } Cc = \frac{(dfA \text{ at } Cc)(F_A \text{at } Cc - 1)}{(a-1)(F_A-1)+(a-1)(c-1)(F_{AC}-1)}.$$

In more complicated cases:

$$\hat{\omega}^2 c \text{ at } ABab = \frac{MSc \text{ at } ABab - MS_{WG}}{(c-1)(MSc - MS_{WG})+(a-1)(b-1)(c-1)(MS_{ABC} - MS_{WG}) + (a-1)(c-1)(MS_{AC} - MS_{WG})+(b-1)(c-1)(MS_{BC} - MS_{WG})},$$

$$\text{or } \hat{\omega}^2 c \text{ at } Abab = \frac{(dfC \text{ at } ABab)\ (Fc \text{ at } ABab - 1)}{(c-1)(F_c-1)+(a-1)(b-1)(c-1)(F_{ABC}-1)+(b-1)(c-1)(F_{BC}-1)+(a-1)(c-1)(F_{AC}-1)}$$

With this method of estimating strength of effects, the factors could be of different types and the estimation still be valid. Some of the factors could be nested in others, the experiment could contain repeated observations (even in the tested factor) unequal numbers, where the non-tested factors may be fixed or random, and still a meaningful estimation could be made. However, there may be cases in which these estimations are not necessarily unbiased.

It is hoped that this simple procedure will enhance the interpretation of analysis of variance by assisting to estimate the contribution made by various components in the different factors.

APPENDIX IIID Visual words task: means matrix

Table IIID1 Visual words task: unweighted means matrix

Ⓐ	Ⓑ	Ⓢ Subj.no.	Ⓓ FIRST (m.sec.)	REST (m.sec.)	TOTAL (m.sec.)
SAME	WITHIN	1	763.70	576.95	1,340.65
		2	734.55	669.59	1,404.14
		12	572.00	547.06	1,119.06
		15	739.22	748.78	1,488.00
		20	852.33	643.74	1,496.07
		21	493.20	510.82	1,004,02
		T	4,155.00	3,696.94	7,851.94
	BETWEEN	6	858.00	646.83	1,504.83
		8	760.87	569.38	1,330.25
		11	640.77	555.17	1,195.94
		14	579.28	565.27	1,164.55
		17	599.00	579.01	1,178.01
		19	796.42	633.61	1,430.03
		T	4,234,34	3,569.27	7,803.61
DIFFERENT	WITHIN	3	819.88	595.93	1,415.81
		7	759.20	577.61	1,336.81
		9	703.11	612.96	1,316.07
		13	638.22	570.51	1,208.73
		22	677.10	557.65	1,234.75
		24	726.10	589.83	1,315.93
		T	4,323.61	3,504.49	7,828.10
	BETWEEN	4	662.25	548.21	1,210.46
		5	725.87	503.56	1,229.43
		10	870.50	644.35	1,514.85
		16	584.16	564.45	1,148.61
		18	665.33	611.19	1,276.52
		23	745.77	557.57	1,303.34
		T	4,253.88	3,429.33	7,683.21
TOTAL	SAME		8,389.34	7,266.21	15,655.55
	DIFFERENT		8,577.49	6,933.82	15,511.31
	WITHIN		8,478.61	7,201.43	15,680.04
	BETWEEN		8,288.22	6,998.60	15,486.82
TOTAL			16,966.83	14,200.03	31,166.86

APPENDIX IIIE   Visual words task: statistical calculations for ANOVA

All the following calculations are based on the formulae developed in Appendix IIIB.

Appendix IIIE1   Calculations of error terms:

The data for these calculations are extracted from Table 2.3.6.

$$\Sigma\frac{(AB)^2}{cdes} = \frac{254{,}377^2}{407} + \frac{243{,}680^2}{400} + \frac{250{,}247^2}{415} + \frac{230{,}181^2}{392}$$

$$= 593{,}498{,}339$$

$$\Sigma\frac{(ABC)^2}{des} = \frac{38{,}080^2}{55} + \frac{32{,}201^2}{45} + \cdots + \frac{209{,}172^2}{358} + \frac{199{,}644^2}{349}$$

$$= 596{,}004{,}908$$

$$\Sigma\frac{(ABS)^2}{cde} = \frac{42{,}831^2}{71} + \frac{48{,}126^2}{71} + \cdots + \frac{41{,}886^2}{68} + \frac{39{,}609^2}{68}$$

$$= 597{,}667{,}750$$

$$\Sigma\frac{(ABCS)^2}{de} = \frac{7{,}637^2}{10} + \frac{6{,}611^2}{9} + \cdots + \frac{37{,}894}{62} + \frac{32{,}897^2}{59}$$

$$= 601{,}245{,}875$$

Appendix IIIE2   Calculations of other terms:

The data for these calculations are extracted from Appendix IIID.

$$\frac{(T')^2}{abcs} = \frac{31{,}166.86^2}{48} = 20{,}236{,}940.88$$

$$\frac{\Sigma(A')^2}{abs} = \frac{15{,}655.55^2 + 15{,}511.31^2}{24} = 20{,}237{,}374.32$$

$$\frac{\Sigma(B')^2}{acs} = \frac{15{,}680{,}04^2 + 15{,}486.82^2}{24} = 20{,}237{,}718.67$$

$$\frac{\Sigma(C')^2}{abs} = \frac{16{,}966.83^2 + 14{,}200.03^2}{24} = 20{,}396{,}423.84$$

$$\frac{\Sigma(AB')^2}{cs} = \frac{7{,}851.94^2 + 7{,}803.61^2 + 7{,}828.10^2 + 7{,}683.21^2}{12} = 20{,}238{,}346.35$$

$$\frac{\Sigma(AC')^2}{bs} = \frac{8{,}389.34^2 + 8{,}577.49^2 + 7{,}266.21^2 + 6{,}933.82^2}{12} = 20{,}402{,}502.32$$

Appendix IIIE1 (Continued)

$$\frac{\Sigma(BC')^2}{as} = \frac{8{,}478.61^2 + 8{,}488.22^2 + 7{,}201.43^2 + 6{,}998.60^2}{12} = 20{,}398.141.85$$

$$\frac{\Sigma(ABC')^2}{s} = \frac{4{,}155.00^2 + 4{,}234.34^2 + \cdots + 3{,}504.49^2 + 3{,}429.33^2}{6} =$$

20,405,261.13

Appendix IIIE3 Calculation of harmonic mean:

The 'n' is extracted from Table 2.3.6 in the same order at which the subjects appear.

$$\bar{n}_h = \frac{2.2.2.6}{\frac{1}{10}+\frac{1}{9}+\ldots+\frac{1}{62}+\frac{1}{59}} = 14.14346700$$

APPENDIX IIIF Visual words task: statistical calculations for planned comparisons

The formula used for these calculations was developed to fit this particular experimental design. For further discussion about planned comparisons in unequal samples see Winer (1971 pp.215 - 218) and Keppel (1973 pp.352 - 355 and 360 - 362).

$$SS_C \text{ at } Aa = \bar{n}_h \frac{(\overline{ACac'} - \overline{ACac'})^2 . b . s}{2} = \bar{n}_h \frac{(ACac' - ACac')^2}{2 . b . s}$$

where $\bar{n}_h$ - is the harmonic mean

ACac' - are the relevant sums from the means matrix

b - the number of levels in factor B

S - the number of subjects

The following sums of squares are needed for the planned comparisons (data from Table III D1.):

$$SSc \text{ at } A1 = 14.143 \frac{(8{,}389.34 - 7{,}266.21)^2}{2 \times 2 \times 6} = 743{,}369.43$$

$$SSc \text{ at } A2 = 14.143 \frac{(8{,}577.49 - 6{,}933.82)^2}{24} = 1{,}592{,}113.03$$

$$SSc \text{ at } B1 = 14.143 \frac{(8{,}478.61 - 7{,}201.43)^2}{24} = 961{,}277.68$$

$$SSc \text{ at } B2 = 14.143 \frac{(8{,}488.22 - 6{,}998.60)^2}{24} = 1{,}307{,}662.38$$

$$SSc \text{ at } AB11 = 14.143 \frac{(4{,}155.00 - 3{,}696.94)^2}{2 \times 6} = 247{,}297.30$$

$$SSc \text{ at } AB12 = 14.143 \frac{(4{,}234.34 - 3{,}569.27)^2}{12} = 521{,}325.96$$

$$SSc \text{ at } AB21 = 14.143 \frac{(4{,}323.61 - 3{,}504.49)^2}{12} = 790{,}805.53$$

$$SSc \text{ at } AB22 = 14.143 \frac{(4{,}253.88 - 3{,}429.33)^2}{12} = 801{,}324.88$$

Appendix IIIF (Continued)

In order to check whether the method of calculating the sum of squares and the actual calculations are correct, Winer (1971 p.441) suggests the following formulae:

Σ SSc at Aa = SSc + SS_{AC}

743,369 + 1,592,113 $\overset{?}{=}$ 2,255,642 + 79,840

2,335,482 = 2,335,482

Σ SSc at Bb = SSc + SS_{BC}

961,278 + 1,307,662 $\overset{?}{=}$ 2,255,642 + 13,298

2,268,940 = 2,268,940

Σ SSc at ABab = SSc + SS_{ABC} + SS_{AC} + SS_{BC} (Winder (1971 p.457)).

247,297 + 521,326 + 790,806 + 801,325 $\overset{?}{=}$ 2,255,642 + 79,840 + 13,298 + 11,973

2,360,753 = 2,360,753

APPENDIX IIIG Visual words task: estimation of magnitude of experimental effects

The data for the calculations are extracted from Tables 2.3.8, 2.3.9.

$$\hat{\omega}^2_c \text{ at Aa} = \frac{MSc \text{ at Aa} - MSc \times MS/_{AxB}}{(c-1)(MSc - MSc \times S/_{AxB}) + (a-1)(c-1)(MS_{AxC} - MS_{CxS/AxB})}$$

$$\hat{\omega}^2_c \text{ at } A_1 = \frac{743{,}369 - 53{,}577.75}{(2-1)(2{,}255{,}641.8-53{,}577.75)+(2-1)(2-1)(79{,}840.44-53{,}577.75)} =$$

0.3095556

$$\hat{\omega}^2_c \text{ at } A_2 = \frac{1{,}592{,}113 - 53{,}577.75}{2{,}228{,}326.8} = 0.6904441$$

$$\hat{\omega}^2_c \text{ at } B_1 = \frac{961{,}278 - 53{,}577.75}{(2-1)(2{,}255{,}641.8-53{,}577.75)+(2-1)(c-1)(13{,}297.98-53{,}577.75)} =$$

0.4198847

$$\hat{\omega}^2_c \text{ at } B_2 = \frac{1{,}307{,}662 - 53{,}577.75}{2{,}161{,}784.3} = 0.5801153$$

$$\hat{\omega}^2_c \text{ at ABab} = \frac{MSc \text{ at Abab} - MScxs/_{AxB}}{(c-1)(MSc - MScxs/_{AxB}) + (a-1)(b-1)(c-1)\, MS_{AxBxC} - MScxs/_{AxB}) + (a-1)(c-1)(MS_{AxC} - MScxs/_{AxB}) + (b-1)(c-1)(S_{BxC} - S_{CxS/AxB})}$$

$$\hat{\omega}^2_c \text{ at } AB_{11} = \frac{247{,}297 - 53{,}577.75}{(2-1)(2{,}255{,}641.8-53{,}577.75)+(2-1)(2-1)(2-1)(11{,}973.0-53{,}577.75+(2-1)(2-1)(79{,}840.44-53{,}577.75)+(2-1)(2-1)(13{,}297.98-53{,}577.75)} =$$

0.0902513

$$\hat{\omega}^2_c \text{ at } AB_{12} = \frac{521{,}326 - 53{,}577.75}{2{,}146{,}442.2} = 0.2179179$$

$$\hat{\omega}^2_c \text{ at } AB_{21} = \frac{790{,}806 - 53{,}577.75}{2{,}146{,}442.2} = 0.343652$$

$$\hat{\omega}^2_c \text{ at } AB_{22} = \frac{801{,}325 - 53{,}577.75}{2{,}146{,}442.2} = 0.3483658$$

Appendix IIIG (Continued)

The accuracy of this estimation can be checked in the following manner:

$$\hat{\omega}^2 c \text{ at } Aa = 1$$

$$\hat{\omega}^2 c \text{ at } A_1 + \hat{\omega}^2 c \text{ at } A_2 = 0.3095556 + 0.690441 = 0.9999997.$$

$$\hat{\omega}^2 c \text{ at } Bb = 1$$

$$\hat{\omega}^2 c \text{ at } B_1 + \hat{\omega}^2 c \text{ at } B_2 = 0.4198847 + 0.5801153 = 1.0000000.$$

$$\hat{\omega}^2 c \text{ at } ABab = 1$$

$\hat{\omega}^2 c$ at AB_{11} + $\hat{\omega}^2 c$ at AB_{12} + $\hat{\omega}^2 c$ at AB_{21} + $\hat{\omega}^2 c$ at AB_{22} = 0.0902513 + 0.2179179 + 0.3434652 + 0.3483658 = 1.0000002.

APPENDIX IIIH All the other tasks: Means matrix

Table IIIH1 All the other tasks: unweighted means matrix

Ⓐ	Ⓑ	Ⓢ subj.no.	Ⓓ FIRST (m.sec.)	REST (m.sec.)	TOTAL (m.sec.)
SAME	WITHIN	1	632.00	584.88	1,216.88
		2	635.60	614.62	1,250.22
		12	594.28	519.68	1,113.96
		15	649.35	698.41	1,347.76
		20	822.44	640.79	1,463.23
		21	446.10	454.78	900.88
		T	3,779.77	513.16	7,292.93
	BETWEEN	6	771.50	720.71	1,492.21
		8	593.44	531.68	1,025.12
		11	597.75	659.73	1,257.48
		14	630.00	585.20	1,215.20
		17	584.42	575.64	1,160.06
		19	667.66	635.00	1,302.66
		T	3,844.77	3,607.96	7,452.73
DIFFERENCE	WITHIN	3	663.60	538.82	1,202.42
		7	608.50	464.27	1,072.77
		9	536.30	450.09	986.39
		13	662.60	471.47	1,134.07
		22	655.00	495.31	1,150.31
		24	662.60	520.16	1,182.76
		T	3,788.60	2,940.12	6,728.72
	BETWEEN	4	690.62	492.25	1,182.87
		5	985.66	473.26	1,458.92
		10	591.87	394.10	985.97
		16	514.71	393.96	908.67
		18	685.37	452.62	1,137.99
		23	658.42	499.68	1,158.10
		T	4,126.65	2,705.87	6,832.52
TOTAL	SAME		7,624.54	7,121.12	14,745.66
	DIFFERENT		7,915.25	5,645.99	13,561.24
	WITHIN		7,568.37	6,453.28	14,021.65
	BETWEEN		7,971.42	6,313.83	14,285.25
TOTAL			15,539.79	12,767.11	28,306.90

APPENDIX III I All the other tasks: statistical calculations for ANOVA

The calculations are based on the formulae developed in Appendix IIIB.

Appendix III I 1 Calculations of error terms:

The data for these calculations are extracted from Table 2.3.10.

$$\Sigma \frac{(AB)^2}{cdes} = \frac{240,174^2}{408} + \frac{249,127^2}{402} + \frac{219,094^2}{430} + \frac{187,694^2}{391} = 497,502,782$$

$$\Sigma \frac{(ABC)^2}{cde} = \frac{34,545^2}{55} + \frac{30,062^2}{47} + \cdots + \frac{181,863^2}{317} + \frac{154,868^2}{344} = 501,180,271$$

$$\Sigma \frac{(ABS)^2}{cde} = \frac{41,998^2}{71} + \frac{43,848^2}{71} + \cdots + \frac{29,925^2}{62} + \frac{31,592^2}{61} = 503,105,171$$

$$\Sigma \frac{(ABCS)^2}{de} = \frac{6,320^2}{10} + \frac{6,356^2}{10} + \cdots + \frac{24,442^2}{54} + \frac{26,983^2}{54} = 507,832,324$$

Appendix III I 2 Calculations of other terms:

The data for these calculations are extracted from Table III H 1.

$$\frac{(T')^2}{abcs} = \frac{28,306.89^2}{48} = 16,693,345.57$$

$$\frac{\Sigma(A')^2}{bcs} = \frac{14,745.66^2 + 13,561.24^2}{24} = 16,722,571.63$$

$$\frac{\Sigma(B')^2}{acs} = \frac{14,021.65^2 + 14,285.25^2}{24} = 16,694,793.17$$

$$\frac{\Sigma(C')^2}{abs} = \frac{15,539.79^2 + 12,767.11^2}{24} = 16,853.507.12$$

$$\frac{\Sigma(AB')^2}{cs} = \frac{7,292.93^2 + 7,452.73^2 + 6,728.72^2 + 6,832.52^2}{12} = 16,724,084.56$$

$$\frac{\Sigma(AC')^2}{bs} = \frac{7,624.54^2 + 7,915.25^2 + 7,121.12^2 + 5,645.99^2}{12} = 16,947,695.49$$

$$\frac{\Sigma(BC')^2}{as} = \frac{7,568.37^2 + 7,917.42^2 + 6,453.28^2 + 6,313.83^2}{12} = 16,861,086.10$$

Appendix III I 2 (Continued)

$$\frac{\Sigma(ABC')^2}{s} = \frac{3,779.77^2 + 3,844.77^2 + \cdots + 2,940.12^2 + 2,705.87^2}{6} = 16,962,892.40$$

Appendix III I 3 Calculation of harmonic mean:

The 'n' is extracted from Table 2.3.10.

$$\bar{n}_h = \frac{2 \times 2 \times 2 \times 6}{\frac{1}{10} + \frac{1}{10} + \ldots + \frac{1}{54} + \frac{1}{54}} = 14.83553400$$

APPENDIX IIIJ All the other tasks: statistical calculations for planned comparisons

The sum of squares for factor C at any level of the other factors will be calculated in the same manner as for visual words task (Appendix IIIF). For example:

$$SSc \text{ at } Bb = \bar{n}_h \frac{(BC'bc - BC'bc)^2}{2as}$$

The following sum of squares are needed for the planned comparisons:

$$SSc \text{ at } A_1 = 14.835 \frac{(7{,}624.54 - 7{,}121.12)^2}{2 \times 2 \times 6} = 156{,}658.11$$

$$SSc \text{ at } A_2 = 14.835 \frac{(7{,}915.25 - 5{,}645.99)^2}{24} = 3{,}183{,}174.58$$

$$SSC \text{ at } B_1 = 14.835 \frac{(7{,}568.37 - 6{,}453.28)^2}{24} = 768{,}620.18$$

$$SSc \text{ at } B_2 = 14.835 \frac{(7{,}971.42 - 6{,}313.83)^2}{24} = 1{,}698{,}424.23$$

$$SSc \text{ at } AB_{11} = 14.835 \frac{(3{,}779.77 - 3{,}513.16)^2}{2 \times 6} = 87{,}876.92$$

$$SSc \text{ at } AB_{12} = 14.835 \frac{(3{,}844.77 - 3{,}607.96)^2}{12} = 69{,}330.13$$

$$SSc \text{ at } AB_{21} = 14.835 \frac{(3{,}788.60 - 2{,}940.12)^2}{12} = 890{,}031.05$$

$$SSc \text{ at } AB_{22} = 14.835 \frac{(4{,}126.65 - 2{,}705.87)^2}{12} = 2{,}495{,}603.62$$

The data for these calculations were extracted from the summary means matrix (Table III.H1).

In order to check whether the calculations were carried out properly, Winer (1971 p.441) suggests the following formulae:

Appendix IIIJ (Continued)

ΣSSc at Aa = $SSc + SS_{AC}$

$$156{,}658.11 + 3{,}183{,}174.58 \overset{?}{=} 2{,}376{,}082.12 + 963{,}750.57$$

$$3{,}339{,}832.68 \approx 3{,}339{,}832.69$$

ΣSSc at Bb = $SSc + SS_{BC}$

$$768{,}620.18 + 1{,}698{,}424.23 \overset{?}{=} 2{,}376{,}082.12 + 90{,}962.30$$

$$2{,}467{,}044.41 \approx 2{,}467{,}044.42$$

ΣSSc at ABab = $SSc + SS_{ABC} + SS_{AC} + SS_{BC}$ (Winer (1971 p.457)

$$87{,}876.92 + 69{,}330.13 + 890{,}031.05 + 2{,}495{,}603.62 \overset{?}{=} 2{,}376{,}082.12 + 112{,}046.85 + 963{,}750.56 + 90{,}962.30$$

$$3{,}542{,}841.72 \approx 3{,}542{,}841.83$$

APPENDIX IIIK All the other tasks: estimation of magnitude of experimental effects.

The data for the calculations are extracted from Tables 2.3.12, 2.3.13.

$$\hat{\omega}_c^2 \text{ at } A_1 = \frac{156{,}658.11 - 52{,}483.20}{(2-1)(2{,}376{,}082.12 - 52{,}483.20) + (2-1)(2-1)(963{,}750.56 - 52{,}483.20)} =$$

$$= 0.0322037$$

$$\hat{\omega}_c^2 \text{ at } A_2 = \frac{3{,}183{,}174.58 - 52{,}483.20}{3{,}234{,}866.2} = 0.9677962$$

$$\hat{\omega}_c^2 \text{ at } B_1 = \frac{768{,}620.18 - 52{,}483.20}{(2-1)(2{,}376{,}082.12 - 52{,}483.20) + (2-1)(2-1)(90{,}962.30 - 52{,}483.20)} =$$

$$= 0.3031809$$

$$\hat{\omega}_c^2 \text{ at } B_2 = \frac{1{,}698{,}424.23 - 52{,}483.20}{2362078} = 0.696819$$

$$\hat{\omega}_c^2 \text{ at } AB_{11} = \frac{87{,}876.92 - 52{,}483.20}{(2-1)(2{,}376{,}082.12 - 52{,}483.20) + (2-1)(2-1)(2-1)(112{,}046.85 - 52{,}483.20) + (2-1)(2-1)(963{,}750.56 - 52{,}483.20) + (2-1)(2-1)(90{,}962.30 - 52{,}483.20)} =$$

$$= 0.0106194$$

$$\hat{\omega}_c^2 \text{ at } AB_{12} = \frac{69{,}330.13 - 52{,}483.20}{3{,}332{,}908.9} = 0.0050547$$

$$\hat{\omega}_c^2 \text{ at } AB_{21} = \frac{890{,}031.05 - 52{,}483.20}{3{,}332{,}908.9} = 0.2512963$$

$$\hat{\omega}_c^2 \text{ at } AB_{22} = \frac{2{,}495{,}603.62 - 52{,}483.20}{3{,}332{,}908.9} = 0.7330294$$

The accuracy of these estimations can be checked in the following manner:

$$\Sigma\, \hat{\omega}_c^2 \text{ at } Aa \overset{?}{=} 1$$

$$\hat{\omega}_c^2 \text{ at } A_1 + \hat{\omega}_c^2 \text{ at } A_2 = 0.0322037 + 0.9677962 = 0.9999999$$

Appendix IIIK (Continued)

$$\Sigma\, \hat{\omega}^2_c \text{ at Bb} \overset{?}{=} 1$$

$\hat{\omega}^2_c$ at B_1 + $\hat{\omega}^2_c$ at B_2 = 0.3031809 + 0.696819 = 0.9999999

$$\Sigma\, \hat{\omega}^2_c \text{ at ABab} \overset{?}{=} 1$$

$\hat{\omega}^2_c$ at AB_{11} + $\hat{\omega}^2_c$ at AB_{12} + $\hat{\omega}^2_c$ at AB_{21} + $\hat{\omega}^2_c$ at AB_{22} = 0.0106194 + 0.0050547 + 0.2512963+0.7330294 = 0.9999998

APPENDIX IVA   Shadowing passages

The passages were extracted from W. Somerset Maughan's Collected Short Stories, volume 4, Penguin Books (1963 edition).

An example of such a passage is given below (from page 254):

"For the rest of the journey those men spoilt Miss Reid outrageously. They treated her with the consideration they would have shown to someone who was convalescent after a long and dangerous illness. Though her appetite was excellent they sought to tempt her with new dishes. The doctor ordered wine and insisted on her sharing his bottle with him. They played dominoes with her. They played chess with her. They played bridge with her. They engaged her in conversation. But there was no doubt about it, though she responded to their advances with politeness she kept herself to herself. She seemed to regard them with something very like disdain; you might almost have thought that she looked upon those men and their efforts to be amiable as pleasantly ridiculous. She seldon spoke unless spoken to. She read detective stories and at night sat on the deck looking at the stars."

The following table shows the shadowing passages which were used in the experimental condition. In some cases the passages were shortened to contain around 150 words.

All the other shadowing passages used for training the subjects were also extracted from the same book of collected stories.

Table IVA1 Experimental shadowing passages

Page	From	To
14	There was something ...	a subject unknown to me.
17	After dinner we ...	was hidden from me.
48	I cannot say ...	was dead.
115	It was quite ...	they generally came.
118	Fred was a postman ...	had to be signed for.
174	Capri is a gaunt rock ...	to haunt him.
185	Before we parted ...	Watts and Lord Leighton.
242	And that of course ...	no wonder they felt low.
254	For the rest of ...	looking at the stars.
300	He was very long-winded ...	and I saw that.
311	The facts that Mrs. Crobie ...	in which she sat.
386	I think they ...	left us to ourselves.
405	The engineer did ...	movements of the hands.
406	But next morning ...	into the water.
447	The path ran over ...	vanish from sight.

APPENDIX IVB   Fourth experiment: ANOVA

Table IVB1   Fourth experiment: Computational formulae

Source	SS: Computational Formulae	df	MS	F
S (subj.)	$\sum \frac{S^2}{abcd} - \frac{T^2}{abcds}$	$s-1$	$\frac{SS_S}{df_S}$	
A (task)	$\bar{n}_h \left(\sum \frac{(A')^2}{bcS} - \frac{(T')^2}{abcS} \right)$	$a-1$	$\frac{SS_A}{df_A}$	$\frac{MS_A}{MS_{AS}}$
SxA	$\sum \frac{(AS)^2}{bcd} - \sum \frac{A^2}{bcds} - [S] + [T]$	$(s-1)(a-1)$	$\frac{SS_{AS}}{df_{AS}}$	
B(cont.exp.)	$\bar{n}_h \left(\sum \frac{(B')^2}{acs} - [T'] \right)$	$b-1$	$\frac{SS_B}{df_B}$	$\frac{MS_B}{MS_{BS}}$
SxB	$\sum \frac{(BS)^2}{acd} - \sum \frac{B^2}{acds} - [S] + [T]$	$(s-1)(b-1)$	$\frac{SS_{BS}}{df_{BS}}$	
C_WB	$\bar{n}_h \left(\sum \frac{(BC')^2}{as} - [B'] \right)$	$(c-b)$	$\frac{SS_{C_WB}}{df_{C_WB}}$	$\frac{MS_{C_WB}}{MS_{C_WBS}}$
C_WB_1	$\bar{n}_h \left(\sum \frac{(BC_1')^2}{as} - \frac{(B_1')^2}{acs} \right)$	(c_1-1)	$\frac{SS_{C_WB_1}}{df_{C_WB_1}}$	$\frac{MS_{C_WB_1}}{MS_{C_WBS_1}}$
C_WB_2	$\bar{n}_h \left(\sum \frac{(BC_2')^2}{as} - \frac{(B_2')^2}{acs} \right)$	(c_2-1)	$\frac{SS_{C_WB_2}}{df_{C_WB_2}}$	$\frac{MS_{C_WB_2}}{MS_{C_WBS_2}}$
SxC_WB	$\sum \frac{(BCS)^2}{ad} - \sum \frac{(BC)^2}{ads} - \sum \frac{(BS)^2}{acd} + \sum \frac{B^2}{acds}$	$(s-1)(c-b)$	$\frac{SS_{C_WBS}}{df_{C_WBS}}$	
SxC_WB_1	$\sum \frac{(BCS_1)^2}{ad} - \sum \frac{(BC_1)^2}{ads} - \sum \frac{(BS_1)^2}{acd} + \sum \frac{B_1^2}{acds}$	$(s-1)(c_1-1)$	$\frac{SS_{C_WBS_1}}{df_{C_WBS_1}}$	
SxC_WB_2	$\sum \frac{(BCS_2)^2}{ad} - \sum \frac{(BC_2)^2}{ads} - \sum \frac{(BS_2)^2}{acd} + \sum \frac{B_2^2}{acds}$	$(s-1)(c_2-1)$	$\frac{SS_{C_WBS_2}}{df_{C_WBS_2}}$	
AxB	$\bar{n}_h \left(\sum \frac{(AB')^2}{cs} - [A'] - [B'] + [T'] \right)$	$(a-1)(b-1)$	$\frac{SS_{AB}}{df_{AB}}$	$\frac{MS_{AB}}{MS_{ABS}}$
SxAxB	$\sum \frac{(ABS)^2}{cd} - \sum \frac{(AB)^2}{cds} - [AS] - [BS] + [A] + [B] + [S] - [T]$	$(s-1)(a-1)(b-1)$	$\frac{SS_{ABS}}{df_{ABS}}$	
AxC_WB	$\bar{n}_h \left(\sum \frac{(ABC')^2}{S} - [BC'] - [AB'] + [B'] \right)$	$(a-1)(c-b)$	$\frac{SS_{AC_WB}}{df_{AC_WB}}$	$\frac{MS_{AC_WB}}{MS_{AC_WBS}}$
$SxAxC_WB$	$\sum \frac{(ABCS)^2}{d} - \sum \frac{(ABC)^2}{ds} - [ABS] - [BCS] + [AB] + [BC] + [BS] - [B]$	$(s-1)(a-1)(c-b)$	$\frac{SS_{AC_WBS}}{df_{AC_WBS}}$	
~~D (trials)~~	•			
~~SxD~~				
•				
•				
•				

Appendix IVB (Continued)

The computational formulae require some clarification:

Following the procedures of the previous experiment, factor D (Table 3.2) and all the interactions containing this factor were excluded from the summary of analysis. This had no influence on the calculation of the other factors.

The harmonic mean ($\bar{n}_h$) used in the unweighted means method, was calculated in the usual manner according to the following formula:

$$\bar{n}_h = \frac{a \times b \times c \times s}{\Sigma\left(\frac{1}{n_i}\right)} = \frac{\text{the total number of treatment means}}{\text{the sum of the various observations per cell}}$$

The number of observations per call are 'd' (i.e. twelve trials) minus the number of human and machine errors.

The error terms for the F ratio were chosen according to the design of repeated measures on three factors.

The table also contains specific comparisons of within control (CwB_1) and within experimental (CwB_2). Their error terms are $SxCwB_1$ and $SxCwB_2$ respectively.

APPENDIX IVC RTs results

The tables in this appendix, except the last two (IVC7 - 8), are summations of the experimental results, and use the following symbols:

- n - the number of RTs in each cell
- ΣX - the sum of those RTs (in m.sec.)
- ΣX^2 - their sum of squares (in m.sec.)
- $\overline{X}$ - the mean RT in each cell (in m.sec.)

Table IVC1 Fourth experiment - results: Total

		Control			Experiment				
		before	after	TOTAL	Exp.1	Exp.2	Exp.3	TOTAL	TOTAL
Subjects	1	57 26,399 13,045,819 463.14	54 24,387 12,373,517 451.61	111 50,786 25,419,336 457.53	50 27,367 15,883,363 547.34	53 28,636 17,167,364 540.30	42 22,484 13,938,032 535.33	145 78,487 45,988,759 541.29	256 129,273 71,408,095 504.97
	2	57 25,130 11,815,346 440.88	56 25,943 13,357,671 463.27	113 51,073 25,173,017 451.97	56 33,439 21,684,365 597.13	55 32,737 22,167,411 595.22	57 30,642 17,576,214 537.58	168 96,818 61,427,990 576.30	281 147,891 86,601,007 526.30
	3	57 28,227 14,858,685 495.21	56 26,961 13,738,477 481.45	113 55,188 28,597,162 488.39	55 32,034 20,217,458 582.44	53 38,644 31,274,714 729.132	59 42,711 34,784,003 723.92	167 113,389 86,276,175 678.98	280 168,577 114,873,337 602.06
	4	56 25,047 11,604,313 447.27	54 23,940 11,285,366 443.33	110 48,987 22,889,679 445.34	50 23,880 12,150,494 477.60	46 21,894 11,221,982 475.96	54 26,634 13,940,428 493.22	150 72,408 37,312,904 482.72	260 121,395 60,202,583 466.90
	5	60 25,749 11,480,039 429.15	55 23,606 10,888,702 429.20	115 49,355 22,368,741 429.17	58 34,898 23,205,712 601.69	53 32,150 22,800,600 606.60	59 31,520 17,888,546 534.24	170 98,568 63,894,858 579.81	285 147,923 86,263,599 519.03
TOTAL		287 130,552 62,804,202 454.89	275 124,837 61,643,733 453.95	562 255,389 124,447,935 454.43	269 151,618 93,141,392 563.64	260 154,061 104,632,071 592.54	271 153,991 97,127,223 568.23	800 459,670 294,900,686 574.59	1,362 715,059 419,348,621 525.01

Table IVC2 Fourth experiment - results: Visual words

		Control			Experiment				TOTAL
		before	after	TOTAL	Exp.1	Exp.2	Exp.3	TOTAL	
Subjects	1	10 4,906 2,431,208 490.60	10 5,663 3,602,059 566.30	20 10,569 6,033,267 528.45	11 6,182 3,537,594 562.00	9 4,810 2,649,780 534.44	9 5,187 3,177,733 576.33	29 16,179 9,365,107 557.89	49 26,748 15,398,374 545.88
	2	11 5,303 2,604,867 482.09	11 5,666 3,017,474 515.09	22 10,969 5,622,341 498.59	12 8,097 5,981,659 674.75	11 6,899 4,600,323 627.18	12 6,113 3,211,143 509.41	35 21,109 13,793,125 603.11	57 32,078 19,415,466 562.77
	3	11 6,022 3,359,106 547.45	12 6,233 3,285,799 519.41	23 12,255 6,644,905 532.82	12 6,076 3,097,506 506.33	12 8,715 6,465,341 726.25	12 9,714 8,588,054 809.50	36 24,505 18,150,901 680.69	59 36,760 24,795,806 623.05
	4	10 4,902 2,446,300 490.20	10 5,360 2,933,204 536.00	20 10,262 5,379,504 513.10	10 5,563 3,176,567 556.30	10 5,156 2,771,878 515.60	12 6,709 4,069,555 559.08	32 17,428 10,018,000 544.62	52 27,690 15,397,504 537.50
	5	12 5,965 2,992,095 498.08	12 5,909 2,981,439 492.41	24 11,874 5,973,534 494.75	12 6,314 3,461,210 526.16	10 5,230 2,854.218 523.00	12 5,899 2,980,531 491.58	34 17,443 9,295,959 513.02	58 29,317 15,269,493 505,47
TOTAL		54 27,098 13,833,576 501.81	55 28,831 15,819,975 524.20	109 55,929 29,653,551 513.11	57 32,232 19,254,536 565.47	52 30,810 19,341,540 592.50	57 33,622 22,027,016 589.86	166 96,664 60,623,092 582.31	275 152,593 90,276,643 554.88

Table IVC3 Fourth experiment - results: Numbers

		Control			Experiment				TOTAL
		before	after	TOTAL	Exp.1	Exp.2	Exp.3	TOTAL	
Subjects	1	11 5,443 2,827,937 494.81	11 4,974 2,281,890 452.18	22 10,417 5,109,827 473.50	8 4,491 2,581,497 561.37	10 5,359 3,157,483 535.90	9 4,645 2,454,543 516.11	27 14,495 8,193,523 536.85	49 24,912 13,303,350 508.40
	2	12 5,290 2,398,490 440.83	11 5,401 2,719,887 491.00	23 10,691 5,118,377 464.82	11 5,945 3,358,951 540.45	9 4,905 2,845,297 545.00	11 5,782 3,316,670 525.63	31 16,632 9,520,918 536.51	54 27,323 14,639,295 505.98
	3	11 5,465 2,751,207 496.81	11 5,819 3,196,635 529.00	22 11,284 5,947,842 512.90	12 6,857 4,032,557 571.41	11 7,249 4,989,113 659.00	12 7,326 4,841,328 610.50	35 21,432 13,862,998 612.34	57 32,716 19,810,840 573.96
	4	12 6,221 3,275,943 518.41	11 4,949 2,310,531 449.90	23 11,170 5,586,474 485.65	9 4,649 2,550,741 516.55	1 4,882 2,854,574 542.44	10 5,185 2,747,553 518.50	28 14,716 8,152,868 525.57	51 25,886 13,739,342 507.56
	5	12 5,249 2,313,849 437.41	10 4,856 2,470,686 485.60	22 10,105 4,784,535 459.31	12 6,223 3,385,481 518.58	10 5,097 2,722,401 509.70	11 5,410 2,777,458 491.81	33 16,730 8,885,340 506.96	55 26,835 13,669,875 487.90
TOTAL		58 27,668 13,567,426 477.03	54 25,999 12,979,629 481.46	112 53,667 26,547,055 479.16	52 28,165 15,909,227 541.63	49 27,492 16,568,868 561.06	53 28,348 16,137,552 534.86	154 84,005 48,615,647 545.48	266 137,672 75,162,702 517.56

Table IVC4 Fourth experiment - results: Lines

		Control			Experiment				TOTAL
		before	after	TOTAL	Exp.1	Exp.2	Exp.3	TOTAL	
Subjects	1	12 4,045 1,379,845 337.08	11 3,445 1,109,193 313.18	23 7,490 2,489,038 325.65	11 4,946 2,311,592 449.63	12 5,528 2,958,624 460.66	6 2,348 968,330 391.33	29 12,822 6,238,546 442.13	52 20,312 8,727,584 390.61
	2	12 4,651 1,820,141 387.58	12 5,198 2,400,232 433.16	24 9,849 4,220,373 410.37	12 5,973 3,039,403 497.75	11 5,606 3,101,125 509.54	12 5,259 2,349,963 438.25	35 16,837 8,490,491 481.05	59 26,686 12,710,864 452.30
	3	12 5,083 2,206,373 423.58	12 5,155 7,395,213 429.58	24 10,238 4,601,586 426.58	12 6,186 3,305,110 515.50	11 5,921 3,300,759 538.27	12 6,199 3,540,913 516.58	35 18,306 10,146,782 523.02	59 28,544 14,748,368 483.79
	4	12 5,130 2,232,652 427.50	12 4,667 1,881,605 388.91	24 9,797 4,114,257 408.20	12 5,688 2,932,870 474.00	12 5,111 2,426,715 425.91	12 4,586 1,783,258 382.16	36 15,385 7,142,843 427.36	60 25,182 11,257,100 419.70
	5	12 4,695 1,847,165 391.25	12 4,615 1,801,531 384.58	24 9,310 3,648,696 387.91	10 5,309 2,875,835 530.90	12 5,897 3,376,405 491.41	12 5,240 2,374,248 436.66	34 16,446 8,626,488 483.70	58 25,756 12,275,184 444.06
TOTAL		60 23,604 9,486,176 393.40	59 23,080 9,587,774 391.18	119 46,684 19,073,950 392.30	57 28,102 14,464,810 493.01	58 28,062 15,163,628 483.82	54 23,632 11,016,712 437.63	169 79,796 40,645,150 472.16	288 126,480 59,719.100 439.16

TABLE IVC5 Fourth experiment - results: Auditory words

		Control			Experiment				TOTAL
		before	after	TOTAL	Exp.1	Exp.2	Exp.3	TOTAL	
Subjects	1	12 6,798 4,052,674 566.50	10 5,966 3,772,904 596.60	22 12,764 7,825,578 580.18	11 7,370 5,205,974 670.00	10 6,884 5,194,312 688,40	8 5,320 3,762,206 665.00	29 19,574 14,162,492 674.96	51 32,338 21,988,070 634.07
	2	11 5,467 3,003,459 497.00	10 4,056 1,774,416 405.60	21 9,523 4,777,875 453.47	12 8,334 6,164,622 694.50	12 8,139 6,683,895 678.25	11 7,179 4,916,033 652.63	35 23,652 17,764,550 675.77	56 33,175 22,542,425 592.41
	3	12 7,445 4,882,079 620.41	10 5,482 3,161,286 548.20	22 12,927 8,043,365 587.59	11 8,375 7,018,773 761.36	12 10,332 10,211,460 861.00	12 10,348 9,850,160 862.33	35 29,055 27,080,393 830.14	57 41,982 35,123,758 736.52
	4	10 4,087 1,731,241 408.70	10 4,950 2,530,686 495.00	20 9,037 4,261,927 451.85	8 3,094 1,248,238 386.75	4 2,161 1,201,101 540.25	9 4,662 2,496,756 518.00	21 9,917 4,946,095 472.23	41 18,954 9,208,022 462.29
	5	12 5,980 3,046,912 498.33	9 4,007 2,001,003 445.22	21 9,987 5,047,915 475.57	12 7,505 5,008,219 625.41	12 9,903 9,671,879 825.25	12 7,775 5,159,103 647.91	36 25,183 19,839,201 699.52	57 35,170 24,887,116 617.01
TOTAL		57 29,777 16,716,365 522.40	49 24,461 13,240,295 499.20	106 54,238 29,956,660 511.67	54 34,678 24,645,826 642.18	50 37,419 32,962,647 748.30	52 35,284 26,184,258 678.53	156 107,381 83,792,731 688.33	262 161,619 113,749,391 616.86

Table IVC6 Fourth experiment - results: Pips

		Control			Experiment				TOTAL
		before	after	TOTAL	Exp.1	Exp.2	Exp.3	TOTAL	
Subjects	1	12 5,207 2,354,155 433,91	12 4,339 1,607,471 361.58	24 9,546 3,961,626 397.75	9 4,378 2,246,706 486.44	12 6,055 3,207,165 504.58	10 4,984 3,961,626 498.40	31 15,417 8,029,091 497.32	55 24,963 11,990,717 453.87
	2	11 4,419 1,988,389 401.72	12 5,622 3,445,662 468.50	23 10,041 5,434,051 436.55	9 5,090 3,139,730 565.55	12 7,189 4,936,771 599.08	11 6,309 3,782,405 573.54	32 18,588 11,858,906 580.87	55 28,629 17,292,957 520.52
	3	11 4,212 1,659,920 382.90	11 4,272 1,699,544 388.36	22 8,482 3,359,464 385.63	8 4,540 2,763,512 567.50	7 6,427 6,308,041 918.14	11 9,124 7,963,548 829.45	26 20,091 17,035,101 772.73	48 28,575 20,394,565 595.31
	4	12 4,707 1,918,177 392.25	11 4,014 1,629,340 364.90	23 8,721 3,547,517 379.17	11 4,886 2,242,078 444.18	11 4,584 1,967,714 416.72	11 5,492 2,843,306 499.27	33 14,962 7,053,098 453.39	56 23,683 10,600,615 422.91
	5	12 3,860 1,280,018 321.66	12 4,219 1,634,043 351.58	24 8,079 2,914,061 336.62	12 9,547 8,474,967 795.58	9 6,023 4,175,697 669.22	12 7,196 4,597,206 599.66	33 22,766 17,247,870 689.87	57 30,845 20,161,931 541.14
TOTAL		58 22,405 9,200,659 386.29	58 22,466 10,016,060 387.34	116 44,871 19,216,719 386.81	49 28,441 18,866,973 580.42	51 30,278 20,595,388 593.68	55 33,105 21,761,705 601.90	155 91,824 61,224,066 592.41	271 136,695 80,440,785 504.40

Table IVC7 Fourth experiment: unweighted means matrix

		Subj.	W	N	L	W	P	TOTAL
CONTROL	BEFORE	1	490.60	494.81	337,08	566.50	433.91	2,322.90
		2	482.09	440.83	387.58	497.00	401.72	2,209.22
		3	547.45	496.81	423.58	620.41	382.90	2,471.15
		4	490.20	518.41	427.50	408.70	392.25	2,237.06
		5	497.08	437.41	391.25	498.33	321.66	2,145.73
		T	2,507.42	2,388.27	1,966.99	2,590.94	1,932.44	11,386.06
	AFTER	1	566.30	452.18	313.18	596.60	361.58	2,289.84
		2	515.09	491.00	433.16	405.60	468.50	2,313.35
		3	519.41	529.00	429.58	548.20	388.36	2,414.55
		4	536.00	449.90	388.91	495.00	364.90	2,234.71
		5	492.41	485.60	384.58	445.22	351.58	2,159.39
		T	2,629.21	2,407,68	1,949.41	2,490.62	1,934.92	11,411.84
	TOTAL		5,136.63	4,795.95	3,916.40	5,081.56	3,867.36	22,797.90
EXPERIMENT	Exp.1	1	562.00	561.37	449.63	670.00	486.44	2,729.44
		2	674.75	540.45	497.75	694.50	565.55	2,973.00
		3	506.33	571.41	515.50	761.36	567.50	2,922.10
		4	556.30	516.55	474.00	386.75	444.18	2,377.78
		5	526.16	518.58	530.90	625.41	795.58	2,996.63
		T	2,825.54	2,708.36	2,467.78	3,138.02	2,859.25	13,998.95
	Exp.2	1	594.44	535.90	460.66	688.40	504.58	2,723.98
		2	627.18	545.00	509.54	678.25	599.08	2,959.05
		3	726.25	659.00	538.27	861.00	918.14	3,702.66
		4	515.60	542.44	425.91	540.25	416.72	2,440.92
		5	523.00	509.70	491.41	825.25	669.22	3,018.58
		T	2,926.47	2,792.04	2,425.79	3,593.15	3,107.74	14,845.19
	Exp.3	1	576.33	516.11	391.33	665.00	498.40	2,647.17
		2	509.41	525.63	438.25	652.63	537.54	2,663.46
		3	809.50	610.50	516.58	862.33	829.45	3,628.36
		4	559.08	518.50	382.16	518.00	499.27	2,477.01
		5	491.58	491.81	436.66	647.91	599.66	2,667.62
		T	2,945.90	2,662.55	2,164.98	3,345.87	2,964.32	14,083.62
	TOTAL		8,697.91	8,162.95	7,058.55	10,077.04	8,931.31	42,927.76
TOTAL			13,834.54	12,958.90	10,974.95	15,158.60	12,798.67	65,725.66

Table IVC8 Fourth experiment: means of unweighted means matrix

Condition	Tasks				
	visual words	numbers	lines	auditory words	pips
control	513.66	479.60	391.64	508.16	386.74
experimental	579.86	544.19	470.57	671.80	595.42

There is a slight difference between this means, based on an unweighted method, and the means of Table 3.5 which are based on the actual experimental results (or weighted method).

APPENDIX IVD Statistical calculations for control comparisons

The formula for calculating the sum of squares was developed to fit this particular experimental design. For further discussion about planned comparisons in unequal samples see Winer (1971 pp.215 - 218) and Keppel (1973 pp.352 - 355 and 360 - 363).

$$SS_{Aa - Aa \text{ at } Bb} = \bar{n}_h \cdot \frac{(\overline{AB}'ab - \overline{AB}'ab)^2}{\frac{1}{n_n Cc} + \frac{1}{n_n Cc}}$$

Where $\bar{n}_h$ - is the harmonic mean

$\overline{AB}'ab$ - are the means to be compared, based on the unweighted means matrix (Appendix IVC, Table IVC8).

n_n - is the number of means per condition (i.e. number of subjects.

Cc - is the number of conditions (i.e. before and after).

APPENDIX IVD 1   Calculations of sums of squares:

$$SS_{A} \text{ vis. words} - {}_{A} \text{ aud. words at } B_1 = 10.632 \frac{(513.66-508.16)^2}{\frac{1}{5x2} + \frac{1}{5x2}} = 1{,}608.09$$

$$SS_{AL} - {}_{AP} \text{ at } B_1 = 10.632 \frac{(391.64-386.74)^2}{\frac{2}{10}} = 1{,}276.37$$

The denominator of the F ratio (the formula used and the various approaches for calculating the degrees of freedom were discussed in the study:

$$\frac{\text{MS error a} + (b-1) \text{ MS error ab}}{b} =$$

$$\frac{72{,}560.0 + (2-1)\ 55{,}752.62}{2} = 64{,}156.31$$

The data for this calculation was extracted from the summary of the analysis Table 3.7.

Appendix IVD2   Calculation of harmonic mean:

The formula for this mean was developed in Appendix IVB. The 'ni' is extracted from Appendix IVC (Tables IVC2, 3, ... 6).

$$\bar{n}_h = \frac{axbxcxs}{\Sigma(\frac{1}{n_i})} = \frac{5x5x5}{\frac{1}{10}+\frac{1}{11}+ \dots +\frac{1}{11}+\frac{1}{12}}$$

$$\bar{n}_h = 10.631{,}512{,}4$$

APPENDIX IVE Fourth experiment: statistical calculations for ANOVA

The calculations are based on the formulae developed in Appendix IVB.

Appendix IVE 1 Calculation of error terms:

The data for these calculations are extracted from Table 3.5 and Appendix IVC, Tables IVC 1, 2, ... 6.

$$\frac{T^2}{abcds} = \frac{715{,}059^2}{1362} = 375{,}410{,}700.059$$

$$\Sigma X^2 = 419{,}348{,}621$$

$$\Sigma \frac{A^2}{bcds} = \frac{152{,}593^2}{275} + \frac{137{,}672^2}{266} \quad \frac{126{,}480^2}{288} + \frac{161{,}619^2}{262} + \frac{136{,}695^2}{271} =$$

$$380{,}118{,}819$$

$$\Sigma \frac{B^2}{acds} = \frac{255{,}389^2}{562} + \frac{459{,}670^2}{800} = 380{,}176{,}759$$

$$\frac{B_1{}^2}{acds} = \frac{255{,}389^2}{562} = 116{,}056{,}123$$

$$\frac{B_2{}^2}{acds} = \frac{459{,}670^2}{800} = 264{,}120{,}636$$

$$\Sigma \frac{(BC)^2}{ads} = \frac{130{,}552^2}{287} + \frac{124{,}837^2}{275} + \frac{151{,}618^2}{269} + \frac{154{,}061^2}{260} + \frac{153{,}991^2}{271} =$$

$$380{,}303{,}908.2$$

$$\Sigma \frac{(BC_1)^2}{ads} = \frac{130{,}552^2}{287} + \frac{124{,}837^2}{275} = 116{,}056{,}245$$

$$\Sigma \frac{(BC_2)^2}{ads} = \frac{151{,}618^2}{269} + \frac{154{,}061^2}{260} + \frac{153{,}991^2}{271} = 264{,}247{,}663$$

$$\Sigma \frac{(AB)^2}{cds} = \frac{55{,}929^2}{109} + \frac{53{,}667^2}{112} + \cdots + \frac{107{,}381^2}{156} + \frac{91{,}824^2}{155} = 385{,}938{,}619$$

$$\Sigma \frac{(ABC)^2}{ds} = \frac{27{,}098^2}{54} + \frac{28{,}831^2}{55} + \cdots + \frac{30{,}278^2}{51} + \frac{33{,}105^2}{55} = 386{,}420{,}055.1$$

$$\Sigma \frac{(AS)^2}{bcd} = \frac{26{,}748^2}{49} + \frac{32{,}078^2}{57} + \cdots + \frac{23{,}683^2}{56} + \frac{30{,}845^2}{57} = 383{,}933{,}368$$

Appendix IVE 1 (Continued)

$$\Sigma \frac{(BS)^2}{acd} = \frac{50,786^2}{111} + \frac{51,073^2}{113} + \cdots + \frac{72,408^2}{150} + \frac{98,568^2}{170} = 383,642,924$$

$$\Sigma \frac{(BS_1)^2}{acd} = \frac{50,786^2}{111} + \frac{51,072^2}{113} + \cdots + \frac{48,987^2}{110} + \frac{49,355^2}{115} = 116,270,650$$

$$\Sigma \frac{(BS_2)^2}{acd} = \frac{78,487^2}{145} + \frac{96,818^2}{168} + \cdots + \frac{72,408^2}{150} + \frac{98,568^2}{170} = 267,372,274$$

$$\Sigma \frac{(BCS)^2}{ad} = \frac{26,399^2}{57} + \frac{25,130^2}{57} + \cdots + \frac{26,634^2}{54} + \frac{31,520^2}{59} = 384,762,141.0$$

$$\Sigma \frac{(BCS_1)^2}{ad} = \frac{26,399^2}{57} + \frac{25,130^2}{57} + \cdots + \frac{23,940^2}{54} + \frac{23,606^2}{55} = 116,294,265.4$$

$$\Sigma \frac{(BCS_2)^2}{ad} = \frac{27,367^2}{50} + \frac{33,439^2}{56} + \cdots + \frac{26,634^2}{54} + \frac{31,520^2}{59} = 268,467,875.6$$

$$\Sigma \frac{(ABS)^2}{cd} = \frac{10,569^2}{20} + \frac{10,969^2}{22} + \cdots + \frac{14,962^2}{33} + \frac{22,766^2}{33} = 391,457,771.3$$

$$\Sigma \frac{(ABCS)^2}{d} = \frac{4,906^2}{10} + \frac{5,303^2}{11} + \cdots + \frac{5,492^2}{11} + \frac{7,196^2}{12} = 393,563,903.7$$

$$\Sigma \frac{S^2}{abcd} = \frac{129,273^2}{256} + \frac{147,891^2}{281} + \cdots + \frac{121,395^2}{260} + \frac{147,923^2}{285} = 378,064,289$$

Appendix IVE 2 Calculation of other terms:

The data for these calculations are extracted from Appendix IVC, Table IVC7.

$$\frac{(T')^2}{abcs} = \frac{65,725.66^2}{125} = 34,558,899.05$$

$$\Sigma X^2 = 419,348,621$$

$$\Sigma \frac{(A')^2}{bcs} = \frac{13,834.54^2}{25} + \frac{12,958.90^2}{25} + \frac{10,974.95^2}{25} + \frac{15,158.60^2}{25} +$$

$$\Sigma \frac{12,798.67^2}{25} = 34,934,648.85$$

$$\Sigma \frac{(B')^2}{acs} = \frac{22,797.90^2}{50} + \frac{42,927.76^2}{75} = 34,965,452.60$$

$$\frac{(B_1')^2}{acs} = \frac{22,797.90^2}{50} = 10,394,884.80$$

Appendix IVE 2 (Continued)

$$\frac{(B_2')^2}{acs} = \frac{42{,}927.76^2}{75} = 24{,}570{,}567.80$$

$$\Sigma \frac{(BC')^2}{as} = \frac{11{,}386.06^2}{25} + \frac{11{,}411.84^2}{25} + \frac{13{,}998.95^2}{25} + \frac{14{,}845.19^2}{} +$$

$$\Sigma \frac{14{,}083.62^2}{25} = 34{,}982{,}842.96$$

$$\Sigma \frac{(BC_1')^2}{as} = \frac{11{,}386.06^2}{25} + \frac{11{,}411.84^2}{25} = 10{,}394{,}898.18$$

$$\Sigma \frac{(BC_2')^2}{as} = \frac{13{,}998.95^2}{25} + \frac{14{,}845.19^2}{25} + \frac{14{,}083.62^2}{25} = 24{,}587{,}944.78$$

$$\Sigma \frac{(AB')^2}{cs} = \frac{5{,}136.63^2}{10} + \frac{4{,}795.95^2}{10} + \cdots + \frac{10{,}077.04^2}{15} + \frac{8{,}931.31^2}{15} =$$

35,445,338.69

$$\Sigma \frac{(ABC')^2}{s} = \frac{2{,}507.42^2}{5} + \frac{2{,}629.21^2}{5} + \cdots + \frac{3{,}107.74^2}{5} + \frac{2{,}964.32^2}{5} =$$

35,489,046.97

APPENDIX IVF   Statistical calculations for planned comparisons within tasks

The formula for calculating the sum of squares was already discussed in Appendix IVD.

$$SS_B \text{ at } A_a = \bar{n}_h \frac{(\overline{AB}'ab - \overline{AB}'ab)}{\frac{1}{n_n C_1} + \frac{1}{n_n C_2}}$$

The following sums of squares are needed for the calculations:

$$SS_B \text{ at }_A \text{ vis. words} = 10.632 \frac{(513.66 - 579.86)^2}{\frac{1}{5x2} \quad \frac{1}{5x3}} = 279,564.61$$

$$SS_B \text{ at }_A \text{ numbers} = 10.632 \frac{(479.60 - 544.19)2}{\frac{1}{10} + \frac{1}{15}} = 266,131.81$$

$$SS_B \text{ at }_A \text{ lines} = 10.632 \frac{(391.64 - 470.57)^2}{\frac{1}{10} + \frac{1}{15}} = 397,420.65$$

$$SS_B \text{ at }_A \text{ aud. words} = 10.632 \frac{(508.16 - 671.80)^2}{\frac{1}{10} + \frac{1}{15}} = 1,708,225.34$$

$$SS_B \text{ at }_A \text{ pips} = 10,632 \frac{(386.74 - 595.42)^2}{\frac{1}{10} + \frac{1}{15}} = 2,777,972.07$$

The denominator of the F ratio (the formula used and the considerations for calculating the degrees of freedom were discussed earlier in the study):

$$\frac{MS \text{ error } b + (a-1)\ MS \text{ error } ab}{a} = \frac{203,140.25 + (5-1)\ 55,752.62}{5} =$$

85,230.14

The data for the calculation was extracted from Table 3.7.

APPENDIX IVF (Continued)

In order to check whether the calculations were carried out properly, Winer (1971 p.441) suggests the following formula:

$$SS_{\Sigma B \text{ at } Ai} = SS_B + SS_{AxB}$$

$$5,429,314.47 \overset{?}{\approx} 4,322,284 + 1,107,123$$

$$5,429,314.47 \approx 5,429,407.00$$

The difference between the two results is less than .00002%.

APPENDIX IVG Planned comparisons within tasks: estimation of magnitude of experimental effects

Estimations of magnitude of experimental effects are based either on mean squares or directly on F ratios. The calculations of the comparisons, to be estimated, are based on an approximate MS error developed by Satterthwaite (1946) and adopted by Winer (1971 pp.544 - 545). The estimations of magnitude of experimental effect can only be as accurate as the approximation of the F ratios on which they are based.

The formula used here for calculating $\hat{\omega}^2$ is based directly on the F ratios (developed in Appendix IIC), but it was slightly changed - in a conservative manner - to fit this particular design

$$\hat{\omega}^2_{B \text{ at } Aa} = \frac{(df_B \text{ at } _{Aa})\ (F_B \text{ at } _{Aa} - 1)}{(b-1)(F_B-1)+(b-1)(a-1)(F_{AB}-1)+(abc-1)}$$

$$\hat{\omega}^2_{B \text{ at } A \text{ vis. words}} = \frac{1x(3.28-1)}{1x(21.28-1)+1x4x(4.96-1)+(5x5-1)} = 0.0379241$$

$$\hat{\omega}^2_{B \text{ at } A \text{ numbers}} = \frac{3.12-1}{60.12} = 0.0352628$$

$$\hat{\omega}^2_{B \text{ at } A \text{ lines}} = \frac{4.66-1}{60.12} = 0.0608782$$

$$\hat{\omega}^2_{B \text{ at } A \text{ aud. words}} = \frac{20.04-1}{60.12} = 0.3166999$$

$$\hat{\omega}^2_{B \text{ at } A \text{ pips}} = \frac{32.59-1}{60.12} = 0.5254491$$

The accuracy of these estimations can be checked in the following manner:

$$\Sigma\, \hat{\omega}^2_{B \text{ at } Aa} \stackrel{?}{=} 1$$

Appendix IVG (Continued)

The actual sum of the estimation is 0.9762141. Due to the fact that these estimations are based on approximations they can only be regarded as rough guidelines.

APPENDIX IVH Statistical calculations for experimental comparisons

This appendix uses the same formula and the same error terms used in Appendix IVD and in Table 3.6.

The following sums of squares are needed for the calculations:

$$SS_{A} \text{ vis. words} - {}_{A} \text{ aud. words at } B_2 = 10.632 \frac{(579.86 - 671.80)^2}{\frac{1}{5x3} + \frac{1}{5x3}} = 674,039.32$$

$$SS_{AL} - AP \text{ at } B_2 = 10.632 \frac{(470.57 - 595.42)^2}{\frac{1}{5x3} + \frac{1}{5x3}} = 1,242,949.04$$

Table IVH 1 Experimental comparisons: visual - auditory words, lines - pips

Source	SS	df	S	F
A vis.w. - A aud.w. at B_2	674,039.32	1	674,039.32	10.51*
A lines - A pips at B_2	1,242,949.04	1	1,242,949.04	19.37**
error		upper lim.100 lower lim. 20	64,156.31	

* $p < .01$ ** $p < .001$ according to lower or upper limits.

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