VISUAL INFORMATION PROCESSING IN VARIOUS DEGREES OF ALERTNESS

by

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ABSTRACT

The performance of the visual system under different attentional situations is unknown. This research has been undertaken to examine the normative characteristics of the peripheral visual field and how these functions change with allocation of attention to progressively demanding visual central tasks and when the auditory system is also stimulated.

For this purpose experiments were conducted with 24 subjects in which they responded to a variety of stimuli affecting their central and peripheral visual fields. Using a YES-NO method, their performance was evaluated for every task and stimulus position. Reaction times were also measured for every target as well as the effect of different audio inputs. Hardware and software were specially designed for these experiments. Some computer programs were also developed for data analysis.

An experimental function has been obtained for detectability of peripheral targets versus central task load and the size of the visual field has been determined under different conditions of visual and audio stimulation.

It has been found that peripheral detection is improved when subjects are occupied with a central task and that the visual field narrows when listening to speech.

A model of attention is proposed to better explain up-to-date observations in this field and some suggestions of applications and future work are also given.

Thesis Supervisor: Robert V. Kenyon
Title: Assistant Professor of Aeronautics
and Astronautics

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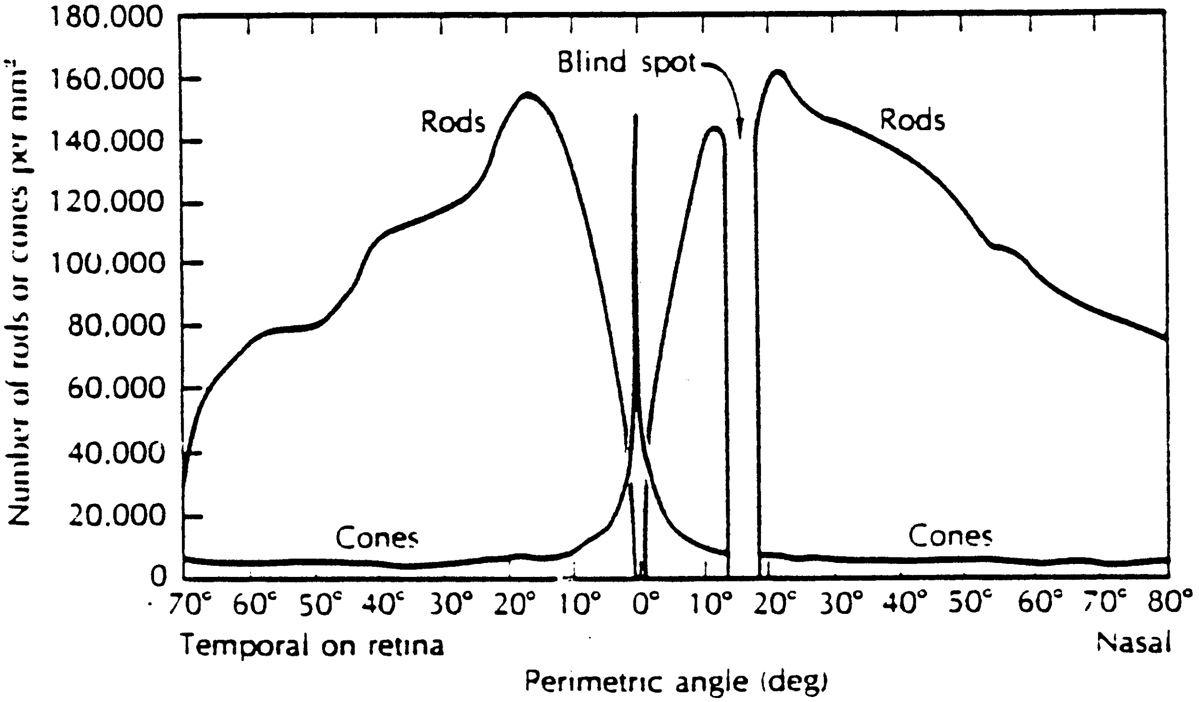
CHAPTER 1

BACKGROUND OF PROJECT AND MOTIVATION

Detection of targets in the peripheral visual field is a task on which all of us rely to successfully interact with our environment. Drivers, pilots, cyclists and pedestrians especially make continuous and competitive use of their central and peripheral visual fields as they must allocate limited attention resources to both central and peripheral tasks and other non-visual tasks such as listening for signals or messages. It is important to know how peripheral visual detection is affected when attention to other events increases. A driver, for instance, will be interested to know whether a over concentrating on a central task or maneuver will make him temporarily blind to peripheral events such as other vehicles overtaking, or on the other hand how non-visual tasks such as talking with a passenger or listening to the radio or the noise of the engine may influence the detection of targets necessary for efficient driving. Pilots will especially benefit as flying a plane makes extensive use of both central and peripheral visual fields in continous competition for attentional resources. Pedestrians and cyclists listening to portable radios may change their habits if the probability of seeing a lateral object decreases while they are listening to music.

Humans are provided with a surface at the back of the eyeball called the retina, where images are formed. The retina contains millions of photosensitive cells called rods and cones. Cones are only present in a significant number (see Figure 1.1) in the center of the retina. This area is called the fovea, its high concentration of cones makes it very sensitive to small detail and for this reason it is always in line with the object being fixated. Outside of this area, mostly rods are responsible for detecting light and objects, the number of rods per mm^2 decays towards the periphery of the retina outside the central area of ± 15 deg as shown in Figure 1.1 (Woodson, 1954). Cones at the fovea are sensitive to high spatial frequency (high detail) and their main task is to detect light, shapes and orientation. Sensitivity to light versus location of the stimulus on the retina has been studied verifying the supposition that the sensitivity follows the rod density (Pirenne, 1967). This is not, however, always so, for instance visual acuity decreases when viewing a bright object if the periphery is dimmed (Davson, 1963). This suggests that central and peripheral sensitivity can be influenced by other than anatomical characteristics. Many external factors affect the perception of peripheral targets, for example concentrating on a particular task, such as an interesting book, makes other events in the surroundings pass unnoticed. This and other examples show that prediction of sensitivity to peripheral events based on the distribution of rods alone may in some cases be completely wrong, in particular attention allotted to central tasks may decrease sensitivity to peripheral targets.



180.000
160.000
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0
Number of rods or cones per mm²
Blind spot
Rods
Rods
Cones
Cones
70° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60° 70° 80°
Temporal on retina
Nasal
Perimetric angle (deg)

FIGURE 1.1

It appears to be very likely that some unknown property of attention exists which selects some sources of information in the visual field over others to achieve an optimum input of relevant information to match the processing requirements at that time. This study will investigate how likely it would be to detect a target or what changes can be introduced to improve detectability.

1.1 Historical Perspective

1.1.1 Introduction

The mechanism by which some external events are selected for processing and others are not is called attention (i.e. Berlyne, 1960). In visual perception, such mechanism is believed responsible for some targets being ignored in favor of others that are classified as more interesting or important at that particular moment (Berlyne, 1950, 1951, 1967, 1970; Berlyne and Lawrance, 1964; McDonnell, 1967, 1970). Figure 1.2 illustrates this point, independent of fixation, either a goblet or a pair of faces is seen indicating a perceptual or central selection. It seems obvious that rules governing attention must exist if we are to make the most of our capailities to deal with information from the outside world. However, there is a limit to the number of things to which we can attend at any given time, regardless of how alert we are. We cannot, for instance, listen to a person talk while effectively watching a television program. On the other hand, attention can be switched from one event to another without difficulty, for example anyone can watch a TV program on one set, while ignoring another set tuned to a different station next to it.

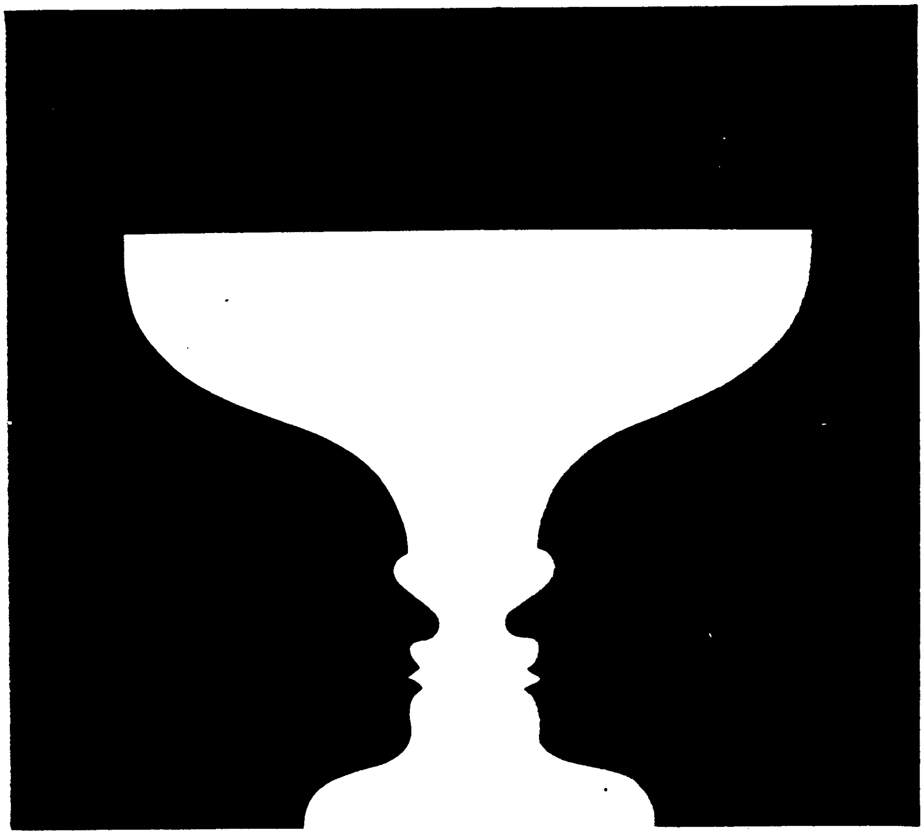


FIGURE 1.2

The early experimental investigators (Berlyne, 1969) began with unrepresentatively simple experimental situations. These were situations in which one stimulus was presented virtually alone or was, at any rate, so much more intense than any other that might be present that the subject's response could be safely ascribed to its influence. In the every day life of higher animals and human beings, however, this is not the way things are. Our sensory organs are generally flooded with stimuli, all of which are capable of evoking unlearned and, especially, learned responses. However, we can hardly perform more than a very small proportion of the responses associated with the objects that are stimulating our receptors. There is severe competition among stimuli for control over our behavior. Laws of attention are therefore needed to supplement the laws of learning and the laws of unlearned behavior if we are to predict what responses will actually occur in realistic stimulus situations.

1.1.2 Evidence for the Selective Aspects of Attention

Information relative to future behavior is picked up from the physical world by biological transducers called sensors. This information is coded, transmitted, processed and then used to make a decision and/or stored for future reference. The amount of information available from a single source (sense) can be enormous and only partially used due to psychological or physiological limitations. Processing or utilization of such information is often selective in that some senses do not receive the treatment necessary to elicit a response or to gain a place in memory, that is, the processing is not enough to guarantee their perception (Shaw, 1982). This phenomenon of selective attention has been studied by a number of investigators and tested in many experiments, arriving at two basic findings:

a) The perceptual mechanism has limited capacity in an informational sense. When stimuli for two tasks arrive simultaneously, the extend of the interference between them depends on the amount of information they conve (Webster and Thomson (1953, 1954), Webster and Solomon (1955), Poulton (1953, 1956) Broadbent (1952, 1956)). In each of these studies, one's ability to listen to the primary message was impaired when a second message was added which had more information than the primary message. It seems quite clear therefore that dealing with too many stimuli at one time is difficult perhaps due to a limit in the amount of information that some central mechanism can process in a given span of time.

(b) The probability of perceiving a target decreases if the number of separate sources containing irrelevant information increases. Many investigators (Duncan, 1980; Erikson and Spencer, 1969; Estes and Taylor, 1964; Fidell, 1970; Gardner, 1973; Green and Swets, 1966; Kinchla, 1969, 1974, 1977; Runelhart, 1970; Shaw, 1980; Shiffrim and Gardner, 1972) found that error rate and response time typically do increase with the number of signal locations.

Many theoretical mechanisms have been suggested to account for such attentional aspects of human information processing. All of them, however, can be classified in one of two proposed models of attention.

1.1.3 Attention Models

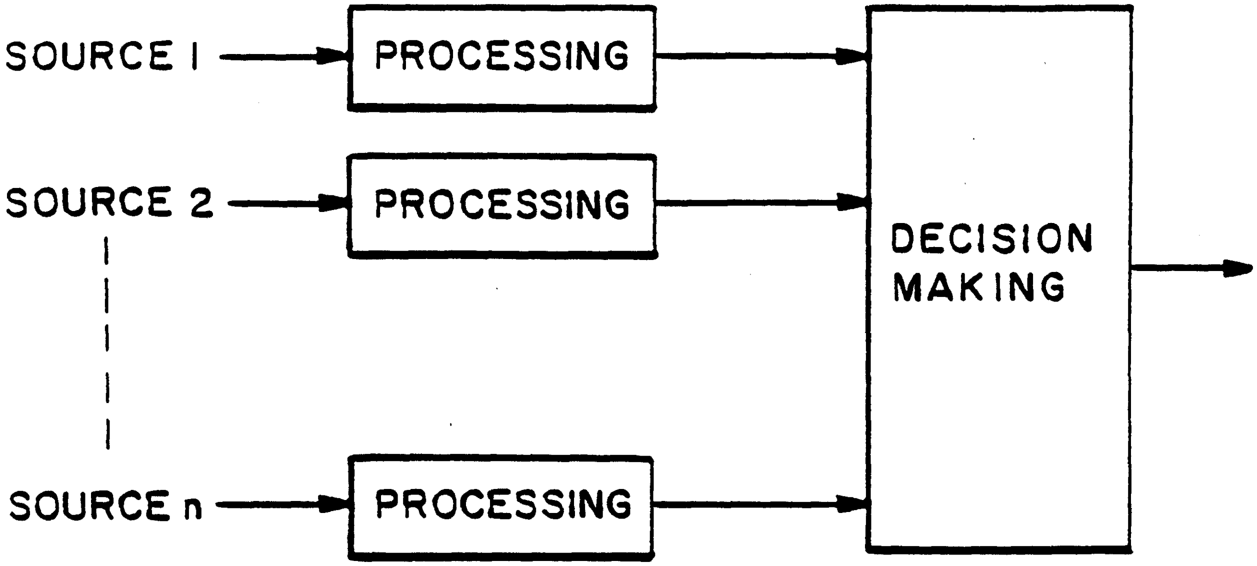
Whether attention is unitary or divisible was hotly debated in the nineteenth century and by experimentalists since 1950, but the question is still unanswered. Two common observations are relevant to the question of the unity of attention, but the answers they suggest are contradictory. The first of these observations is that one often performs several activities in parallel, and apparently divides one's attention among the activities, for instance driving and talking. The second basic observation is that when two stimuli are presented at once, often only one of them is perceived, while the other is completely ignored. If both are perceived, the responses that they elicit are often made in succession rather than simultaneously.

There is a common experience which is a good example for this observation. Sometimes when we are deeply concentrating on a task and someone asks us a question, we answer "what?" and a few seconds later we answer the question without having the question repeated. One possible explanation for this is that there is difficulty in perceiving* the second stimulus and a need to end the first task before responding to the new one. The frequent occurrence of suppresion or queuing in the organization of behaviour suggests a bottleneck, i.e. a stage of internal processing which can only operate on one stimulus at a time.

A person's sensory and motor performance is obviously constrained by some bottlenecks in his biological constitution. For example, a person is equipped with only a narrow field of clear and sharp vision and is therefore dependent on sequential scanning for acquisition of high spatial frequency information. A person is also equipped with a single tongue and must therefore arrange his verbal responses in sequence. Attention theorists have speculated that there are similarly limited processes in the central nervous system which would make a person unable to think, remember, perceive, or decide more than one thing at a time (Sternberg and Knoll, 1972).

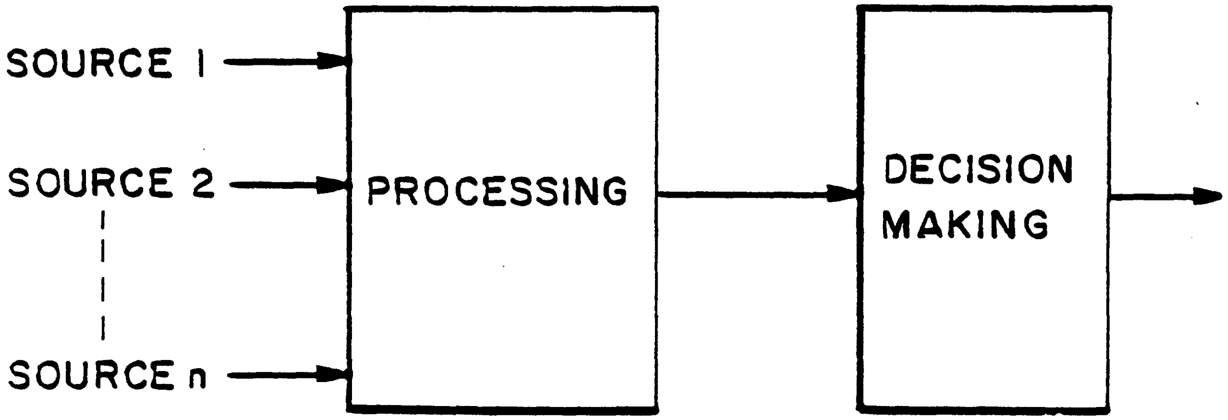
The modern study of attention has been dominated by theories which assume a bottleneck somewhere in the system; but the localization of the bottleneck has been contraversial. Discrepancies in the two models can be summarized in by looking at Figures 1.3 and 1.4 in which the bottleneck is located at different stages.

*Since 1913 (Watson, 1913), the general tendency is to consider perception as neural activity able to elicit a response, avoiding all reference to subjective experience. In this thesis, it is also used in that sense.



PARALLEL MODEL

FIGURE 1.3



SERIAL MODEL

FIGURE 1.4

The serial model illustrates some central aspects of the filter theory first proposed by Broadbent (1957, 1958). This theory assumes a bottleneck at or just before the stage of processing, so that only one stimulus at a time can be perceived (Figure 1.2). When two stimuli are presented at once, one of them is perceived immediately, while the sensory information that corresponds to the other is held briefly as an unanalyzed image. The observer can attend to such images and perceive their content only after the perceptual analysis of the first message has been completed. In this model, attention controls perception.

In the parallel model, which is associated with Deutsch and Deutsch (1963), the bottleneck is located at or just before the stage of decision making (see Figure 1.3). According to this model, the meanings of all stimuli are extracted in parallel and without interference. The bottleneck that imposes sequential processing is only encountered later. This bottleneck prevents the initiation of more than one response at a time and selects the response that best fits the requirements of the situation.

As an example of how the two models provide different answers to the same question, consider a person at a cocktail party who actively participates in the many loud conversations that take place in the room. Assuming that the sensory messages that correspond to several of these conversations reach the central nervous system of the listener, we may ask: (1) at what point is the attended conversation favored over the others? (2) to what level of processing do the unattended messages penetrate? According to the serial model, the unattended messages are "heard". According to the parallel model, all the conversations are heard, but only one is responded to.

Several experiments have been performed to answer these questions. For example, strong evidence was advanced against the serial model soon after it was formulated. Although the serial model accounts very well for the cocktail party phenomenon of selective attention, it fails to explain another common experience at parties: The detection of one's own name as soon as it is mentioned in an otherwise ignored conversation. Moray (1959) documented this everyday experience. He observed that subjects were much more likely to notice a message if it was preceded by their own name, than if it were not. Moray's results are incompatible with Broadbent's assumption that the sounds arriving at the ear are not analyzed as speech.

Neisser (1969) developed a visual analogue to the auditory situation, and he obtained results very similar to Moray's. He required subjects to read coherent text aloud and to ignore words printed in red under each line of the selected text. Subjects could do this very well since this situation is similar to ordinary reading, where the lines just above and below the attended line do not intrude. Neisser also showed that subjects do not recognize the words presented in the ignored lines, even when the same word is repeated in the text several times. Two thirds of his subjects, however, noticed their own name on a rejected line.

The evidence from these studies indicates that selective attention to inputs affects perceptual analysis, attenuating or rejecting the processing of other inputs. This is contrary to the parallel model. However, man is also capable of dividing his attention among concurrent messages. This is contrary to the serial model. Thus one of the main conclusions of research on attention is that man's cognitive operations are far more flexible than either of these bottleneck theories would suggest.

In Chapter 4, I shall propose a new model that solves the particular problem of the serial and parallel models and represents a good account of the experiments described in Chapters 2 and 3 and other investigators' observations.

1.2 Objectives of the Thesis

1.2.1 Summary of Findings

If we review the attention literature of the last few years, we shall find a considerable amount of work, mainly in hearing and vision. These two senses are easy and practical to experiment with and they also represent the most important source of input information as they are used almost constantly in everyday life so that any finding in attention mechanisms in this area would be of interest by itself, even if conclusions could not be generalized to other senses. However, many experiments in this area have mixed both audio and visual input, obtaining results that should be considered as general rules of attention but not necessarily applicable to vision or hearing alone. A typical example is the experiment in which the subject must read a text and simultaneously listen to recorded speech (Treisman, 1969). The differences in processing of audio inputs would make one caucious in applying the results of this experiments to vision. Another example is the experimental procedure to measure workload indirectly by means of a secondary task in a simulator (Wierwille et al, 1977). In this case, the subject is asked to drive safely under different conditions (usually different simulated velocities) and to perform a secondary task, such as reading numbers aloud whenever he thinks that he has time. Assuming that the total processing capability is a constant, the performance in the secondary task is an indication of the difficulty of the primary task. However, if the assumption of constancy is false (Easterbrook (1959) and others admit that total processing capability may be a function of central task demand), the only way to assess workload is using a primary task measure.

The conclusion therefore is that allowing intrusion from a very different task can be useless unless some baselilne data on vision has been previously determined with well defined task changes. Since 1958 (Broadbent, 1958), it has been known that the attention mechanism within the hearing sense is capable of selecting one of two speech messages. However, there have been no equivalent experiments for the visual system to show how two visual inputs compete for attention resources. The reason for this lack of experiments in selective attention within the visual system is that it has several characteristics that make experiments harder to design as compared with hearing; the most important may be that the visual system has an additional mechanism to select a particular target, i.e. the fixation system that aims the fovea to the target for maximum resolution. This way, many other target inputs away from the central field are automatically attenuated (visual acuity is very poor in the periphery) without diverting any attention mechanism whatsoever. It appears clear, however, that it would be of great importance to assess the performance of the visual system under different attentional situations.

The purpose of this thesis is to determine how subjects allocate their attentional resources when they must respond to a variety of tasks. All experiments involve detection of peripheral flashes as measures of the subject's awareness of peripheral visual field events. The results of these experiments are described in Chapter 3.3. The total number of correct detections (the hit rate if a percentage) is also very useful as it is a measure of the attention assigned to the peripheral task. In this case, the d' values will be calculated and thus independent of changes in subject criterion. According to models of attention this function should decrease monotonically as the central workload increases. The effect of audio inputs on visual detection will also be discussed. An audio input is systematically used to investigate how perceptual detection performance is affected while simultaneously attending to a conversation, radio program or acoustic signal. Section 3.4 describes the effects observed for this and other types of audio input such as white noise and music. In Section 3.6 we will look at the reaction time needed by the subjects to detect flashes in each particular range position and will see how it may vary according to central visual field task load.

In the light of the results obtained in this series of experiments and considering up to date literature in this field, I shall propose a model of attention in Chapter 4.4 together with other experiments that would naturally follow the ones that this thesis covers.

Some of the results from this thesis could be immediately applicated to some real life activities. For example, pilots, drivers, and operators of vehicles in general are engaged for a great part of their time in performing a primary task continuously while peripheral events are simultaneously searched. Inputs in the experiments such as talk or noise could simulate conversation, radio listening, radio communication or the background niose of the engine. The performance of the subject in the laboratory under controlled conditions will show what effects are attributable to each variable, which otherwise would be impossible to measure under real life conditions.

1.2.2 Signal Detection Theory

The detectability of flashes in the peripheral visual field is a measure of the psychophysical threshold. The classical theory of thresholds assumes that a real physiological threshold actually exists. A fixed stimulus, however, is not always judged to have the same intensity, but the sensation will follow a normal distribution (see Figure 1.5). A stimulus with an intensity corresponding to the threshold will then be detected 50 percent of the time (see Corso, 1967). This theory, although it has been used successfully for a long time, faces problems when the subject changes his criterion. This may happen, for instance, when he is offered some reward according to the number of correct detections. In this case, he will probably increase the number of detections by taking more risks; that is he will say 'yes' to a doubtful stimulus. On the other hand, if he is going to be penalized according to the number of false detections he will be very careful, signalling detection only when he is very certain that a stimulus exists. Obviously, two different thresholds would be obtained in these cases. As the subject's criterion is unpredictable and varies from subject to subject, we may obtain a collection of different thresholds for different subjects or for the same subject at different times while the threshold we are interested in has not changed. All experiments described in this thesis make use of signal detection theory to get rid of changes in detectability due to changes in the subject's criterion during the course of the experiment, which is possible as the experiments take a long time. To understand the design of the experiments described in the next chapter, it is important to understand signal detection theory. For this reason, we will briefly review the fundamentals of this theory and how it will

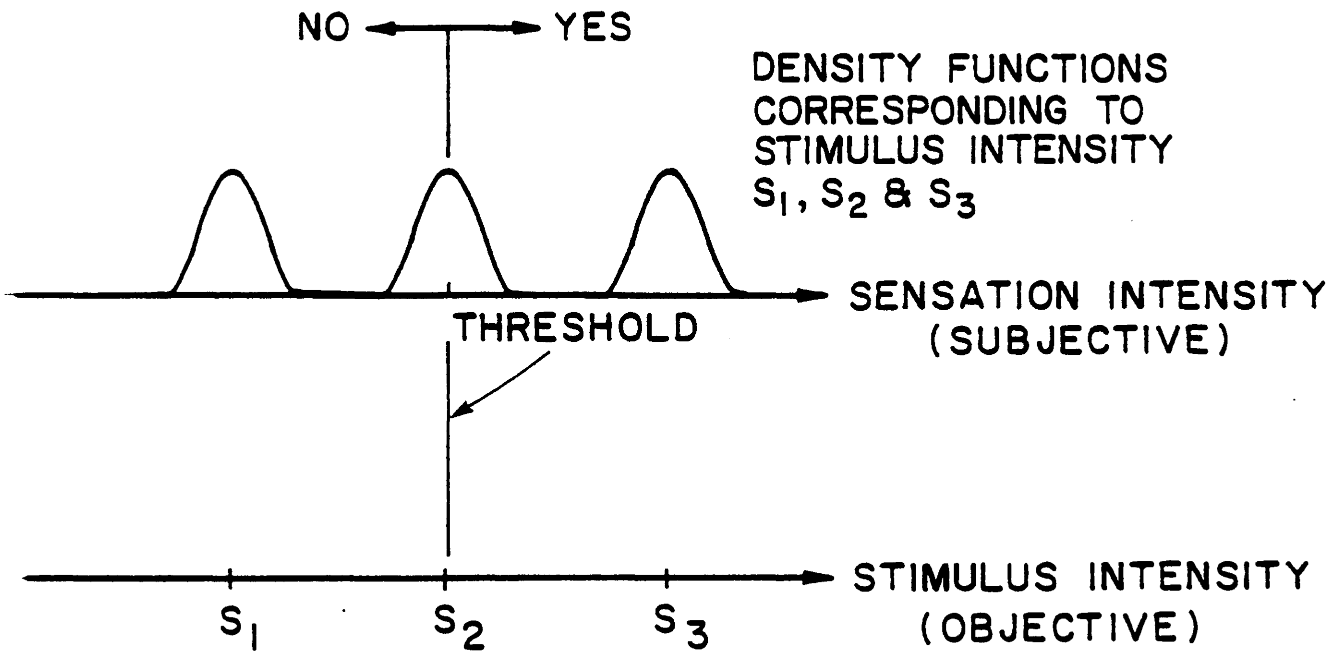


FIGURE 1.5

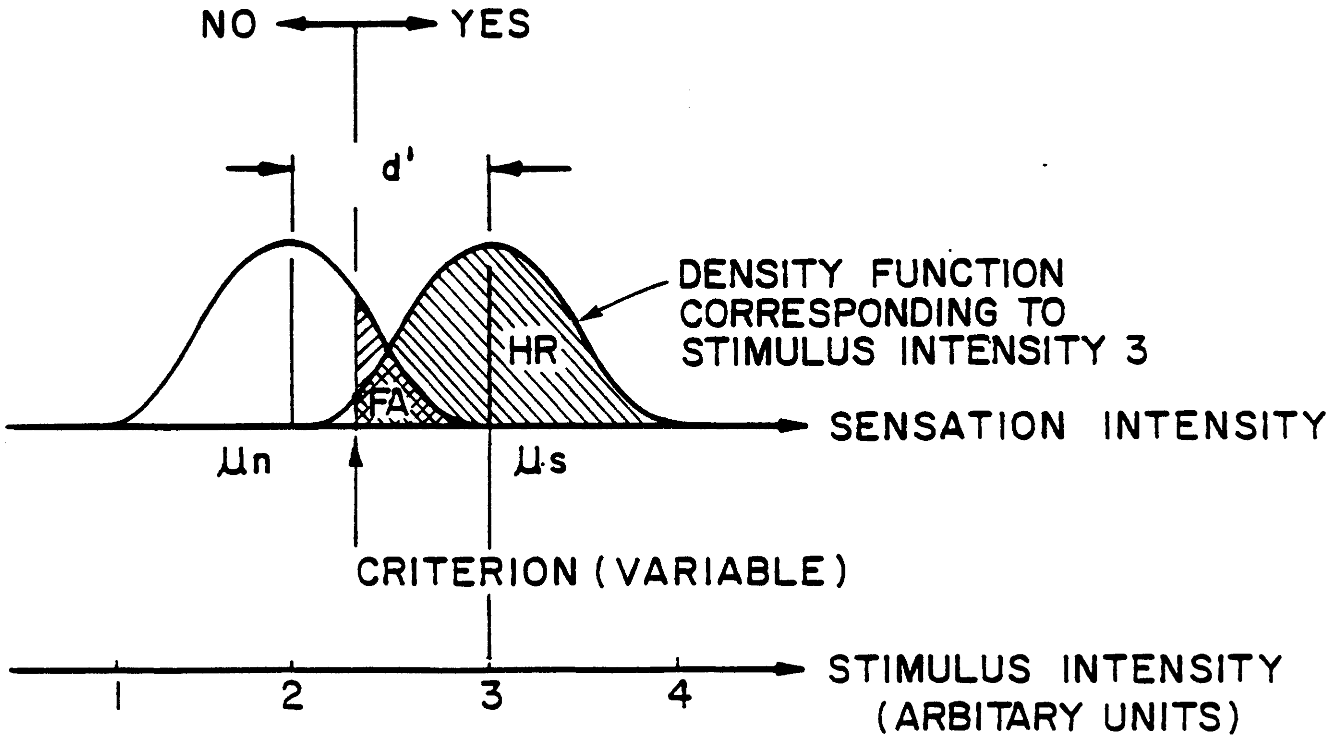


FIGURE 1.6

be applied to the experiments which are the object of this study.

The roots of signal detection theory lie both in statistical decision theory and in electrical engineering. Tanner and Swets (1954) first proposed its application to visual detection, and later Swets (1964) and Green and Swets (1966) compiled an account of its theoretical and empirical bases.

Signal detection theory assumes that sensitivity is continuous and that no true sensory threshold exists. What appears to be a threshold is in fact a response criterion. The only reason that the observer appears to have a threshold is that he is forced to distinguish between a signal and noise. The noise either is produced by internal events, such as random activity of neural origin, or is introduced by the experimenter as background. Since the observer's sensation is continuously variable, rather than discrete, he must set some criterion for deciding whether a signal was presented or not. When a sensation does not exceed the criterion , he responds as if no stimulus had been present. His task is like that of a statistical decision maker, who, on the basis of noisy or variable data, must decide whether or not his experimental manipulation produced a true difference. The decision maker is well aware that even a large difference could have been produced by a combination of chance factors. He therefore sets some criterion that defines the risk he is willing to take in accepting the difference as a true one, when there is no difference. The location of this criterion is assumed to be affected by non-sensory aspects of the experiment, such as the probability that the signal is presented or the rewards and costs of right and wrong decisions.

A necessary experimental condition to test signal detection theory is the inclusion of a substantial proportion of noise trials on which no signal is presented. Thus there are two types of trials: signal present, occurring on proportion p of the trials, and signal absent, occurring on 1-p proportion of the trials.

Noise alone and signal plus noise are assumed to be normally distributed in classical theory. Since the two distributions overlap (Figure 1.6), a sensation of given magnitude could be produced either by a noise alone or by a signal plus noise. Usually the standard deviations of the noise and signal distributions are assumed to be equal. The measure of the subject's sensitivity is the distance between the means of the two distributions m_n and m_s and is called d'. For a given observer and a given signal intensity, d' is assumed to remain constant. This can be checked by plotting the hit rate against the false alarm rate in what is known as the "receiver operating characteristic (ROC) curve" (Figure 1.7). For a fixed stimulus, the ROC curve can be plotted by systematically varying the ratio flash/blank trials or by asking the subject to change his criterion. This plot is checked with the theoretical curves (Figure 1.7) or tables (Swets, 1964).

The value of d' can be calculated from the hit rate and the false alarm rate alone. This can be done by calculating the Z scores (see Broadbent, 1971) or consulting tables (Swets, 1964) or from a plot of a family of d' curves such as that of Figure 1.7. These curves can be approximated by a number of analytical functions (Broadbent, 1971); one of these, modified to suit our experiments, is used in the computer

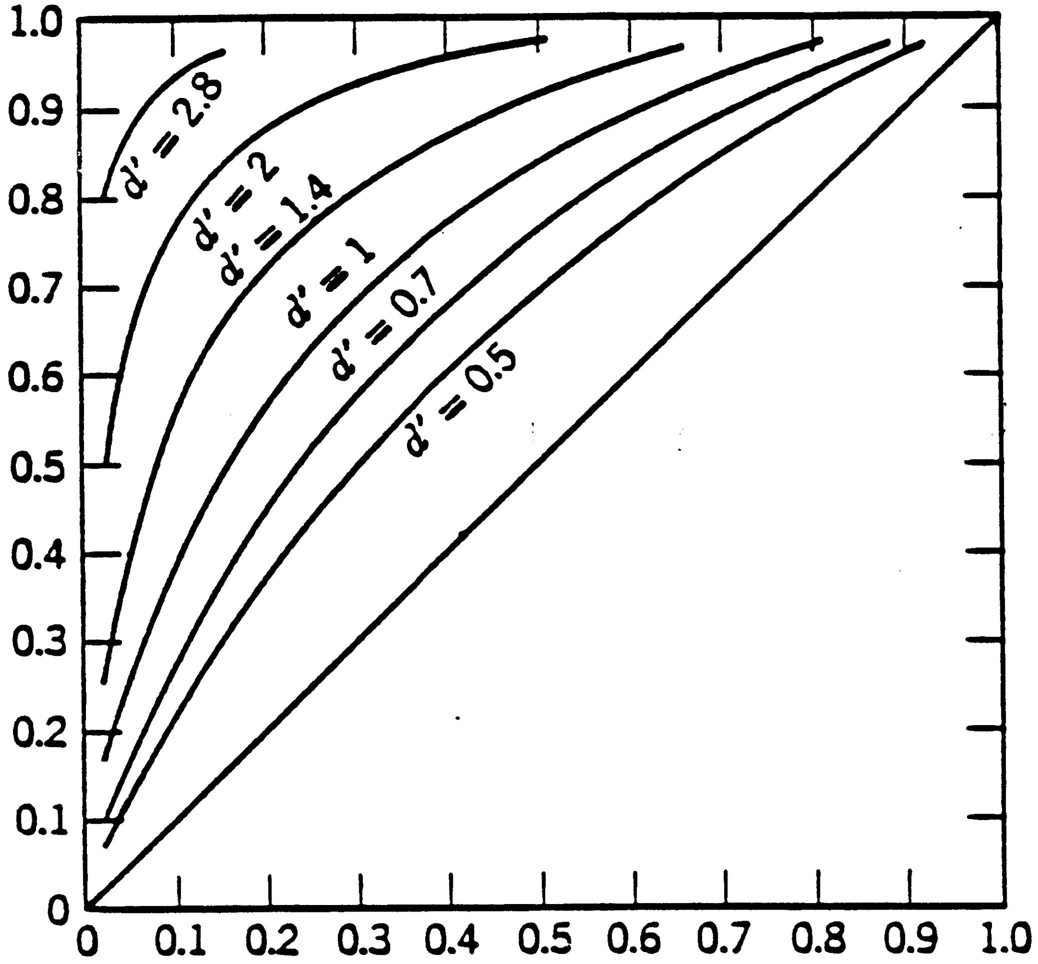

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
d' = 2.8
d' = 2
d' = 1.4
d' = 1
d' = 0.7
d' = 0.5

FIGURE 1.7

program to calculate d' (see chapter 2).

Of course, for signal detection theory to be sensitive and useful, the stimuli have to be dim enough to be barely seen. For these experiments, the stimulus intensity was adjusted so that about 50 percent of them were detected in test runs with no primary task. This adjustment could have been made for every subject, but it was not necessary as we never exceeded the range 20 to 80 percent detectability.

CHAPTER 2

METHODS

2.1 Experiments and Experimental Procedure

Measurement of peripheral field sensitivity with increasing central attention was accomplished by having subjects fixate on a target in the center of a wide field display, then at a random time, an additional target would briefly appears in the periphery, and the subject's task was to detect it. The number of hits, misses, and false alarms were used to indicate the performance of the subject and the sensitivity of the peripheral visual field.

To control the amount of attention allocated to the central visual field the subject's central visual field was occupied with a primary task whose level of difficultly was controlled. Several central tasks were devised for use in these experiments. The first presents the subject with two numbers in his central visual field and he must detect when they differ by a specified amount. For example, to make this a low attention task, the subject was required to detect only when the two numbers were equal, i.e. the difference is equal to zero. Increased amounts of attention are needed when this difference is increased to 1, 2, or 3. Presumably the need to perform a mental calculation to arrive at a decision of whether the central target numbers are at criterion value would increase the attention this central task requires to be performed

Other attention loading tasks involved having the subject listen to speech, white noise, or music, and a task which requires detecting a central number display of 3 as already mentioned, but with peripheral targets flashing 200-400 ms after a central change.

2.2 Set-up and Experimental Description

2.2.1 Peripheral Stimuli Procedure

For all experiments, the set-up is as depicted in Figure 2.1. It consists of a cylindrical surface (arc perimeter), whose center coincides with the subject's eyes and is one meter away from them. This arc perimeter contains 20 green 550 nm light emitting diodes (LEDs) which flash randomly in time and singulary in space for 100 ms. To accomplish this, a computer program randomly choses one of twenty possible numbers which then selected one of the LEDs. Then a specially designed controller to drive the LEDs, sends the appropriate voltage to the selected light to make it flash with the same preadjusted luminous intensity and duration of 400 ms. Subjects press a button, held in their right hand, if they saw a flash. This switch triggers a one shot and debouncer circuit especially designed for this experiment to send an adequate pulse to trigger the computer. The program is then capable of storing the subject's response to the flash and his reaction time. If the button is pressed within a determined maximum time (2 sec) after the onset of the flash, the computer interprets it as a hit; otherwise, a miss is scored.

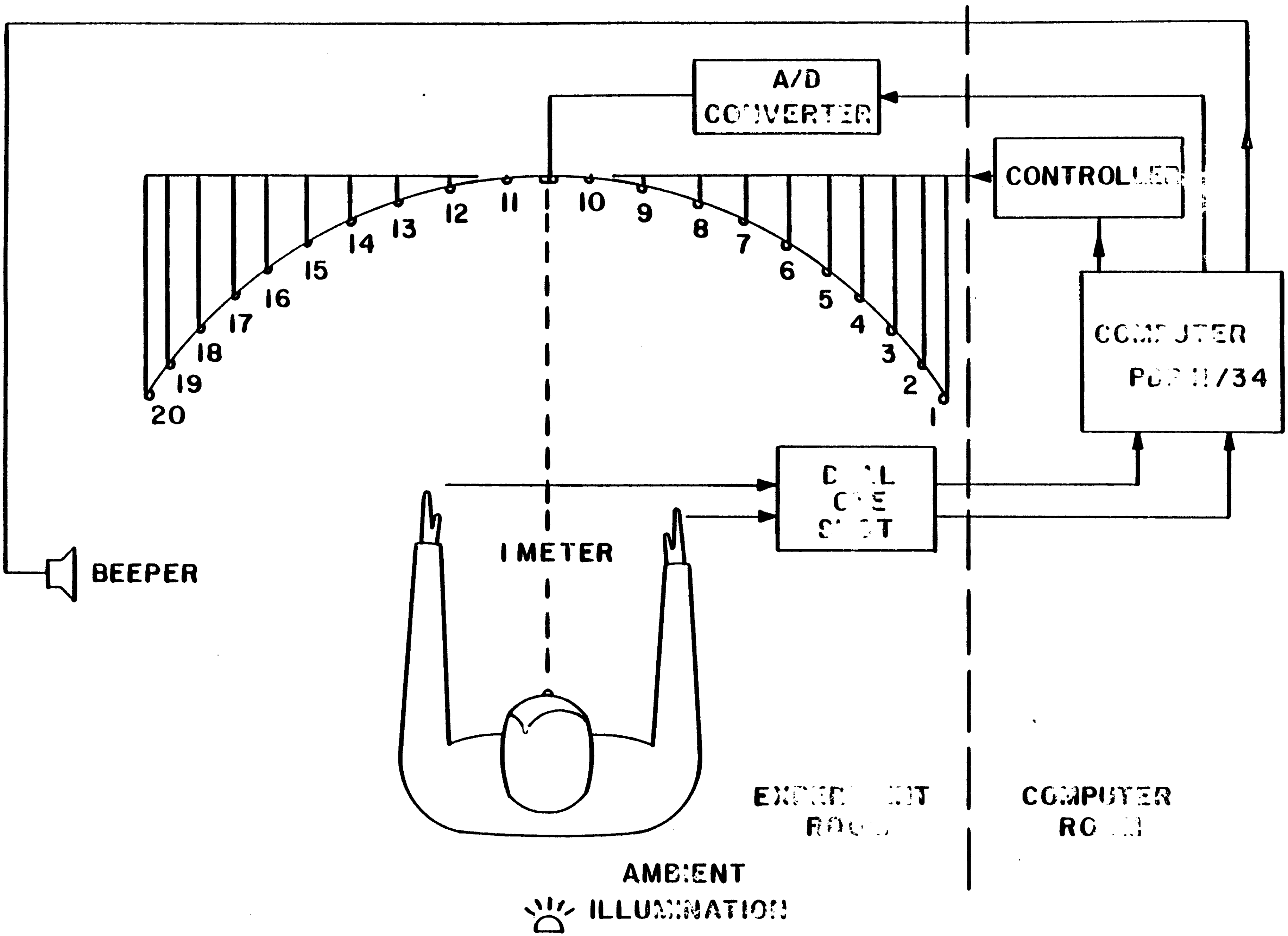

A/D
CONVERTER
CONTROLLER
COMPUTER
PDP 11/34
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
DUAL
ONE
SHOT
BEEPER
1 METER
EXPERIMENT
ROOM
COMPUTER
ROOM
AMBIENT
ILLUMINATION

FIGURE 2.1

According to signal detection theory, blank trials must be inserted among those with flashes to determine the false alarm rate. This was done in the following way: The computer sellected either a flash or blank trial, then after 400 ms sent a 5 V pulse to a buzzer to produce a short beep to request an answer from the subject. If he pressed the response button in a blank trial, the computer increments the false alarm counter by one; again the maximum waiting time is two seconds, after which the program will start a new cycle after a random time of 1 to 3 seconds or 1 to 7.5 seconds, depending on the experiment. Figure 2.2 shows the timing for both versions of the experiment, the fast version (Program ARCTRO) and the slow version (ARCTRL). The total number of trials is always 250, although the fast version had 60 percent flashes and 40 percent blank trials, while the slow version was 50 -50. The reason for the use of two versions will be explained later.

2.2.2 Central Task

The two seven segment displays showed two random numbers generated by the computer between 0 and 9. The central task display consisted of two seven segment displays placed in front of the subject, at eye level in the center of the arc perimeter, and at the middle of the LEDs. The numbers on the display were used to concentrate the subject's attention in the central visual field in a controlled manner. In each experiment, the subject is asked to press a second button, held in his left hand, when the difference between the two numbers is 0, that is when they are equal, 1, 2, 3, or 7. Runs with difference 0 require less attention to the central task than runs with a higher difference. Difference 0 is

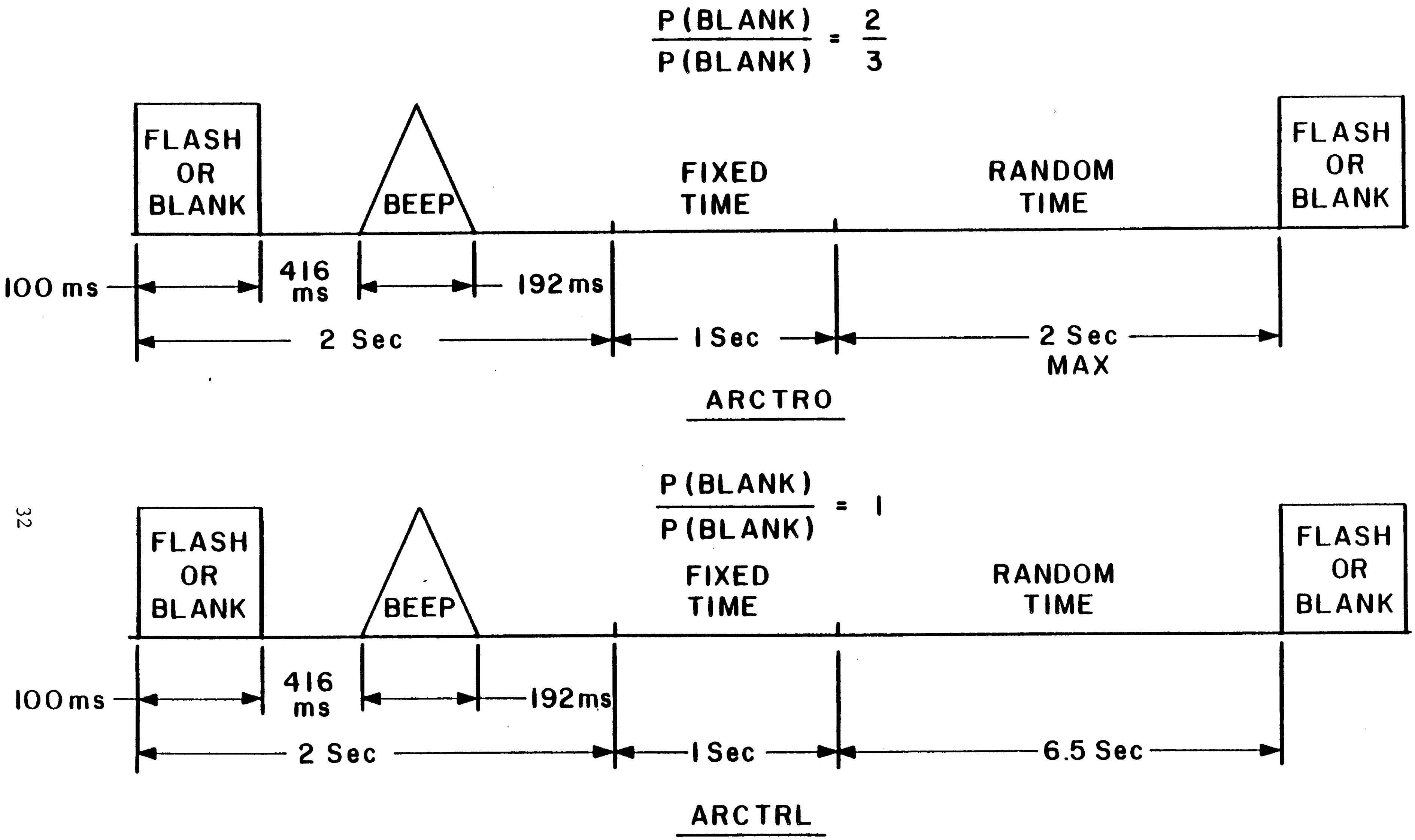

P(BLANK) / P(BLANK) = 2/3
FLASH OR BLANK
BEEP
FIXED TIME
RANDOM TIME
FLASH OR BLANK
100 ms
416 ms
192 ms
2 Sec
1 Sec
2 Sec MAX
ARCTRO
P(BLANK) / P(BLANK) = 1
FLASH OR BLANK
BEEP
FIXED TIME
RANDOM TIME
FLASH OR BLANK
100 ms
416 ms
192 ms
2 Sec
1 Sec
6.5 Sec
ARCTRL

FIGURE 2.2

detected by simply mentally matching the two numbers, while difference 3 or 7 calculations have to be done quickly before the numbers change. Thus the subject must concentrate on the central task so relevant calculations can start as soon as possible after a change of numbers since he must decide and then press the button before the next change in numbers. Woodworth (1954) showed that when a subject is attending and expecting an event to happen, the reaction time is approximately 100 ms shorter than when he is not. Therefore, our subjects will find it easier to perform their central task if they pay more attention to it.

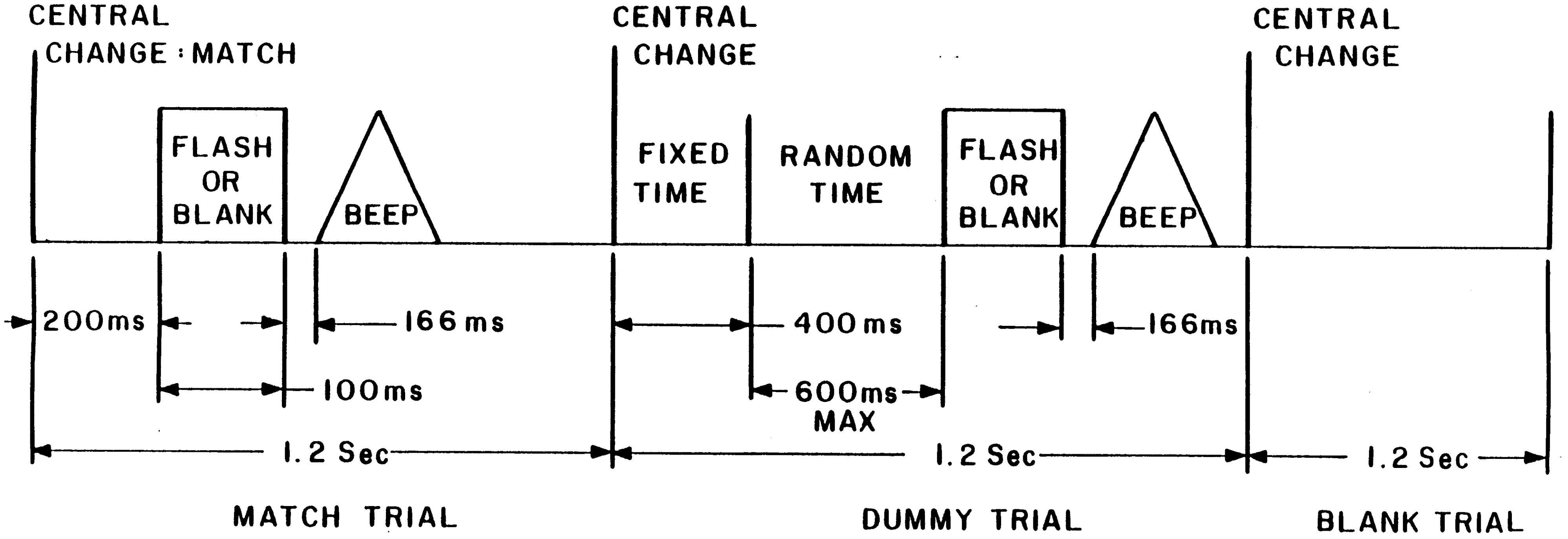
The pair of numbers displayed was changed every two seconds, although there were runs with the difference 3 and 7 when the time was reduced to 1 second to increase even more the attention required from the subject. It was however, not clear whether the task required from the subject was really a visual task or if only mental calculations were involved without intervention of any mechanism dealing with central visual field attention. To check this, two subjects were run with the central task digits dimmed to the point of making them barely visible, then run with a normal intensity; this sequence was repeated for four runs. If looking at the peripheral profiles showed any sign of perceptual narrowing when the central task was made more difficult to see, it would indicate that the paradigm used to increase the central task load by means of two changing numbers was not suitable to measure perceptual funneling.

In all experiments with central tasks, the subject is required to press a button when he detects a match, to let the computer know of his performance and to be able to determine if it is good enough for the corresponding peripheral performance to be included in the data for further analysis. Similarly, when the button for peripheral targets is pressed, the one shot and debouncer circuit sends a pulse to the Schmitt trigger input number 1 of the computer and a hit is stored if there was actually a match, a false alarm if there was no match, and a miss if there was a match but no response.

2.2.3 Experiments with Other Attentional Tasks

Other additional experiments were included. They were mainly variations of the basic experiment with no central task, but included several audio sources to the experiment such as recorded speech. Other types of audio input were tried such as music and white noise. To investigate if attention concentrates on the central task only when a match occurs, a synchronized version of the main program was developed which flashes the LEDs just after a match (difference 3) occurs; there are also flashes which don't follow a match, but they are irrelevant to the results and their mission was only to prevent the subject learning that a flash always follows a match, as then he could change his distribution of attention according to his expectations. Figure 2.3 shows the timing of this run. Other details concerning the software to generate this sequence are discussed in Section 2.4.

$$\frac{P(\text{BLANK})}{P(\text{FLASH})} = 0.1 \qquad \frac{P(\text{DUMMY BLANK})}{P(\text{DUMMY FLASH})} = 0.4$$



TIMING FOR ARC SYN

P (MATCH TRIAL) = .14
P (DUMMY TRIAL) = .17
P (BLANK TRIAL) = .68

FIGURE 2.3

2.2.4 Test Runs

Some test experiment runs were done to find out how short the average time between trials could be. This is very important because 250 trials are needed for meaningful results and considering that each subject must usually take part in five runs, the whole session could become prohibitively long. The fast and slow versions shown in Figure 2.2 were tried and gave identical results except when there was no central task. The possible explanation of this interesting effect will be discussed later, but whatever the reason, it is clear that the optimal solution was to run the no central task experiment with the slow version and the more demanding central task with the fast version to save time.

Experiments were run in a room with illumination adjusted to be within the mesotopic region for rods. Luminous intensity and brightness of the LEDs and the seven segment display, as well as average room illumination, are given in the hardware section.

2.3 Hardware

Basically the equipment used in the experiments consisted of:

- arc perimeter, 20 LEDs plus a central double LED seven segment display
- Digital PDP 11/34 computer
- LED driver and controller
- dual display driver and transcoder
- dual one shot and debouncer

- other additional complementary materials, such as momentary switches, beepers, tape recorder, ambient light source, filters, and power supplies.

Other instruments were used solely for calibration and testing. These include: photometer, eye movement monitor and pulse counter.

Most of the equipment was specially designed and constructed for these experiments. For those pieces of equipment, a more detailed description will follow and circuit diagrams and schematics can be found in Appendix 1, where applicable.

2.3.1 Peripheral Stimulus Hardware

The arc perimeter consists of a black cylindrical surface of one meter radius. Twenty LEDs are placed horizontally every 5 degrees (see Figure 2.1). LEDs were Fairchild type FLV 310, whose relative luminous intensity pattern is depicted in Figure 2.4 . They were coloured green with a wavelength of 525-625 nm. A small pinhole, 0.1" in diameter, also black, was placed in front of each LED. The LEDs were adjusted to have the same luminous intensity of 50 micro-cd measured from the center of the arc, that is from the subject's eye position. The fact that the eyes are separated by a distance of about 60 mm could make it so that the luminous intensity measured from a single point would not correspond to the intensity received by the two eyes, especially if the LEDs had a narrow radiation pattern or if they were badly aligned with the

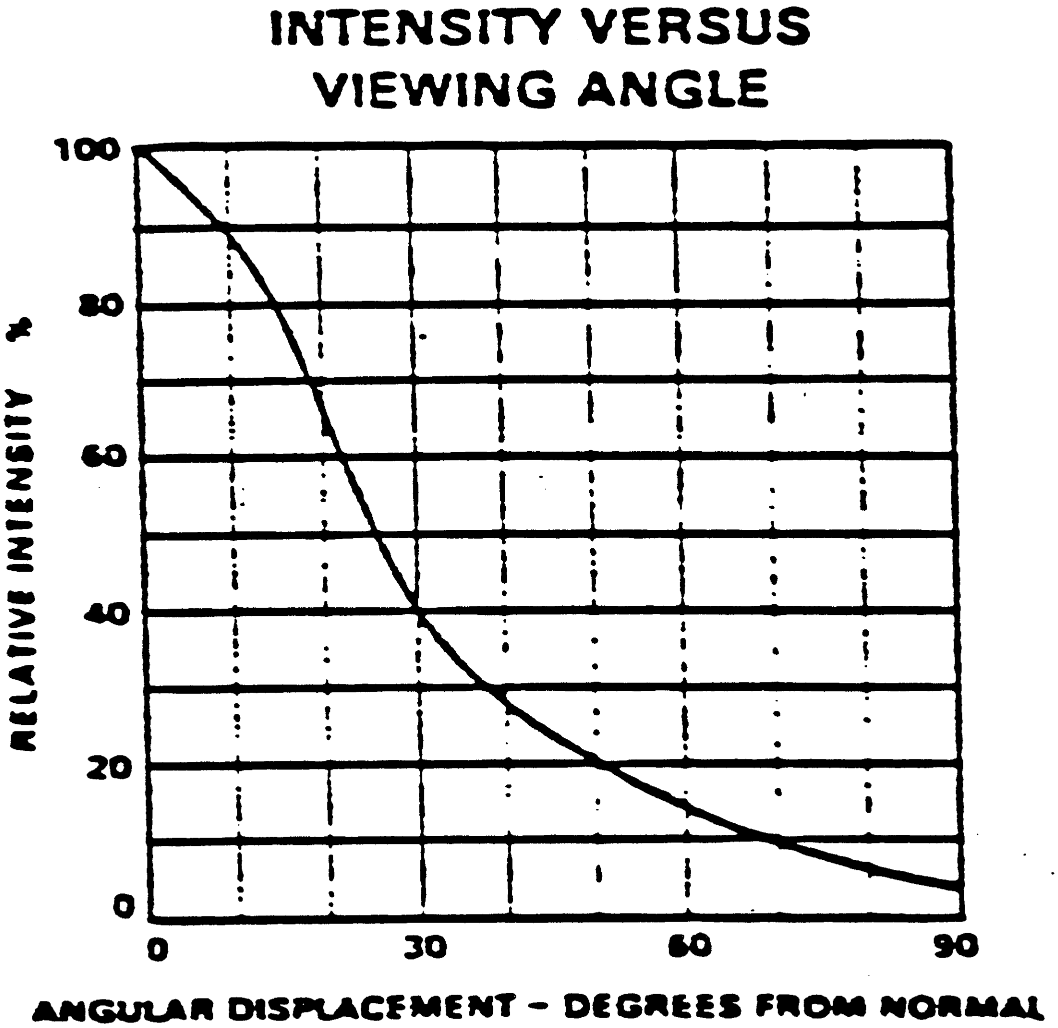

INTENSITY VERSUS VIEWING ANGLE
RELATIVE INTENSITY %
100
80
60
40
20
0
0
30
60
90
ANGULAR DISPLACEMENT - DEGREES FROM NORMAL

FIGURE 2.4

pinhole. To check this possible source of error, the photometer was shifted about 60 mm to the right and to the left for each measurement to detect any large deviation from the central value. No significant change was observed. This also guarantees that small movements of the subject's head during the experiment will not effect the results.

Control over the 20 LED targets is mediated by a digital interface to the PDP 11/34. This special purpose interface, built in-house, allows the computer to address and activate any number of LEDs for any duration and intensity. Using this controller, we have control over the timing and placement of the peripheral target and its luminous intensity. The current through the LEDs could be adjusted simltaneously to the required value by means of a single knob; also each individual LED has an ajustable resistor in series with its anode for purposes of calibration and matching of the LEDs luminous intensities.

2.3.2 Central Stimulus Hardware

The central stimulus was placed in the middle of the arc perimeter and at the same height as the LEDs the pair of LED seven segment displays, Texas Instruments Model TIL 308 were capable of displaying any digit from 0 to 9 in a red color with a wavelength of 660 nm and a luminous intensity measured from the position of the observer's eyes, of 900 micro-cd. The width of the side by side display assembly was 20 mm. This allowed the subject to shift his line of gaze $\pm$ 10 mm so that the peripheral LEDs might also move on his retina. Therefore, peripheral plots will be accurate to within an error of

$$e = \tan^{-1} 0.01 = 0.57 \text{ deg (about 10 percent)}$$

A 60 watt bulb illuminated the room with an average illuminance of 1 fc. The contrast ratio measured for each LED is shown in Table 2.1.

A device using an A/D converter was designed to illuminate the twin seven segment display. The description,block diagram and schematics of this device are shown in appendix I.

2.3.3 Subject Computer Interface

The mission of the one shot circuitry is to produce debounced pulses from the two switches operated by the subject to fire the Schmitt triggers of the computer. The IC 7400 (see Appendix 1) was used as a bistable to output a debounced 5 volt output each time the switch was pressed. The IC 74-121 generated a pulse of 300 ms with the positive going edge of the anterior level signal. When the Schmitt triggers in the computer are set to positive going edge triggering, the pressing of a switch will be immediately detected exept for a few microseconds delay due to the digital gates.

2.4 Software

Software was written by professor Kenyon to control the duration, placement and timing of the peripheral stimuli on the LED arc perimeter using the interface controller. Three programs have been developed to issue a stimulus to the arc perimeter to light up one diode. The position of the illuminated target and when it is turned on is rando-

ANGULAR DISPLACEMENT (DEGREES)	CONTRAST RATIO
-45	6.2
-40	6.5
-35	6.4
-30	5.8
-25	6.4
-20	6.2
-15	5.7
-10	6.5
-5	6.0
5	6.6
10	6.6
15	5.7
20	5.8
25	5.6
30	5.6
35	5.4
40	5.8
45	6.2

All LEDs adjusted to 50µCd

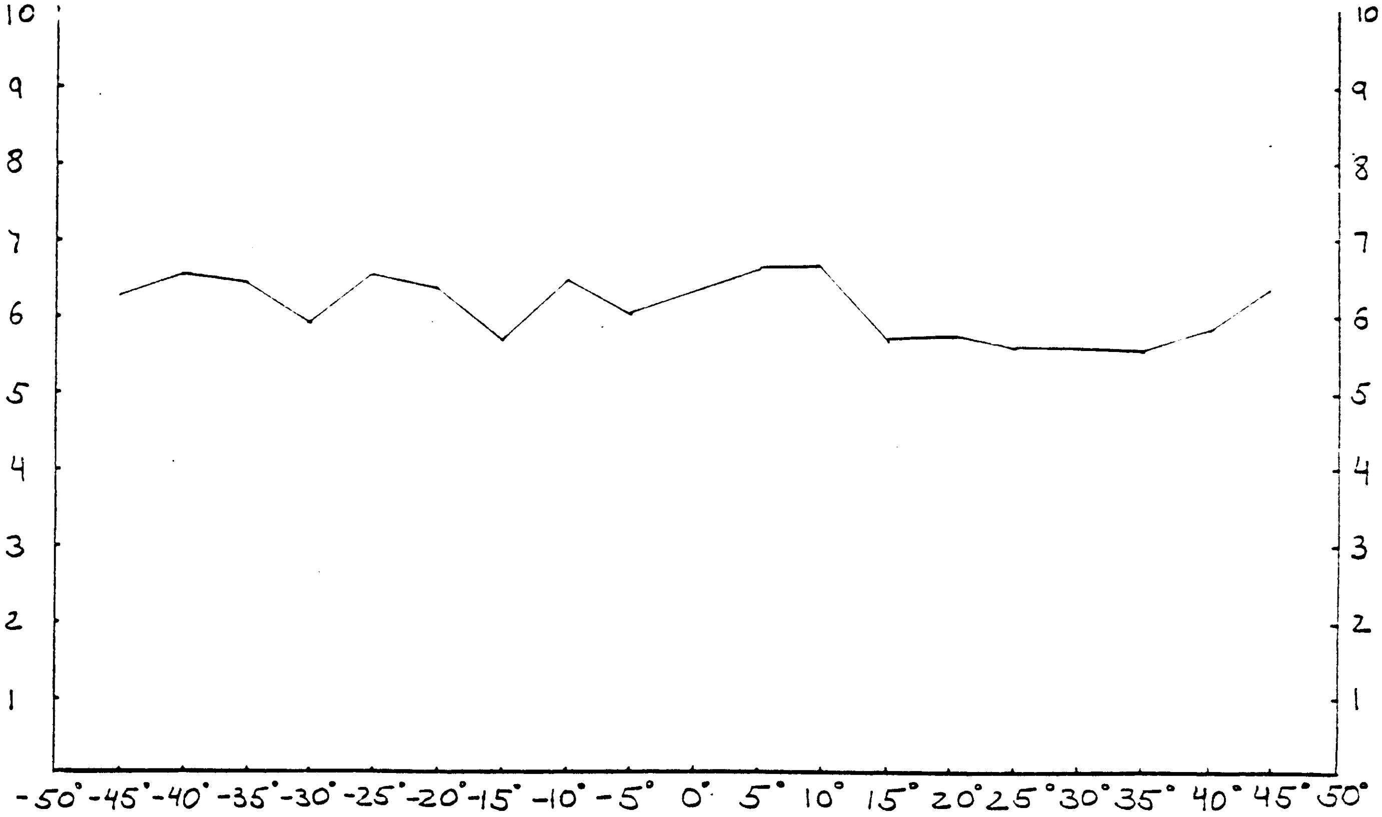


TABLE 2.1

mized by the programs to prevent any subject prediction. They also display a set of random numbers independently to a two digit display. When the two agree with a predetermined difference between them, the program looks for a response from the subject to indicate detection. These three programs have been named ARCTRL, ARCTRO, and ARCSYN, and a copy of them, together with their flow charts, can be found in Appendix 2. ARCTRL lights an LED every 10.50 seconds (average) and then waits 2 seconds forthe subject's response. Fifty percent of these trials are flashes (see Figure 2.1). ARCTRO is a fast version of ARCTRL, the only difference is that the mean time between trials has been reduced to 4 seconds and that the proportion of flash trials over blank trials is now 2 to 3. This reduces the duration of an experimental run from 25 minutes (ARCTRL) to 12 minutes (ARCTRO), the results being exactly the same except when no central task is used, in which case, the fast and continuous flashing seems to keep the subject in a state of alertness that would disappear during the slow run of ARCTRL. For this reason, ARCTRL was used in the experiments in which the arousal of the central task was so little (no central task or music), that the fast flashing of the LEDs could arouse the subject to a comparable level.

The program ARCSYN, although designed to perform similarly to the other programs, as far as the observer is concerned, is quite different from them. This program will not allow a flash unless a match has previously occurred (400 ms) in the central task display. This synchronicity between the central and peripheral tasks is achieved without letting the subject know by introducing other non-synchronous flashes (catch flashes) and by making matches not necessarily followed by a flash (see Figure 2.2).

ARCTRL and ARCTRO are provided with two additional features: fixation control and staircase methods. The fixation control loop insures that subjects are fixating on the central target and not inadvertently looking at the periphery by checking that the eye position monitor has a value within the central field before issuing a command to the arc controller. This feature was only used for testing that the eyes looked to the central task 99 percent of the time, making the use of the eye movement monitor unnecessary. On the other hand, the use of the infrared eye movement monitor would have made the experiments tiring for the subject and tedious for the experimenter as the D.C. drift has to be periodically checked. Provision for the staircase method of determining each LED threshold was also originally made. However, this method was not used as it would require a prohibitive number of trials. All the programs are capable of calculating d' (the detectability index for each run) from the hit and false alarm rate and are provided with other analysis features including: reaction time for each peripheral hit, displayed as a histogram, mean and standard deviation and maximum and minimum values for reaction time data. Other programs are used for data analysis, DPLOT plots d' versus central task load and normalizes these curves. PPLOT prints out the peripheral profiles for different subjects or runs and averages them. It should be remembered that each run is stored on a disk with a name for access at any time. To print out the histograms, the program BPRINT should be used. RTPLOT prints out histograms of reaction time averaged for all the subjects for each angular position and for each central taskload.

2.5 Subjects and Experimental Protocol

Twenty one subjects including nine members of the laboratory were the population that took part in the experiments mentioned . Most of them were students, graduate and undergraduate. They were all previously checked and asked about any eye pathology; none of them exhibited any sign of vision abnormality. Those who wore spectacles were asked to wear a black shield around their head to prevent any ambient light from reflecting on their glasses through the sides, which might change the contrast ratio of the peripheral LEDs. This could happen because the arc perimeter was painted black and therefore reflected little light, which could be comparable to the light reflected on the temporal edges of the spectacle glasses. The black cardboard shield prevented back light from reaching the glasees. This shield caused no interference with the experiment as the shadow cast by it, together with that cast by the subject's head, fell on the table in front of the subject, well away from the arc perimeter display. Peripheral vision was not restricted in any way.

All subjects were sufficiently informed of the purpose of the experiments and were told what was expected from them not only in an informal way while showing them the apparatus, but were also given the instruction sheet which follows:

> You are going to participate in an experiment to study the relationship between central and peripheral vision perception.

You will be required to press one of two buttons depending upon what you observe.

Please be seated and extend your arms on the table so that you feel comfortable. You should be relaxed during the experiment.

You will see in front of you two numbers. They will change randomly and you are required to press the button in your left hand every time the difference between them has a certain value. In the first experiment, the value is 0, so you have to press the button when the two numbers are the same.

While you are performing this task, you will see green lights flashing for a short time at various distances from the central task. Each time a flash occurs, it will be followed by a beep sound. However, the beep sound will also occur at other times. You should press the button in your right hand as soon as you notice a flash.

Never try to look for the flashes; keep your attention on the central task.

Try to keep your head still during the experiments. The two pushbuttons should be pressed only once and then released each time the conditions are met.

Before the main experiment of about 30 minutes, you will have a five minute trial period.

Please feel free to ask any questions you might have concerning the experiment.

Thank you for your participation.

Subjects were never informed of the synchronization between the central task change and peripheral target onset existing in one of the runs, as this would have defeated its purpose. Subjects were adapted to the illumination of the room for about five minutes. During this time, last minute instructions were given according to any questions the subjects might have.

Before the actual experiments began, all subjects had a test run of five minutes to check that they had understood all the instructions and to familiarize them with the experiment. The order of experiments was changed randomly for every subject to prevent any unwanted effects such as possible improvements in performance due to practice. Between runs, there was always a rest period of about ten minutes. The following run was never begun unless the subject felt relaxed and willing to go on.

Subjects were scheduled for three hours, as this was the usual duration of the experiment, preferably in the morning when they were supposedly more rested and alert. The experiment was never split into two parts and run on different days, as this might introduce important errors due to changes in subject alertness. Between runs and at the end of the experiments, subjects usually made comments spontaneously about their performance and experiences. These comments were noted, together with other points of possible interest. The subjects could also be asked questions at the end of the experiment after a quick look at the data obtained.

Subjects came on a voluntary basis and were not paid for their collaboration. In addition to the instruction sheet, they were asked to read and sign an informed consent statement with a brief description of the purposes and apparatus of the experiment.

2.6 Data Analysis

Experiments were conducted with a total of 24 subjects. However, data was discarded when some perturbance was suspected to have interfered with the normal experimental procedure or when performance in the central task (usually $1.0 < d' < 1.9$) differed more than one unit between runs. This happened only with three subjects and was very probably due to subject fatigue or a drop in interest in the experiment. The amount of information recorded from each subject was enormous. To deal with data from 21 subjects, some computer programs and algorithms were designed. The next section summarizes how the data analysis procedure can answer questions concerning:

1 Detectability of flashes as a function of central task load

2 Narrowing of the visual field as a result of increased central task load or an additional task

3 Effect of central task in reaction time along the visual field

4 Effect of audio inputs (speech, music, and noise) in peripheral detection and visual field size

5 Effect of simultaneous central and peripheral target onset

6 Differences between right and left visual fields

The total number of hits and false alarms in a run is a measure of the detectability of the peripheral targets. For all runs, the total number of hits, misses, and false alarms was recorded and from them the d' value was calculated as described in Section 1.2.2. There is no analytical function for d'. Its value can be easily calculated, however, from tables such as the one in the Appendix or using logarithmic or exponential expressions which are approximations of the real curve. The program designed to calculate d' used the equation:

$$d' = 3.01 - 6.02\ (\log HR/\log FR)$$

where HR is the hit rate and FR is the false alarm rate. The constants 3.01 nd 6.02 were chosen to fit the real curve as closely as possible in the region of interest for the experiments (low false alarm rate and about 0.5 hit rate). It can be checked from the table in the Appendix that this is a good approximation for d'(better than 5%). These d' values have been calculated for every run, then each group of d' values for each experiment has been normalized so that every group has the same area (area between the curve and the horizontal axis). This rids us of effects due to differences in target intensity for a given experiment or difference in subject sensitivity. We are not, therefore, measuring absolute threshold, but differences in sensitivity versus central task load. All d' values for the same central task were then averaged. Some of them, however, were rejected before the averaging; this happened when the d' value for that task was very different from the d' value for the other tasks, i.e. the subject did not pay attention to the center or he attended the center in a markedly different manner than in the other tasks. Only four runs out of ninety seven had to be rejected for these reasons, however.

For each subject and each run, the ratio of central hit rate over peripheral hit rate (C/P) was calculated as a measure of narrowing of the visual field and then all C/P values were averaged across each task. This was repeated for the right and left visual fields.

Reaction times were printed out by the computer after each run for every target position in the form of histograms and the average reaction time and standard deviation were displayed. From this data, the mean reaction time and standard deviation was calculated for each target for every task over all subjects and the profiles of the reaction time versus angular displacement were plotted.

CHAPTER 3

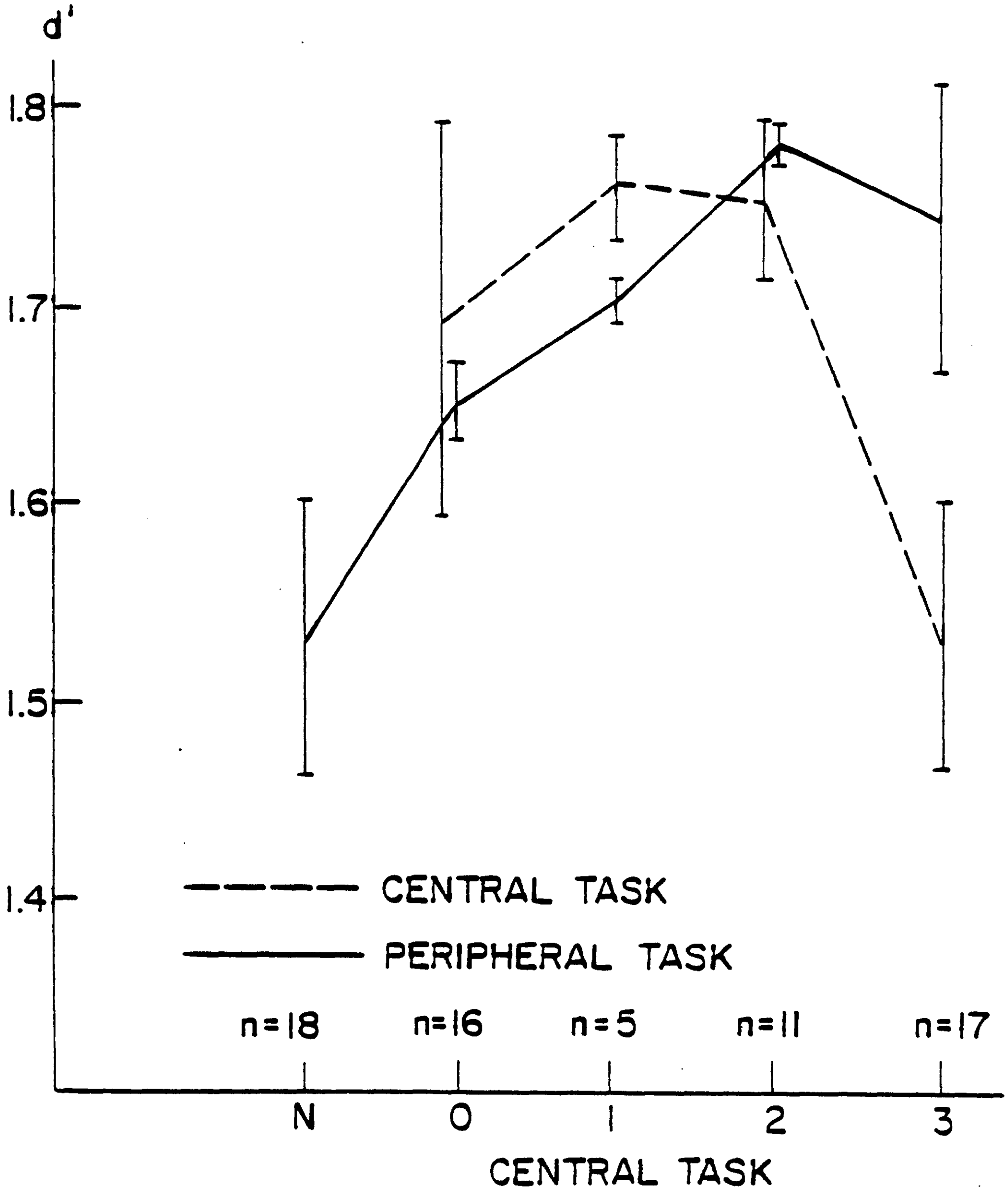
RESULTS

3.1 Detection of Peripheral Flashes versus Central Task Load

In Figure 3.1, the average detectability d' across subjects is plotted for both central and periperal targets(see appendix IV for table of values). The detectability of peripheral targets shows a significant rise as the central task load increases from no task to a difference of 2. The t-test showed this rise to be significant at the $p < 0.02$ level for all four points (N to 2). However, the central task performance changes little except for the highly demanding task of difference 3; this suggests that increased peripheral performance was not gained at the expense of the central task performance. The peripheral d' curve reaches its peak for the central task load correspondng to detecting a difference of 2 in the center and then decreases.

3.2 Distribution of Peripheral Target Detectability

The detectability of peripheral targets, shown in Figure 3.1, is the lumped detectability for all targets (-45 deg to 45 deg) and therefore it does not indicate how the changes in sensitivity are distributed along the visual field. For example the increase in sensitivity up to difference 2 could be due to an increase in sensitivity in only a



NORMALIZED DEDECTABILITY OF CENTRAL & PERIPHERAL TARGETS

FOR INCREASINGLY DIFFICULT CENTRAL TASK

FIGURE 3.1

portion of the visual field, such as the central area. This would imply a narrower visual field.

3.2.1 Definition of Narrowing

For instance, Figure 3.2 depicts two bell shaped curves: f(x) and g(x); we would probably say that f(x) is narrower than g(x) because f(x) has higher values than g(x) around the center and lower ordnate values n the periphery. This intuitive notion of narrowing can be mathematically defined in the following way:

Given two functions f(x) and g(x) defined for $-x_o < x < x_o$, we shall say (see Figure 3.2) that f(x) is narrower than g(x) for $x = x_i$ if

$$\frac{\int_{-x_i}^{x_i} f(x)d(x)}{\int_{-x_o}^{-x_i} f(x)d(x)+\int_{x_i}^{x_o} f(x)d(x)} > \frac{\int_{-x_i}^{x_i} g(x)d(x)}{\int_{-x_o}^{-x_i} g(x)d(x)+\int_{-x_i}^{x_o} g(x)d(x)}$$

What this definition of narrowing means is that the ratio of the area beneath the curve f(x) between $-x_i$ and x_i (center) and the area between $-x_0$ to $-x_i$ and x_i to x_0 should be greater for g(x) if f(x) is going to be said to be narrower than g(x).

It should be noted that this definition requires a region where the narrowing will be tested (x_i). It does not make much sense to speak about narrowing if we do not say where it occurs, at least roughly. The intuitive narrowing first observed in Figure 3.2 was assumed to be in the central area, although it was not specified what the center was.

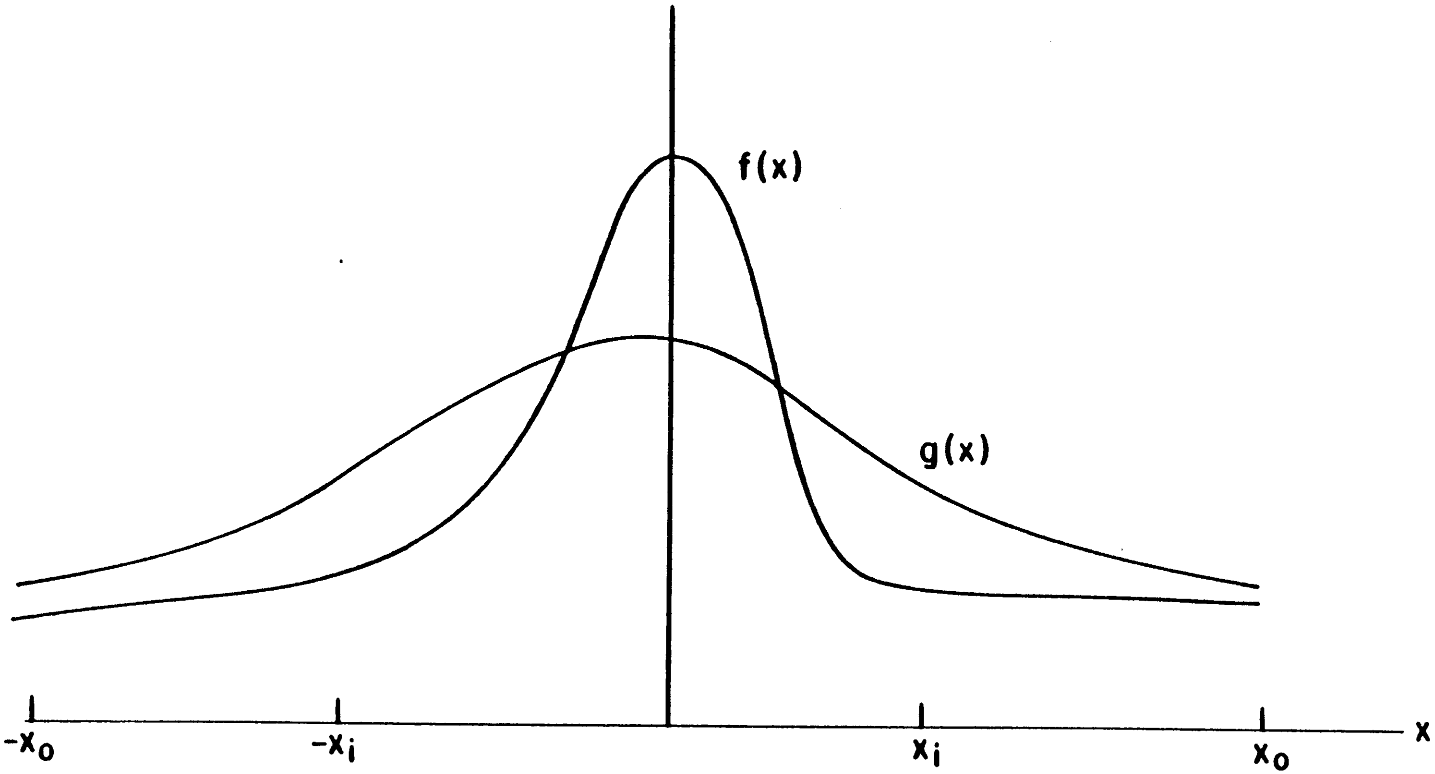
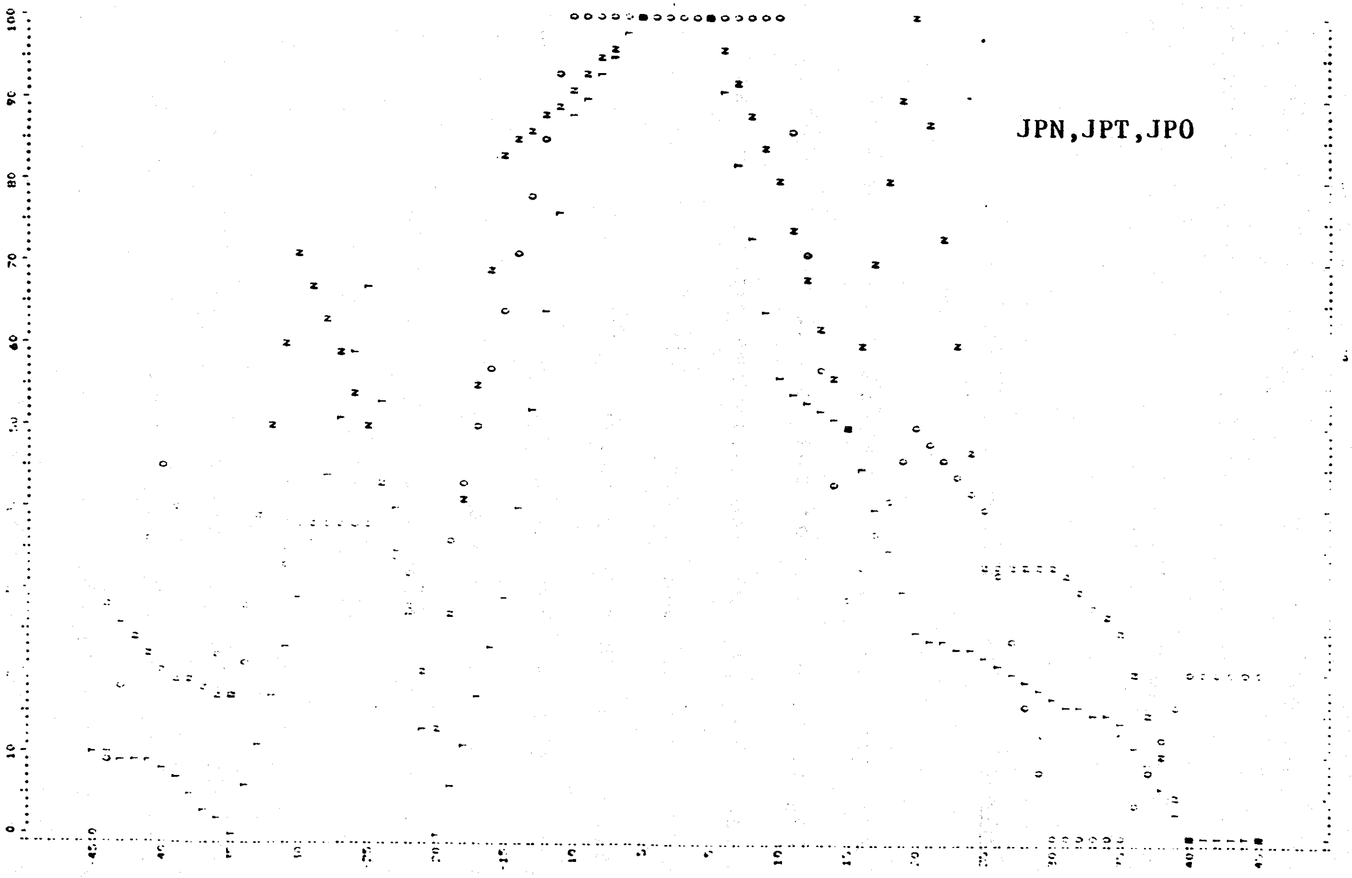


FIGURE 3.2

There is a property of this definition which should be tested, too. If any curve f(x) or g(x) is multiplied by a constant, the definition of narrowing should not be affected, beause the constant would multiply both the numerator and denominator of one of the ratios. In our experiments multiplying by a constant is the equivalent of a change in subject's sensitivity. This definition fits very well therefore with visual field detection as it is independent of drifts in overall subject detectability profiles.

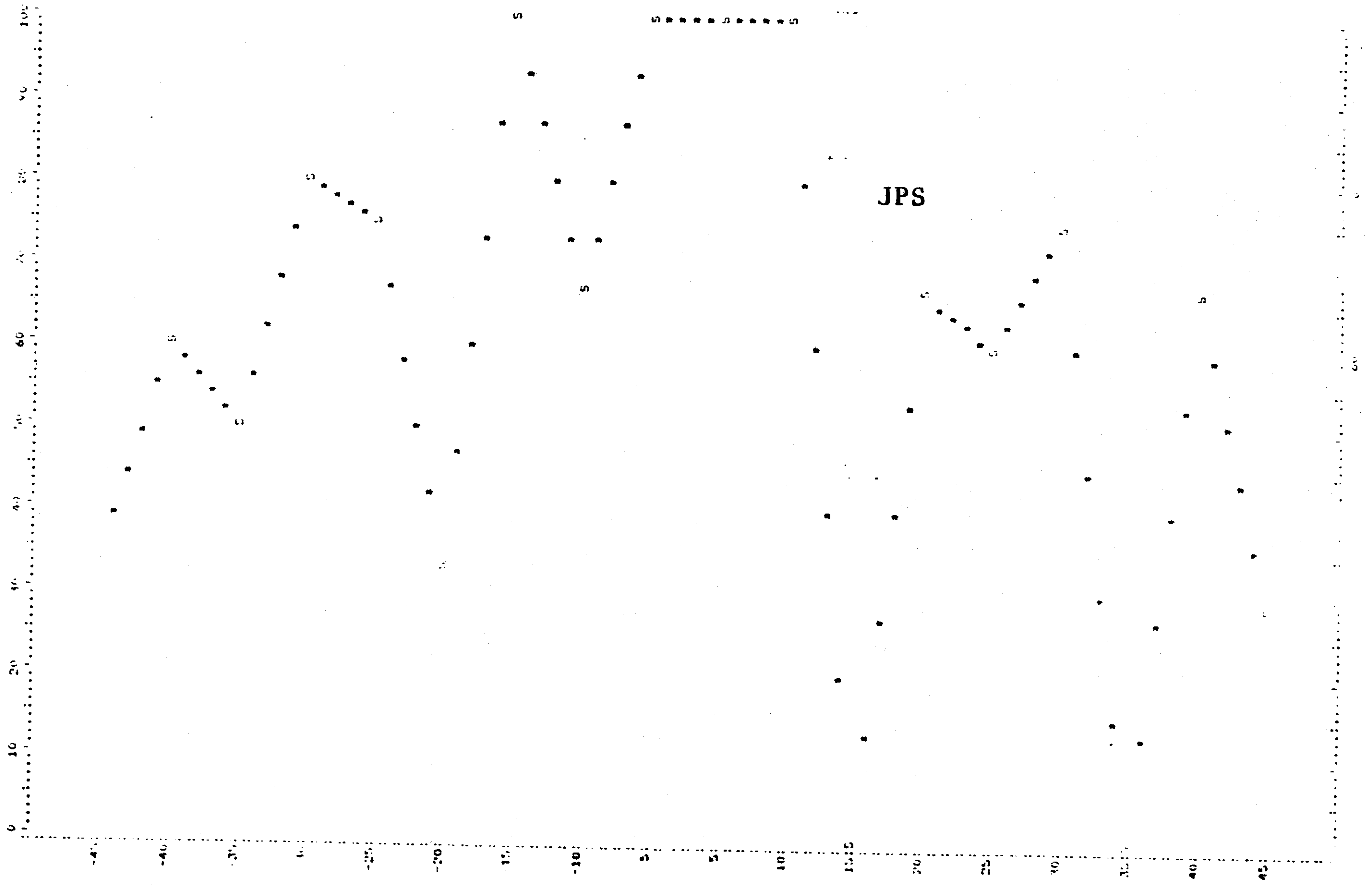
3.2.2 Measure of Narrowing of the Visual Field

There are several parameters that can be used to measure a narrowing or funnelling of the visual field when central task load increases. The simplest one is to use hit rate for each individual LED. This represents the sensitivity profile of the horizontal meridian of the retina for that particular task. By comparing profiles for different tasks, we can check for any concentration towards the center. Figure 3.3 depicts one subject's profiles for different central tasks, they all have an overall bell shape as Pirenne (1967) measured. Note that the notch at around ± 15 deg is due to the blind spot. Also note that some targets sometimes show a very different hit rate; this is probably due to the low number of flashes for that target position (it was usually around 10, but could drop as low as 4). Thus these plots are not the best representation of a possible narrowing visual field. Although a very large funneling effect would be visible this way. There are two reasons why this profile would not show small amounts of funneling. Firstly, the low number of flashes for each angular position



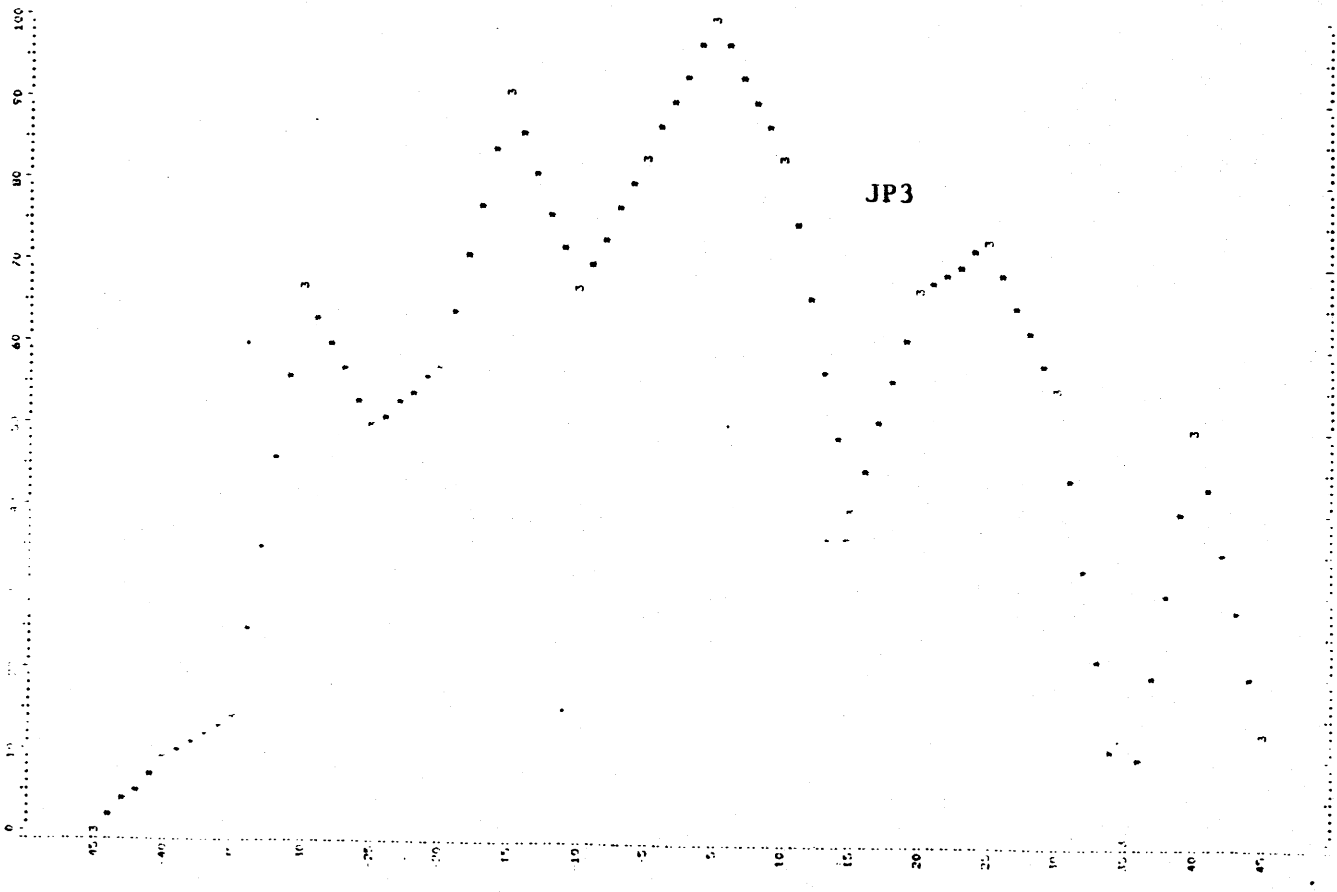
% OF HITS VERSUS TARGET POSITION

FIGURE 3.3 (a)



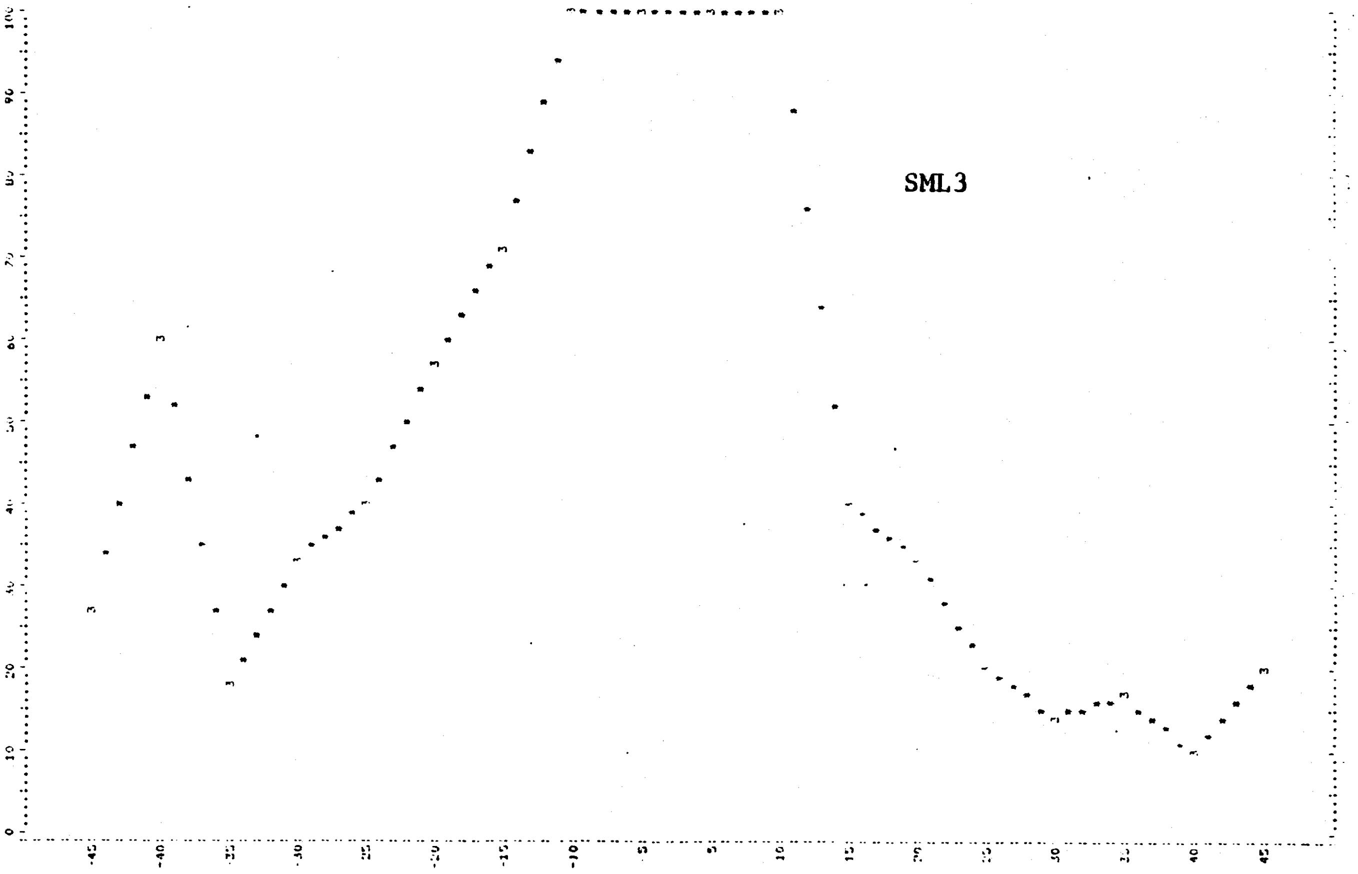
% OF HITS VERSUS TARGET POSITION

FIGURE 3.3 (b)



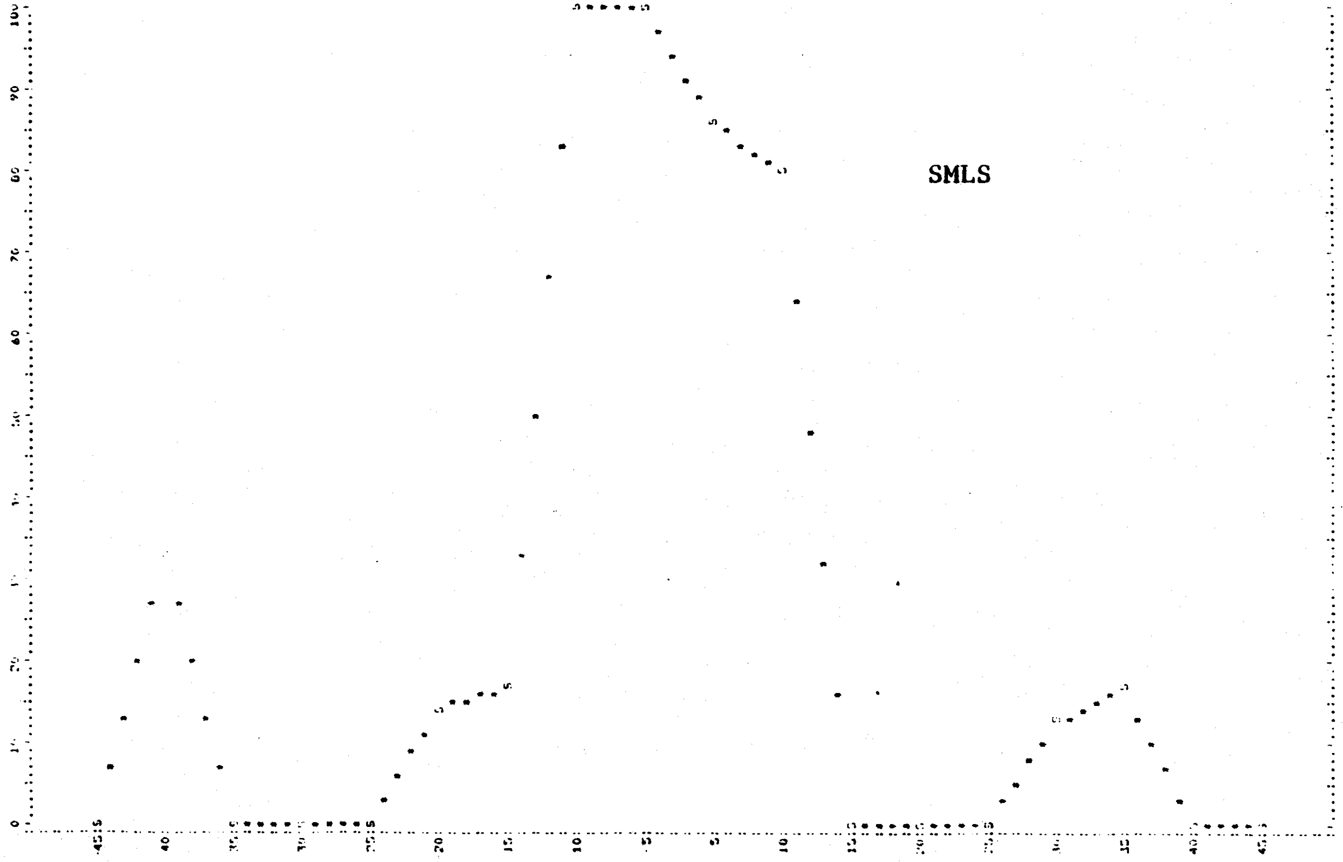
% OF HITS VERSUS TARGET POSITION

FIGURE 3.3 (c)



% OF HITS VERSUS TARGET POSITION

FIGURE 3.3 (d)



% OF HITS VERSUS TARGET POSITION

FIGURE 3.3 (e)

(around 10) makes it difficult to see small changes in the slope (a narrower curve implies a greater slope). Secondly, the total number of hits does not necessarily have to be the same for the curves being compared making comparisons very difficult, especially considering that targets in the center of the visual field are seen 100 percent of the time making the peak of the curve invisible. The reason why these peripheral profiles "saturate" in the center (flashes are seen 100 percent of the time) is that since all LEDs have the same intensity and the peripheral sensitivity is so greatly diminished as we go further from the center, flashes seen only around 10 percent of the time in the periphery are always seen in the center. If LED intensity were reduced to make central flashes visible 90 percent of the time, for example, then peripheral flashes wuold not be detected at all. Figure 3.3(d,e) is an example of how mistakes can occur if based solely on an estimation by eye of the peripheral profiles; anyone would say that the profile SMLS corresponds to a visual field narrower that that of SML3. We shall see with the more elaborate ways of measuring narrowing described next that it is just the opposite.

Another alternative to check what curve is narrower is to consider these profiles as normal distributions and then the standard deviation would be a measure of how peaked or narrow the curves are.

The third possibility is to calculate the ratio between the hit rate in the center and the hit rate in the periphery. The angle that demarcates center from periphery is the angle that defines narrowing, that is, if the two curves are compared in this way, choosing 30 deg as the boundary between center and periphery, for instance, the profile with a higher C/P ratio has a higher concentration of hits for flashes occurring between ± 30 deg than the other. If we assume that the false alarms are evenly distributed along the visual field the detectability for targets between ± 30 deg is greater. If the false alarms are not evenly distributed, but had for example a higher concentration in the periphery the ratio between d' in the center and d' in the periphery would change slightly for all subjects. In the last case, C/P is still useful in measuring narrowing if used only for comparison with other C/P values, as it is in our case, and therefore detectability for targets between ± 30 deg will still be greater for that run with a higher C/P.

These two last algorithms have been used in this data in the following way: for one task, the standard deviations, the ratio of central hit rate (C) and peripheral hit rate (P) was calculated. Two values were obtained for C/P, for targets between ± 15 deg; the only difference between them was that targets in the blind spot (15 - 20 deg) were excluded from the calculation of one of them.

In all three cases (standard deviation, C/P and C/P excluding blind spot), the results were very close, indicating that they are good ways to measure narrowing.

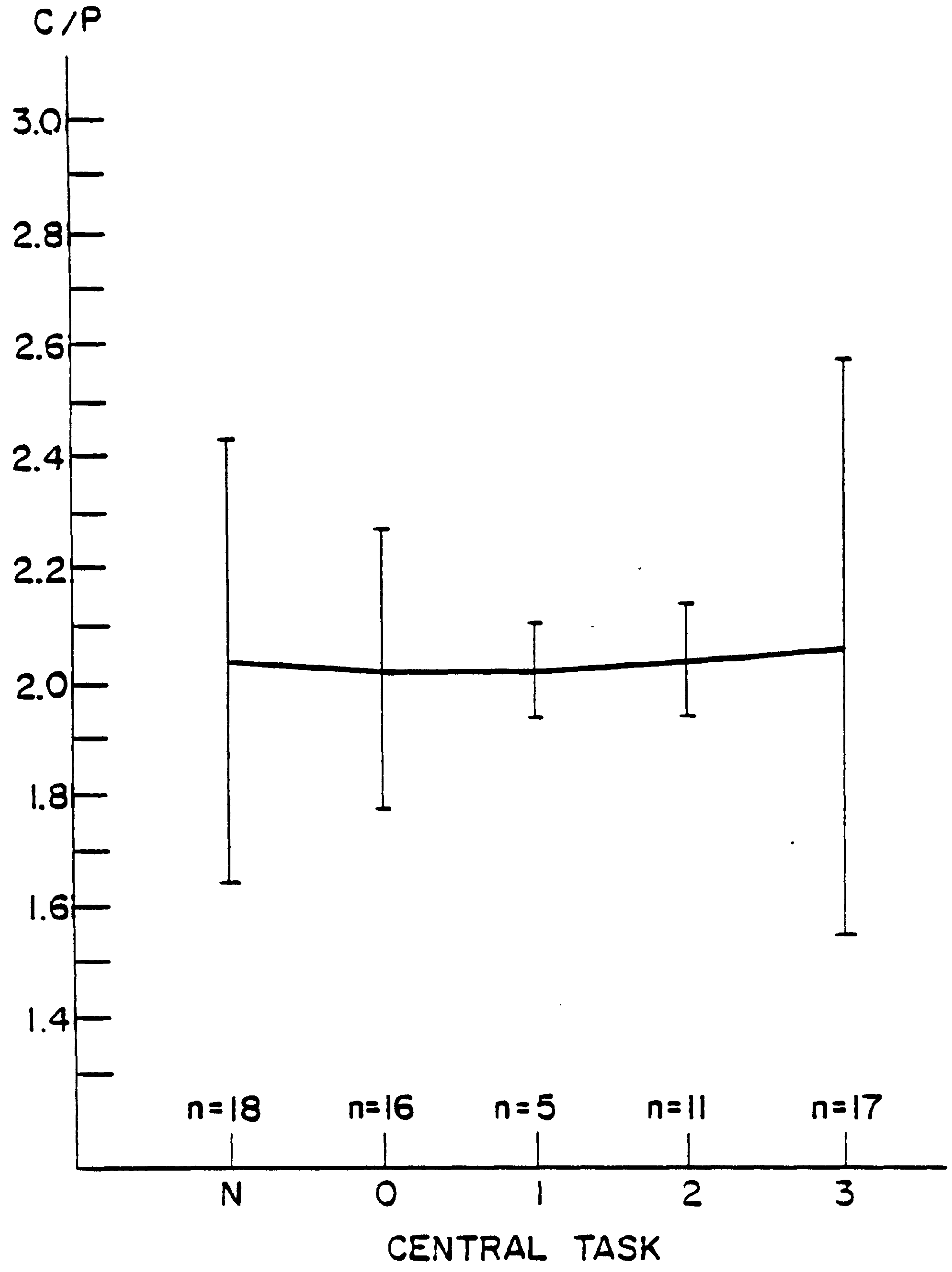
The third method (C/P for all targets), however, has some advantages. Compared to the standard deviation, C/P can be used for right and left visual fields separately and the definition of "periphery" can be shifted in or out as wished. Thus narrowing was calculated using C/P, the values obtained are shown in table 2 in appendix IV. The plot in Figure 3.4 shows C/P versus central task. These data show that C/P is almost independent of the central task load, that is, increasing attention to a central task does not appear to reduce or narrow the visual field.

3.2.3 Narrowing for the Right and Left Visual Fields

The ratio of C/P has been calculated for the right and left visual field independently, that is: C/P for the right hand hemivisual field is the ratio between the hit rate for 0 to 25 deg and the hit rate for -30 to -45 deg. As described in Chapter 2, these values are calculated and averaged for every central task. The results are plotted in Figure 3.5, C/P values for the right field are represented by squares and values for the left field by triangles. The t-test did not show any significant difference between right and left fields for tasks N, 0, 1, 2, and 3, indicating that for this type of task, both visual fields are equally detectable.

3.3 Synchronized Central and Peripheral Targets

Section 3.2 has shown that no narrowing occurs when central task load increases. To further test this, a synchronous expermiment was performed. The hypothesis is that when the central numbers reach a match, a high concentration of attention to the center is required from the subject for a short time. This could cause a drop in the number of targets detected in the periphery, whose onset was only 200 ms later (of course, the subject was unaware of the synchrony; see Section 2.2.3)



NARROWING FOR INCREASINGLY DIFFICULT CENTRAL TASK

FIGURE 3.4

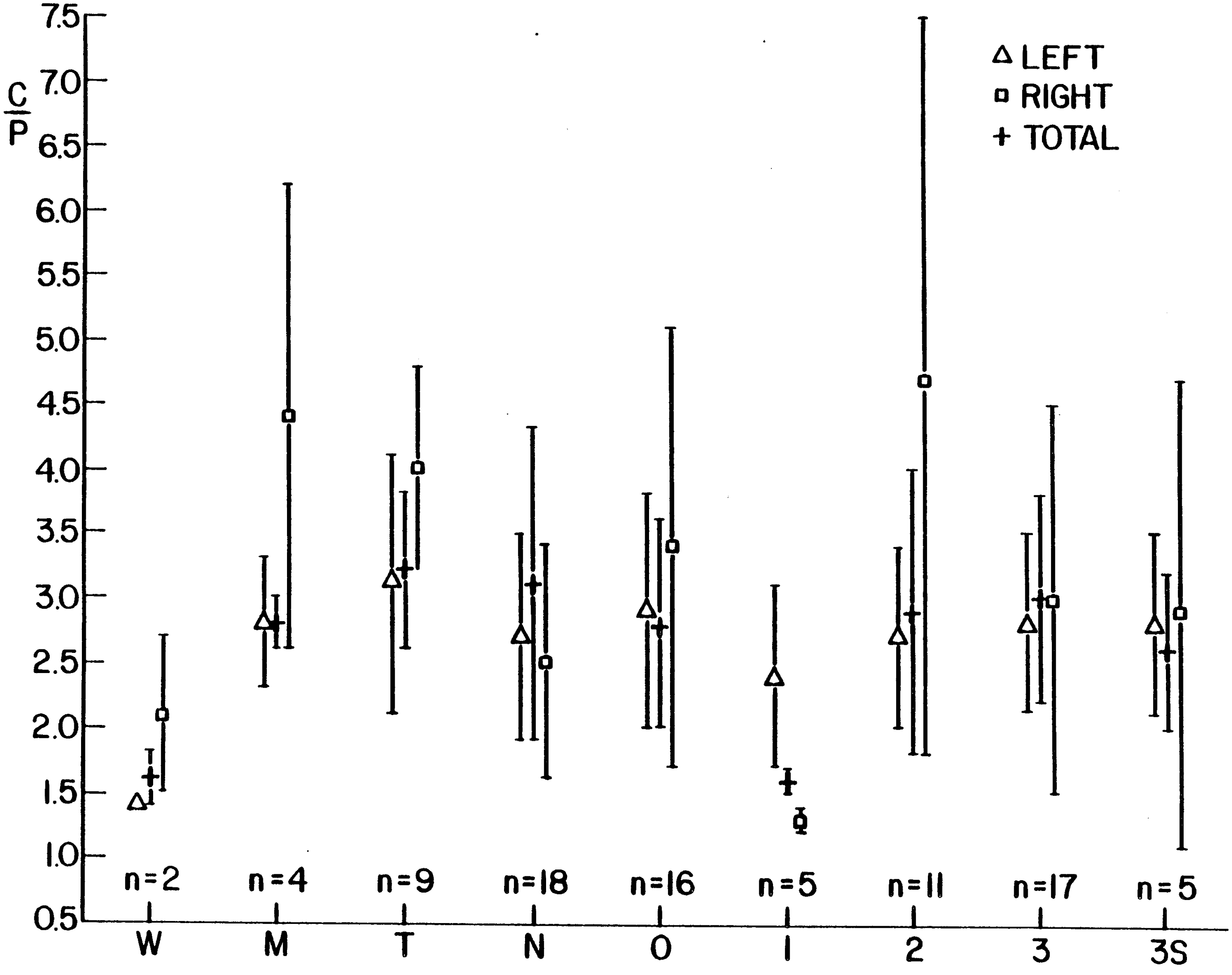

C/P
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
△ LEFT
□ RIGHT
+ TOTAL
n=2
n=4
n=9
n=18
n=16
n=5
n=11
n=17
n=5
W
M
T
N
O
I
2
3
3S

FIGURE 3.5

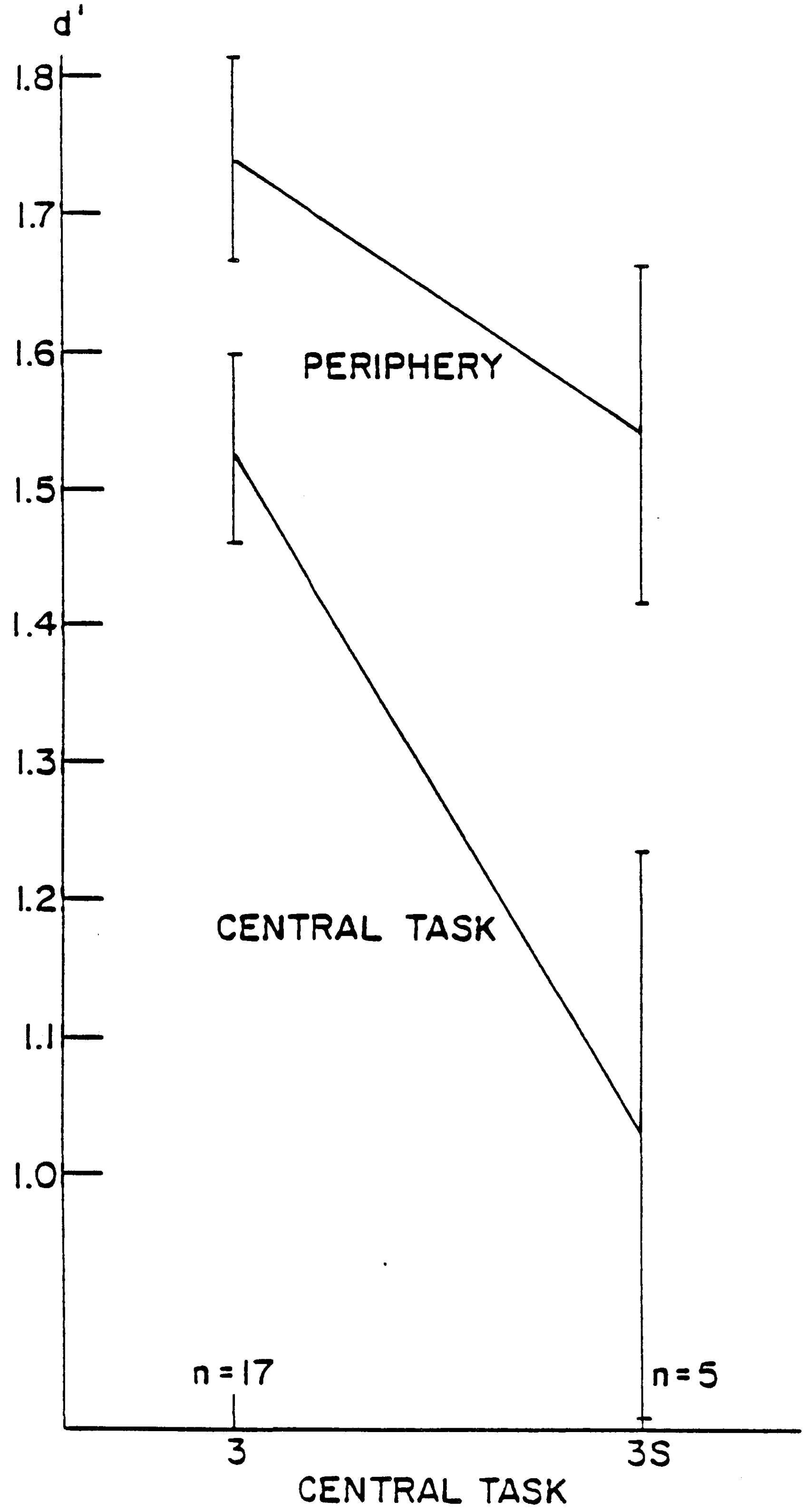
In addition to the normal protocol, five subjects performed an experiment in which central and peripheral onset was synchronized. They were, of course, not informed of this and many of them did not find any difference from the run with simple difference 3. Figure 3.6 shows graphically the results obtained when comparing detectability for the center and peripheral targets. Both detectabilities drop when the onset of the targets is synchronized with a match in central task. Both peripheral and central task reductions are significant beyond the 0.05 level ($p < 0.035$). Figure 3.7 plots C/P for difference 3 and difference 3 with synchronized tasks. It shows clearly that simultaneous target onsets do not make the visual field narrow, even momentarily.

3.4 Audio Inputs

Three different audio inputs, speech (T), white noise (W) and music (M), were introduced in three independent runs with no central task to study the effect of such auditory signals in peripheral performance. Values for overall detectability (d') and narrowing (C/P) have been calculated and compared with the value for no central task (N).

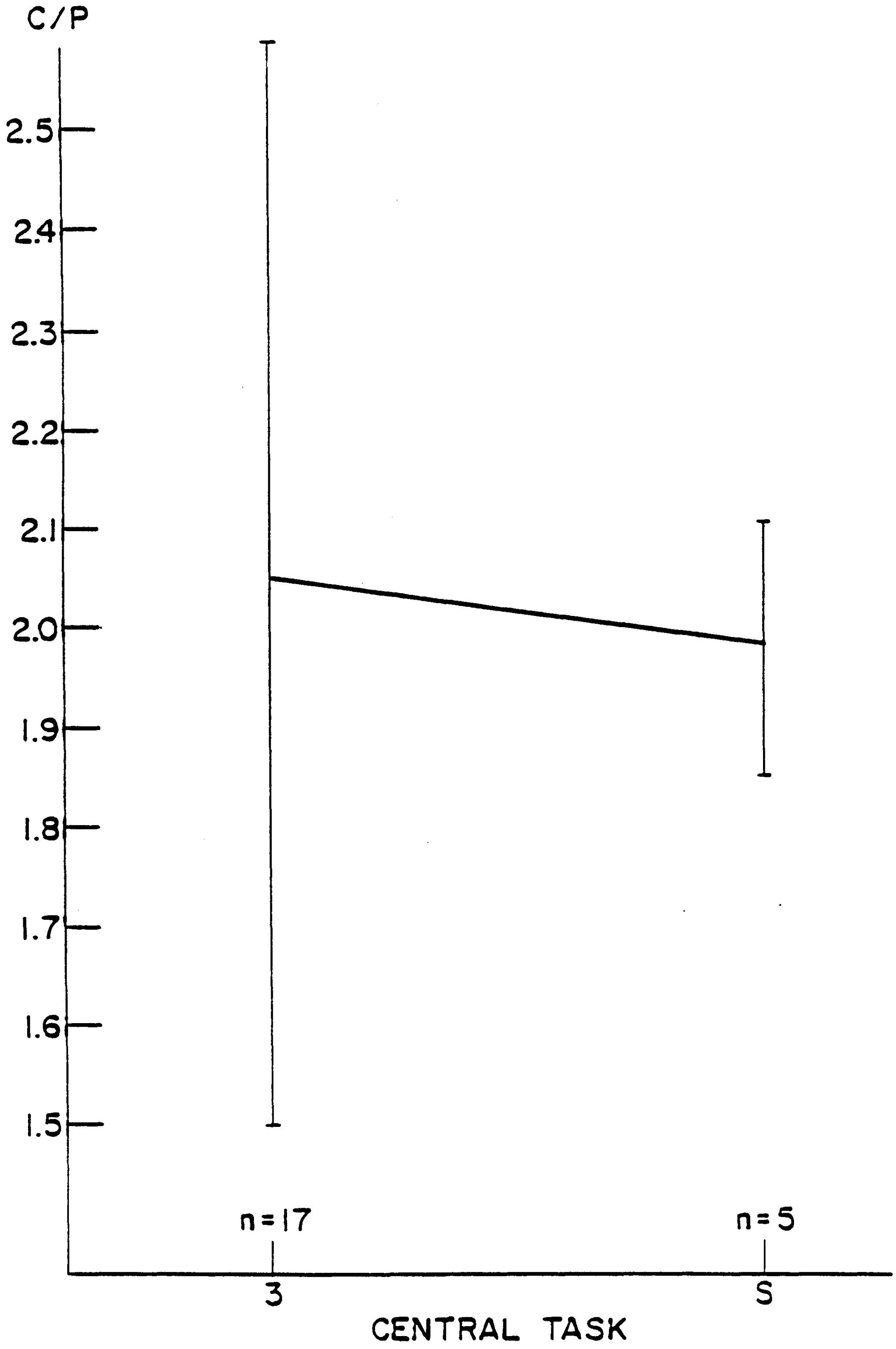
3.4.1 Audio Inputs and Detection of Targets

The mean detectability and standard deviation of peripheral targets has been plotted in Figure 3.8 for the number of subjects indicated, when listening to white noise (W), music (M), speech (T) or no task (N). According to this figure, listening to speech increases the detectability of peripheral flashes. Easy listening music seems to have



DETECTABILITY OF CENTRAL & PERIPHERAL TARGETS FOR DIFFERENCE 3 WITH AND WITHOUT SYNCRHONY BETWEEN TASKS

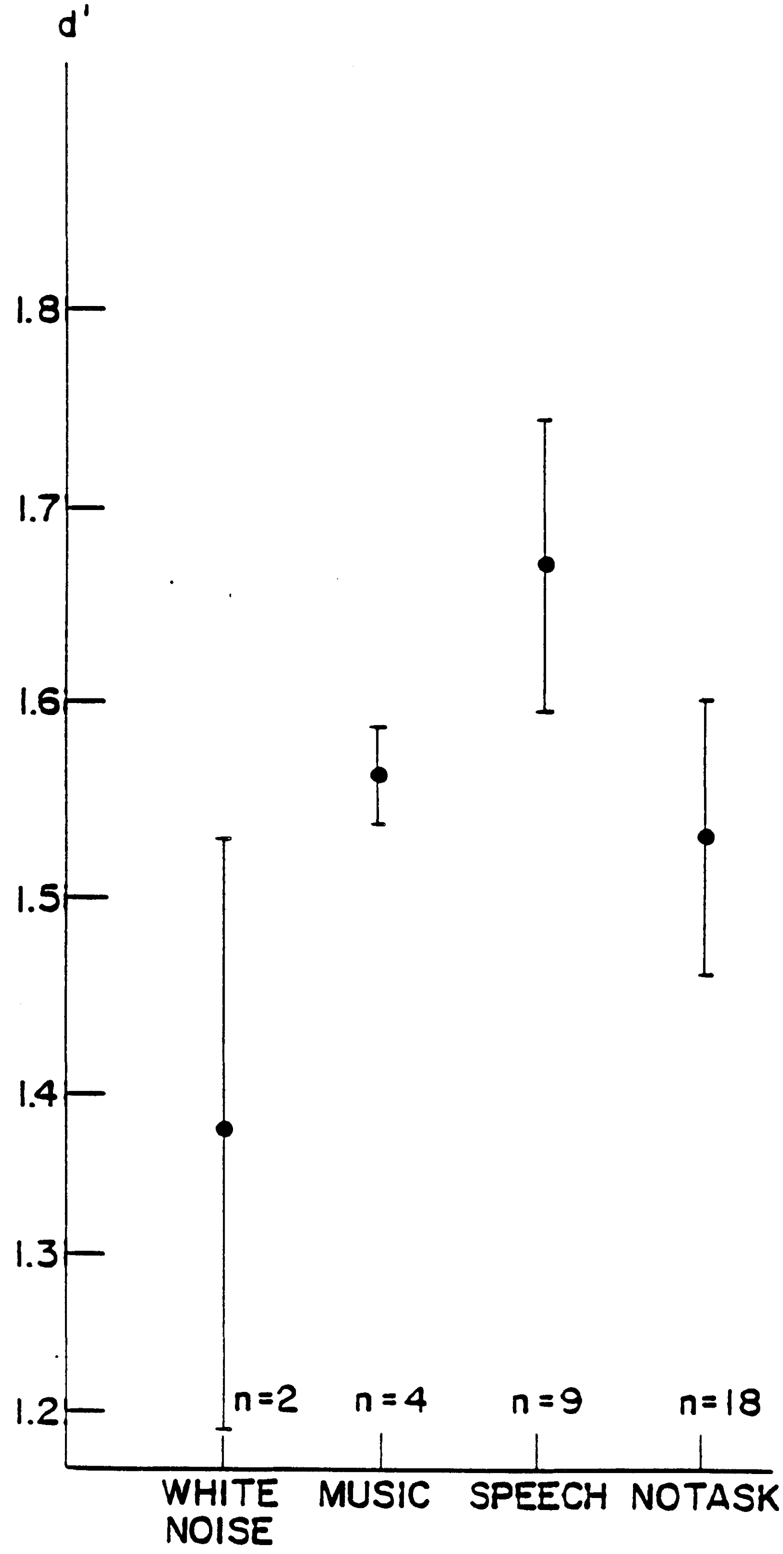
FIGURE 3.6



NARROWING FOR DIFFERENCE 3 WITH AND WITHOUT

SYNCRHONY BETWEEN TASKS

FIGURE 3.7



DETECTABILITY WITH AUDIO INPUTS

FIGURE 3.8

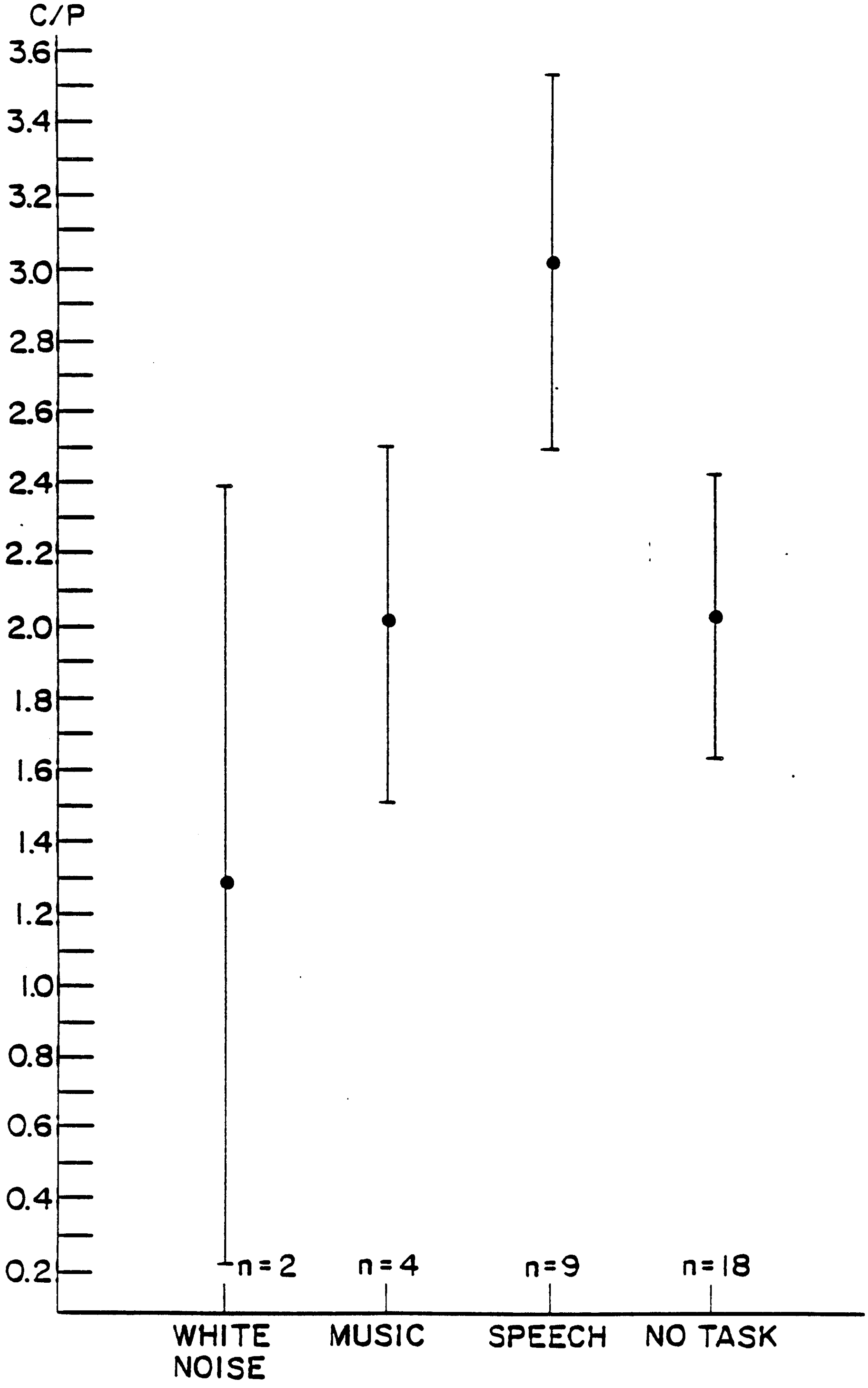
the same trend as silence and white noise makes detection of peripheral targets even lower than silence. These results however, should be taken very carefully because the t-test for differences of means shows no significant difference beyond the 0.05 level, probably due to the small number of samples. The difference between no task and speech is significant at the 0.1 level.

3.4.2 Effect of Audio Inputs on Visual Field Size

Figure 3.9 depicts the ratio (C/P) for the three audio inputs tested and no central task or silence. The (C/P) mean value for speech is significantly different than the other means beyond the 0.05 level ($P < 0.03$). Thus, listening to speech narrows the visual field although the overall detectability is not reduced (see figure 3.8). The concentration of hits in the periphery can be seen in Figure 3.3(A), which depicts the profiles for one subject. It can be seen that the profile for speech (T) shows a lower hit rate for peripheral targets while central detection is not diminished. Consequently listening to speech makes central targets less detectable as compared to listening to white noise, music or silence.

3.4.3 Right and Left Field Narrowing

The ratio (C/P) was also calculated for the right and left field for every run with audio input and all runs within the same audio input were averaged. The means and standard deviations for right, left and



NARROWING WITH AUDIO INPUTS

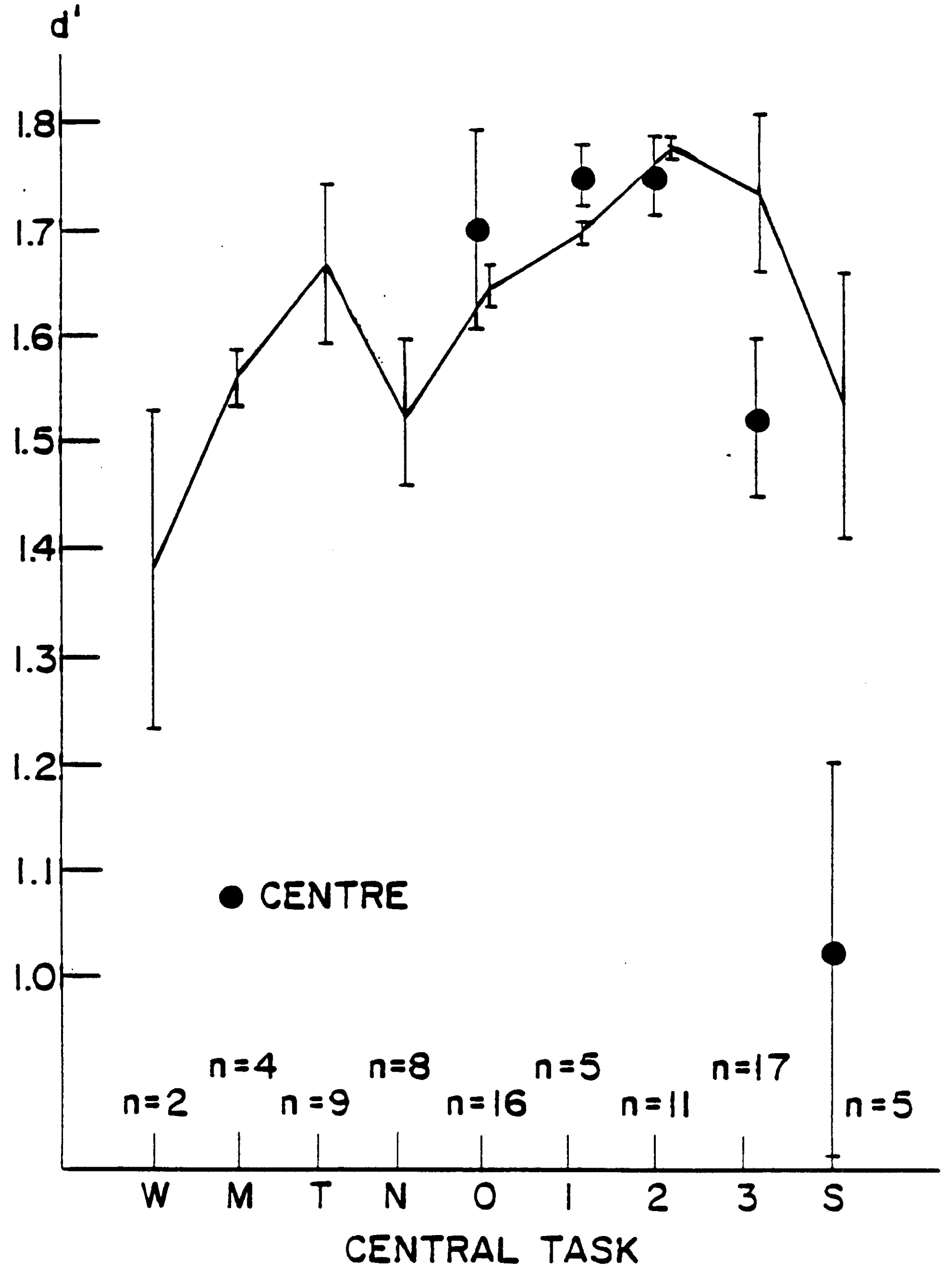
FIGURE 3.9

total are depicted in Figure 3.5 together with ther central tasks for comparison.

It must be noted that tasks with an audio input, white niose, music and speech have a (C/P) higher (but not statistically significant) difference for the right field, especially for speech, while tasks involving the central display do not show this trend. To find out if audio inputs do make the right field less detectable (higher (C/P)) a single averaged (C/P) value was calculated for all audio inputs for the right and left field and the same for the other runs. The t-test applied to the latter showed no significant difference, audio inputs did not show significant differences beyond the 0.05 level, but they did at 0.1. The fact that the difference betweeen right and left field becomes more significant when all audio inputs are considered makes one think that a greater number of subjects could have shown a significant difference.

3.5 Detectability and Narrowing for all Tasks Tested

Figure 3.10 depicts the detectability for all tasks tested, that is audio inputs, increasingly difficult central tasks and synchrony. Synchronizing the central and peripheral target onsets decreases peripheral target detectability from the peak at 2 similar to the decrease for no central task. The lowest physical detectability was reached when - listening to white noise, with a d' value even lower than that for synchronized targets. The drop in central task detectability or performance for synchronization is huge and significantly different from any



DETECTABILITY OF PERIPHERAL TARGETS FOR ALL TASKS TESTED

FIGURE 3.10

other central task detectability. In Figure 3.11 are plotted all the (C/P) values for all tasks. It is obvious from this plot that there is no narrowing effect except for T (speech) which might show some narrowing if tested with a greater population. (C/P) for white noise is lower than the rest of the values, however, its great standard deviation prevents it from achieving any significant difference.

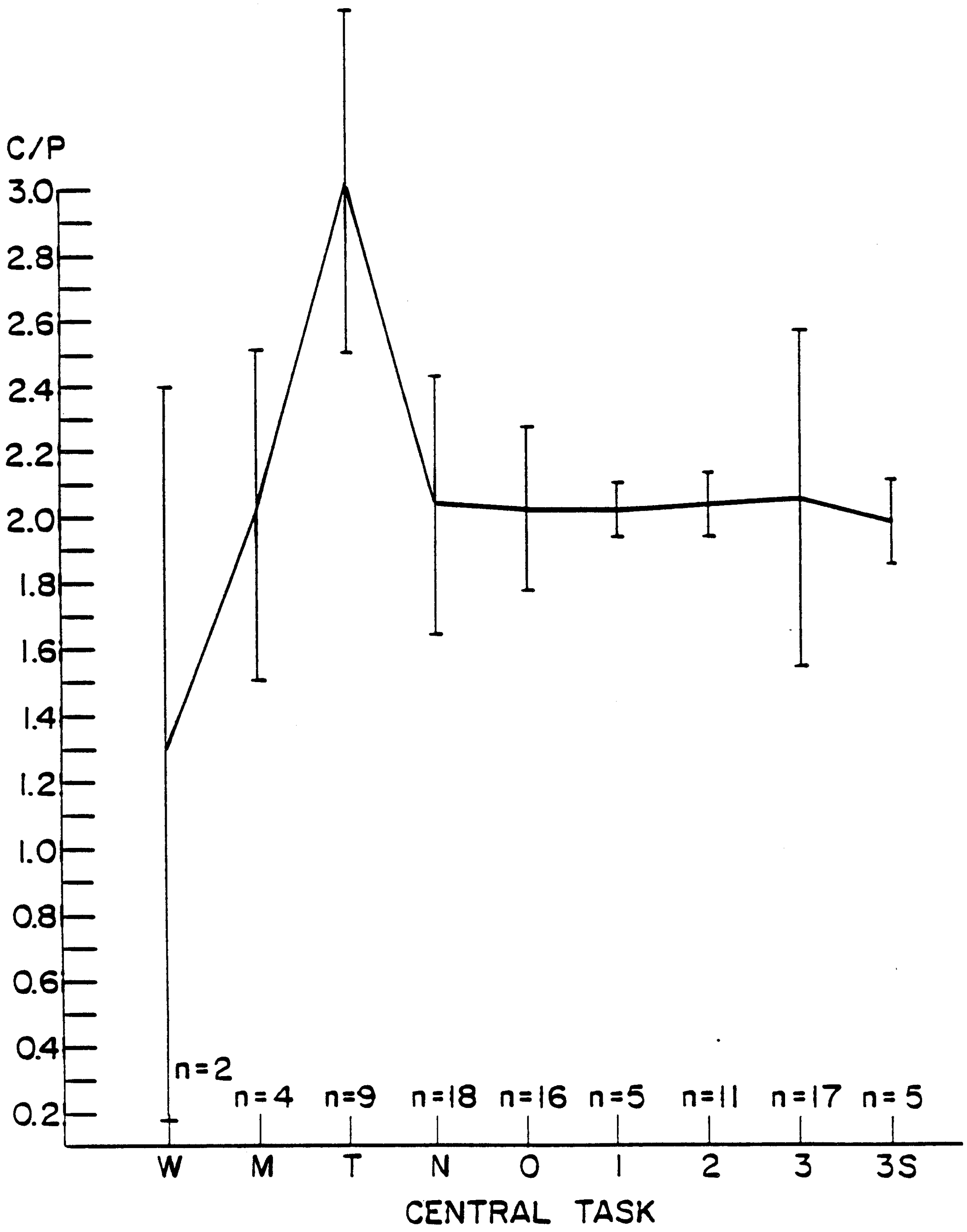
3.6 Reaction Time

It is well known that reaction time (RT) is longer for less detectable targets (Green and Swets, 1966). Measuring RT for every target position is therefore an indirect measure of detectability.

3.6.1 Reaction Time for Nine Subjects Randomly Chosen

Before calculating averages across all subjects, the mean RT and standard deviation for targets located at 5, 25 and 40 deg have been plotted for nine subjects (Figure 3.12) to see individual trends. The nine subjects were chosen randomly among all subjects run with difference 3 in the central task. Difference 3 was chosen because it represents a high central task load and it was thought that differences in RT between several angular positions might be more visible under this condition.

As Figure 3.12 shows almost all subjects (seven) needed a longer



NARROWING OF THE VISUAL FIELD FOR ALL TASKS TESTED

FIGURE 3.11

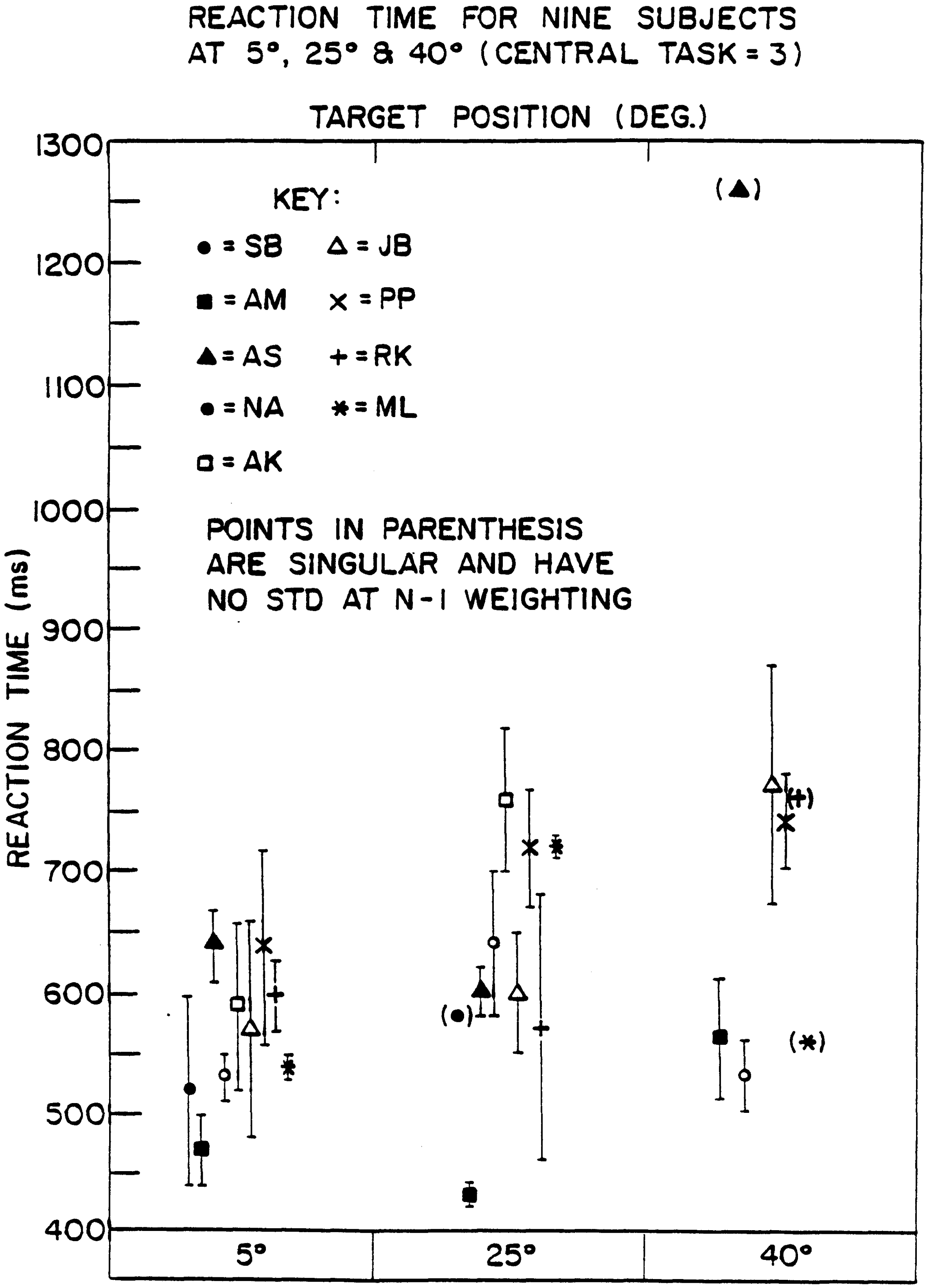

REACTION TIME FOR NINE SUBJECTS
AT 5°, 25° & 40° (CENTRAL TASK = 3)
TARGET POSITION (DEG.)
REACTION TIME (ms)
1300
1200
1100
1000
900
800
700
600
500
400
KEY:
● = SB
△ = JB
■ = AM
× = PP
▲ = AS
+ = RK
● = NA
∗ = ML
□ = AK
POINTS IN PARENTHESIS ARE SINGULAR AND HAVE NO STD AT N-1 WEIGHTING
(▲)
(●)
(+)
(∗)
5°
25°
40°

FIGURE 3.12

reaction time to detect targets at 25 deg as compared to those at 5 deg. From 25 to 40 deg, again, only two other subjects showed a drop in reaction time. All subjects had a longer RT for 40 deg than for 5 deg.

3.6.2 Average Reaction Time Profiles for Each Task

The average reaction time profiles for each task are plotted in Figure 3.13. Each plot represents data from a particular central task or audio input as the letter indicates. Reaction times are invariably longer in the periphery. This increase in reaction time in the periphery is more impressive with audio inputs (more than 400 ms) especially the music and white noise (M,W). Experiments with syncrhonized central tasks showed the opposite trend; no significant differences between center and periphery.

3.6.3 Averge Reaction Times for Each Task

The average for each plot in Figure 3.13 was calculated, with the loss of the angular position information. These averaged reaction times have been plotted versus central task in Figure 3.14 and versus type of audio input in Figure 3.15. It should be noted that reaction time is longer in the synchronized runs and shorter when there is no task ($P > 0.05$). There is no significant difference between reaction times for the other tasks or between reaction times with audio input.

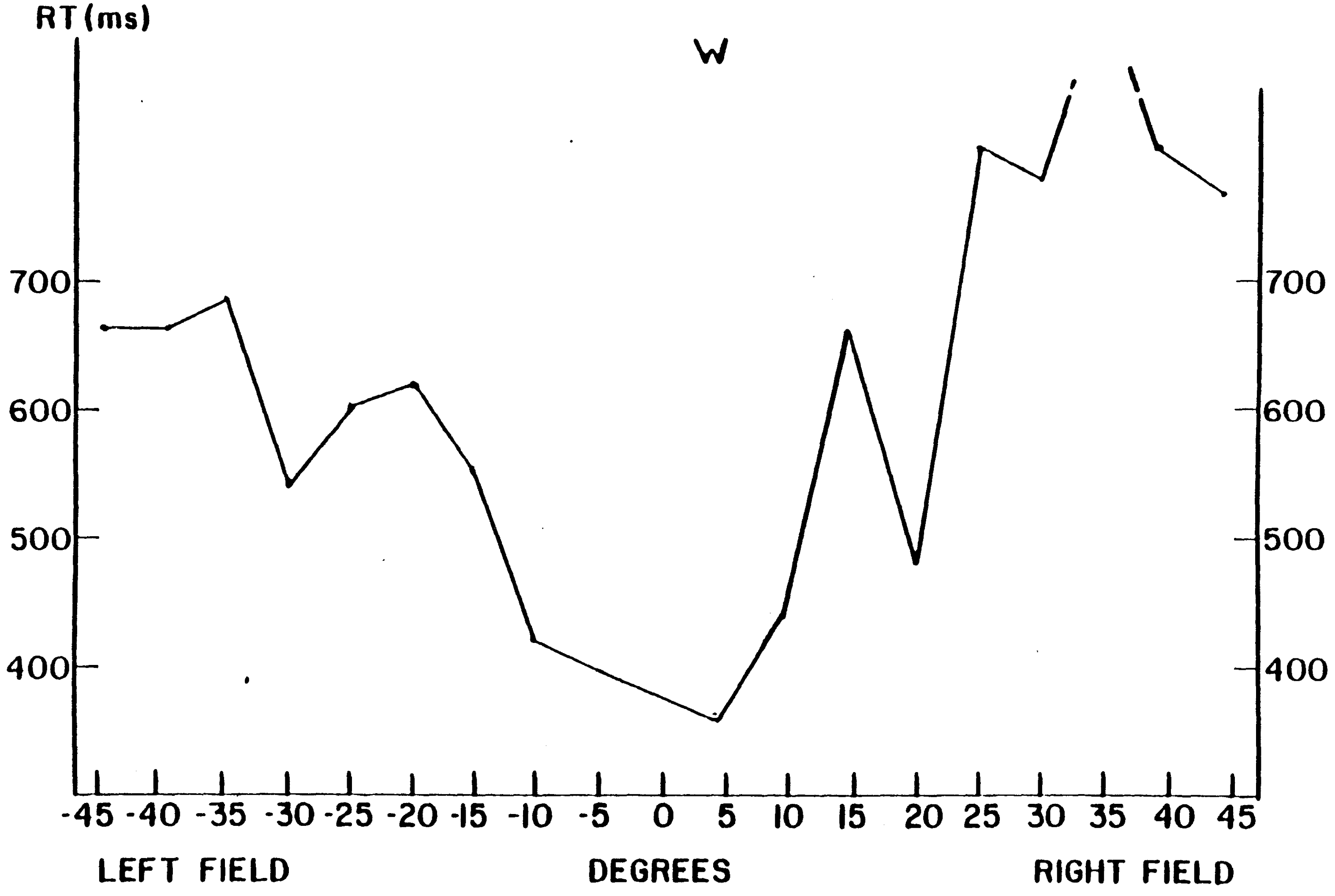

RT (ms)
W
700
600
500
400
700
600
500
400
-45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (W)

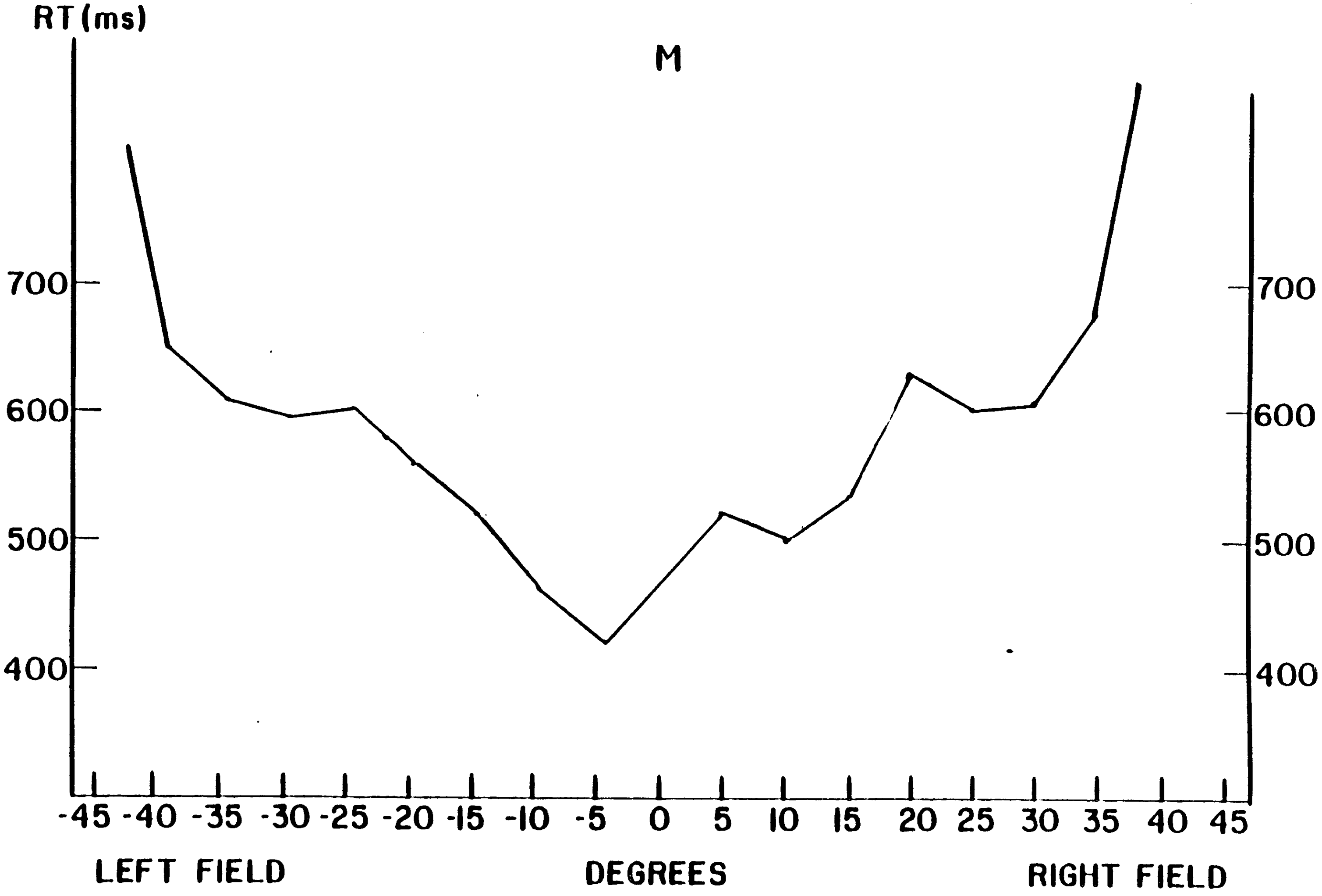

RT (ms)
M
700
600
500
400
700
600
500
400
-45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (M)

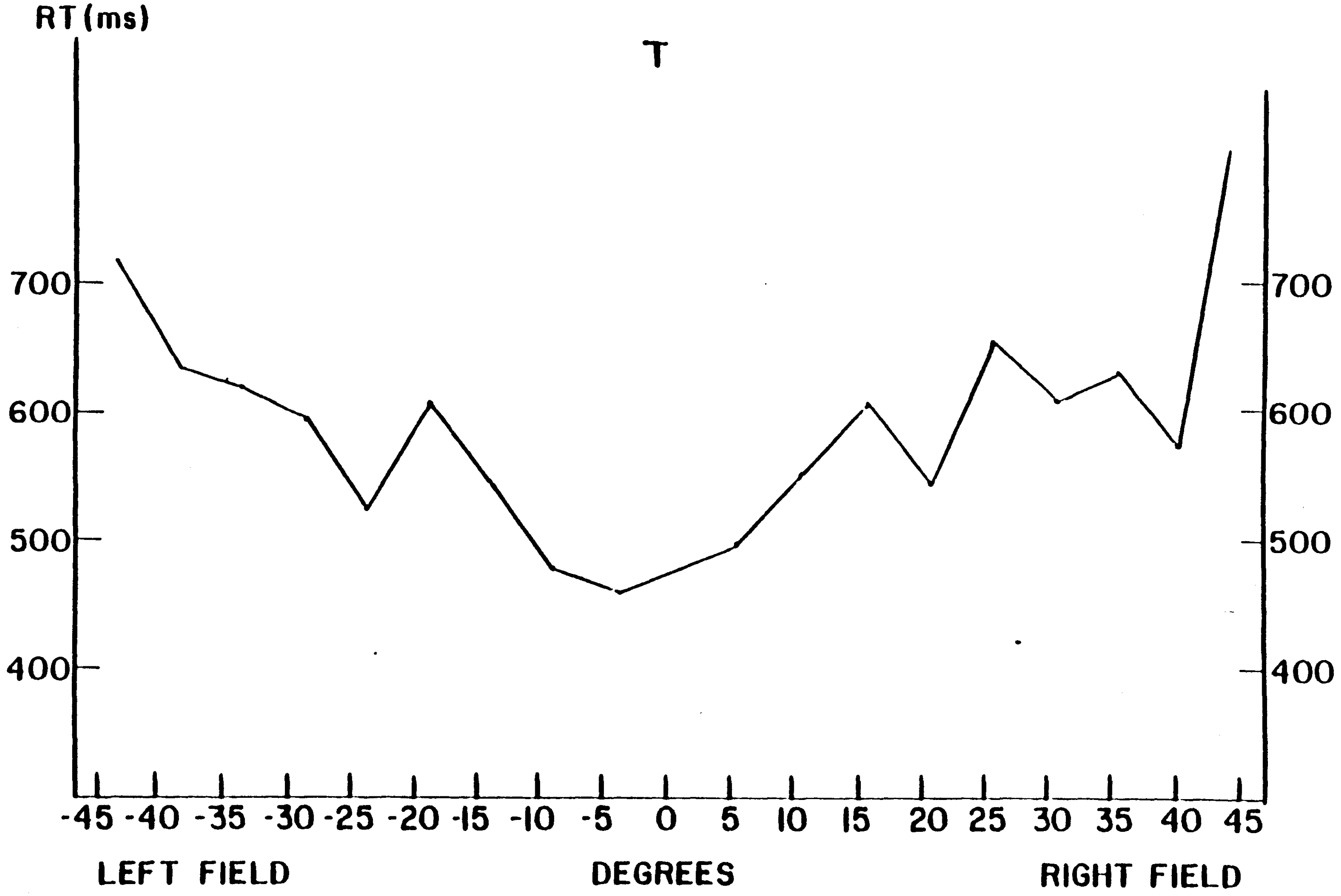

RT (ms)
T
700
600
500
400
-45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (T)

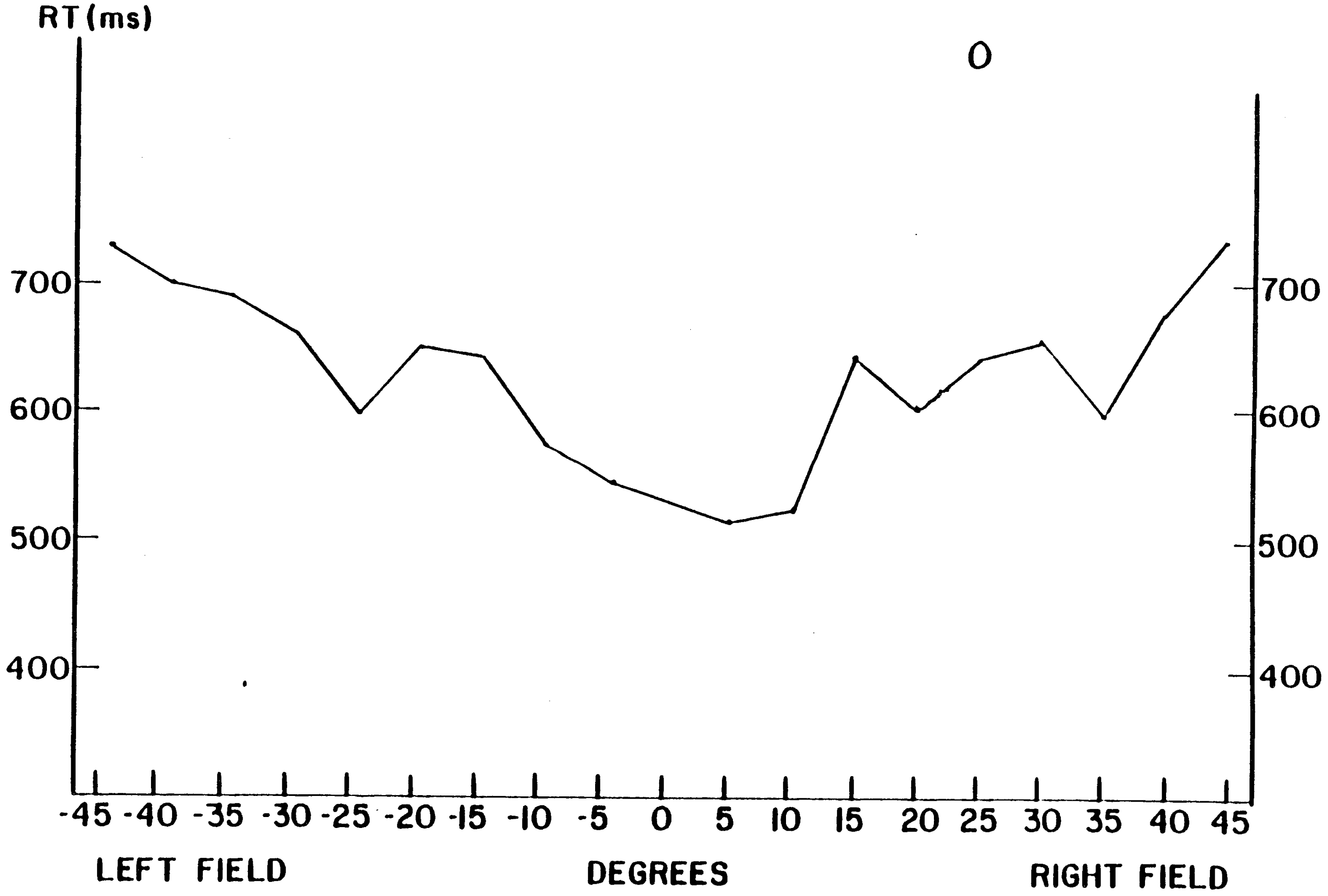

RT (ms)
O
700
600
500
400
700
600
500
400
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (0)

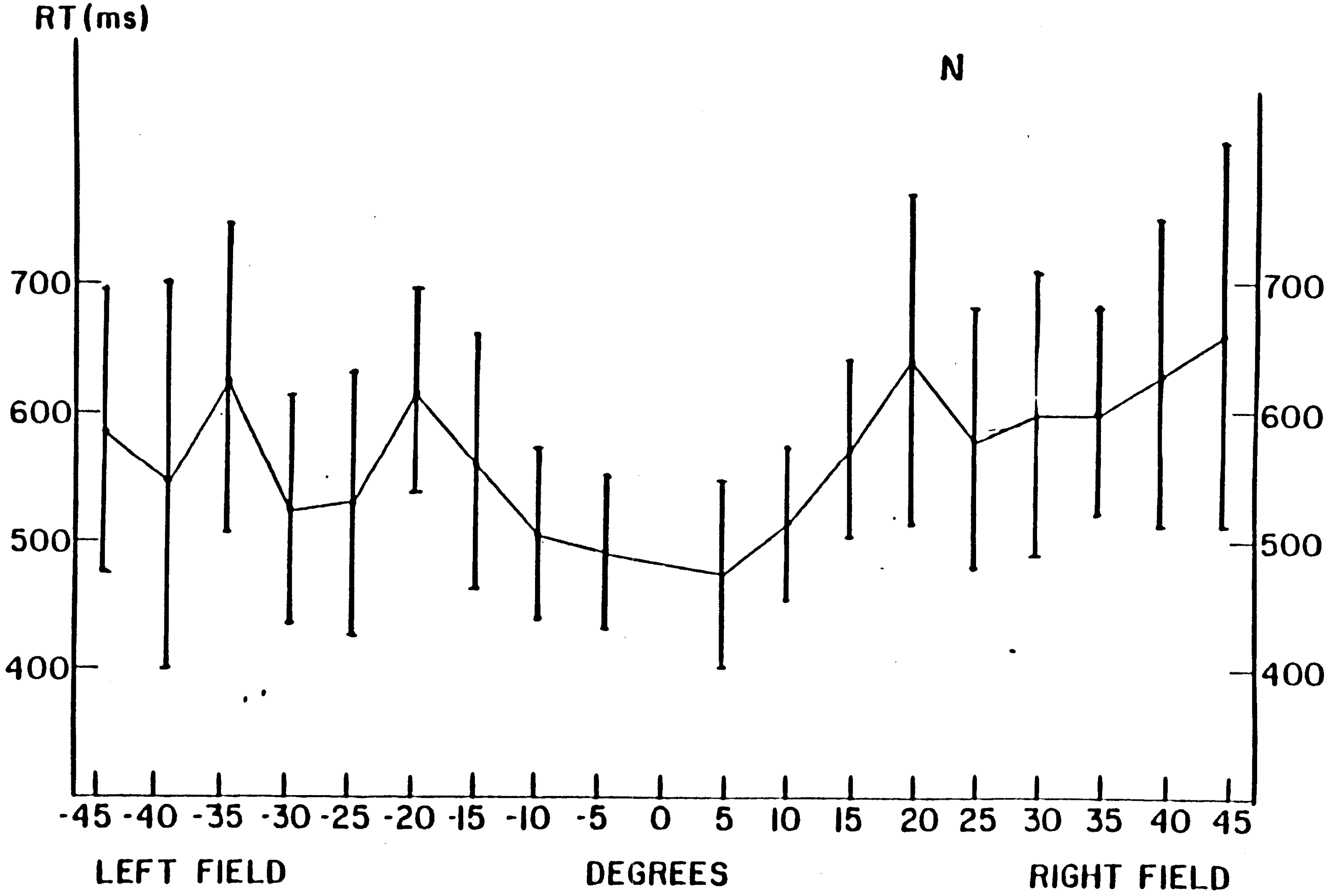

RT (ms)
N
700
600
500
400
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (N)

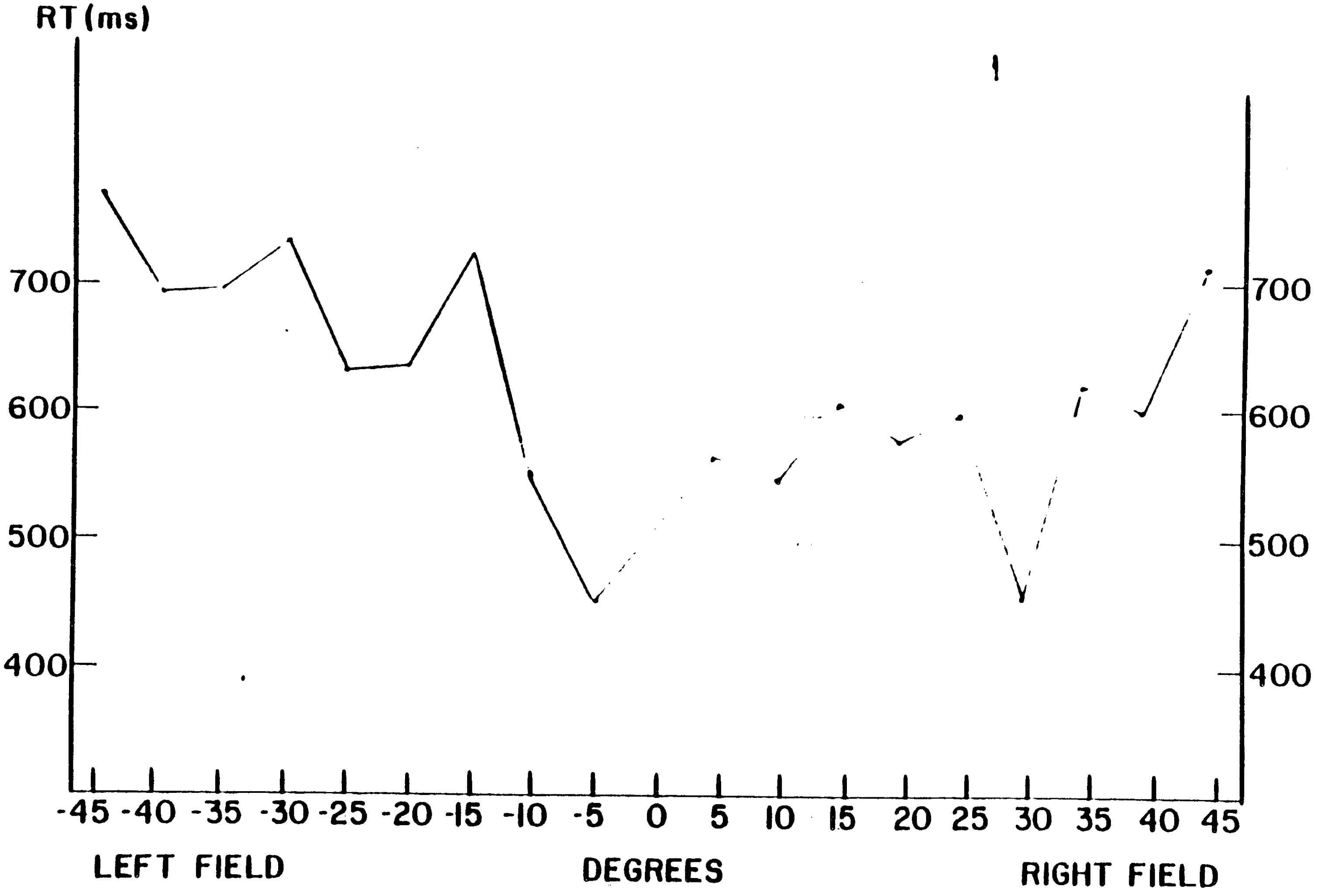

RT (ms)
700
600
500
400
700
600
500
400
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (1)

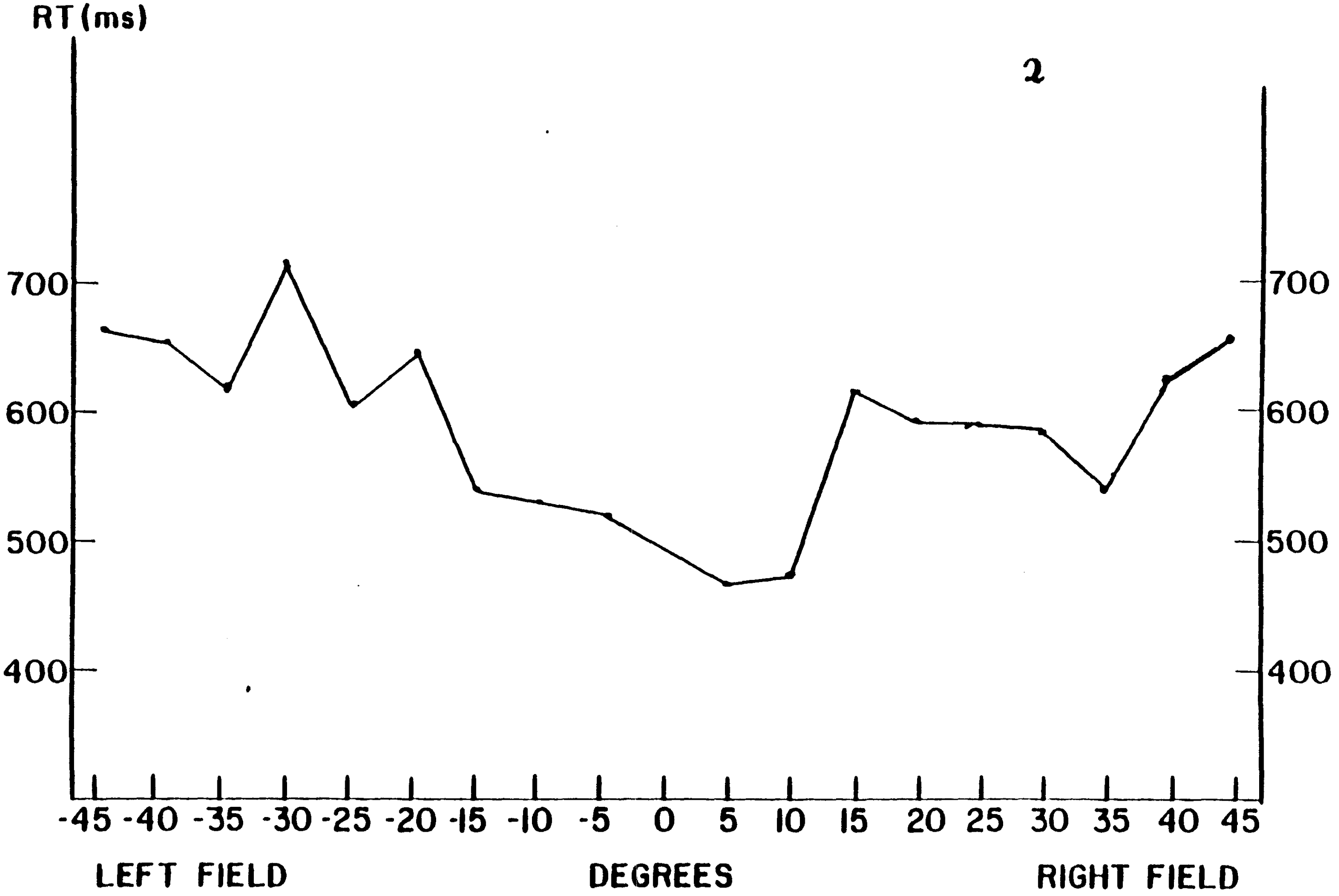

RT (ms)
2
700
600
500
400
700
600
500
400
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (2)

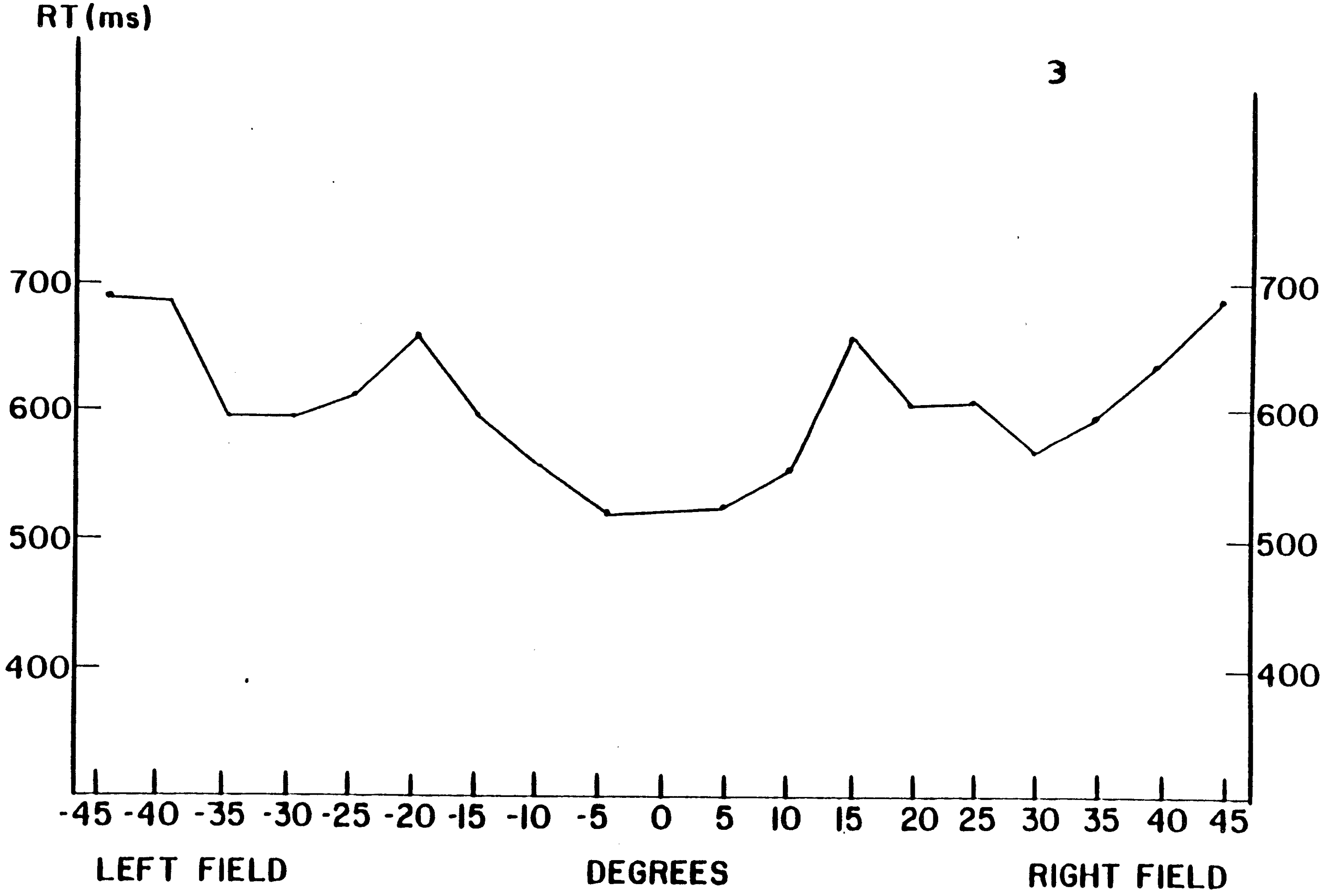

RT (ms)
3
700
600
500
400
700
600
500
400
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
LEFT FIELD
DEGREES
RIGHT FIELD

FIGURE 3.13 (3)

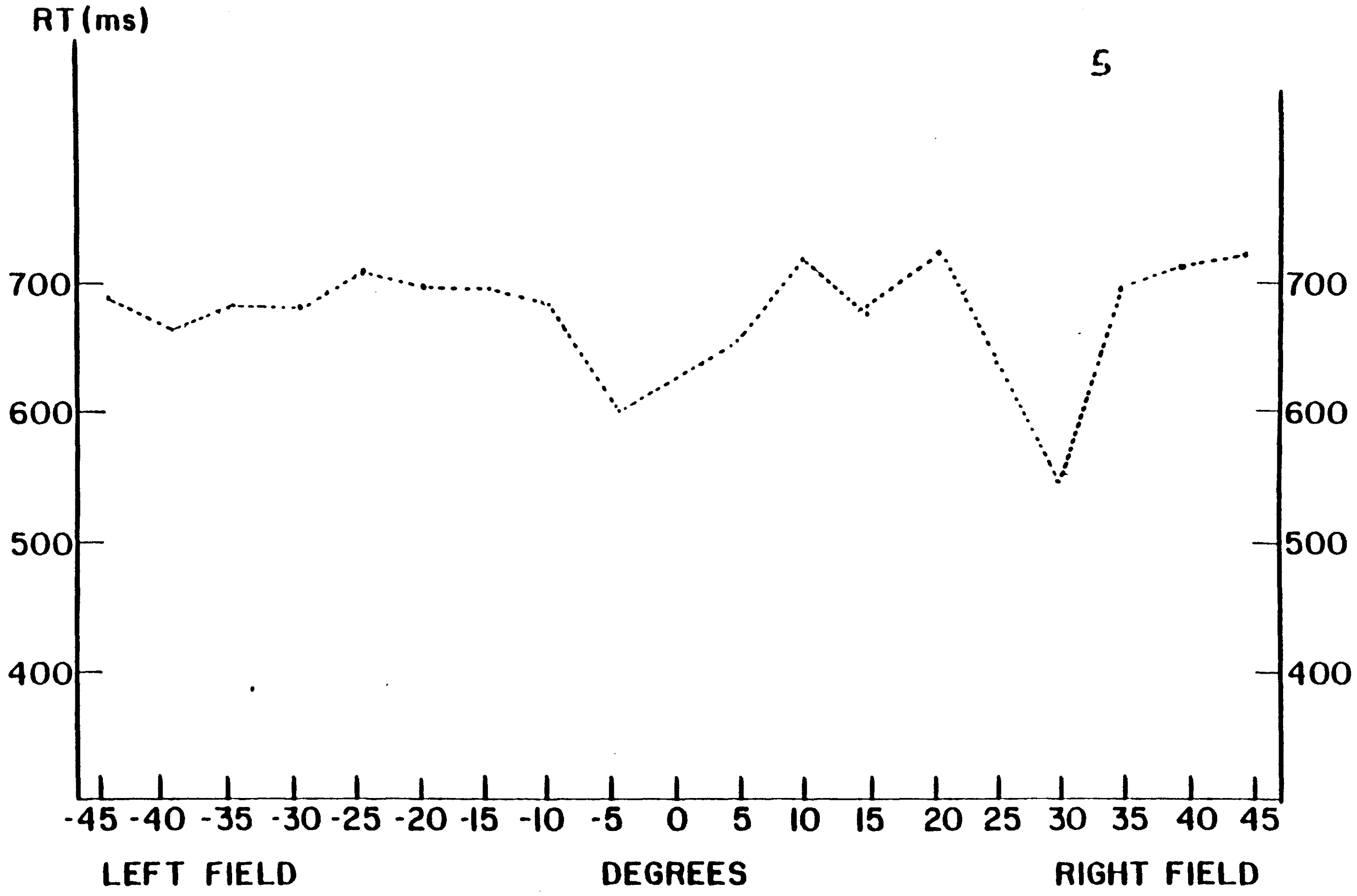
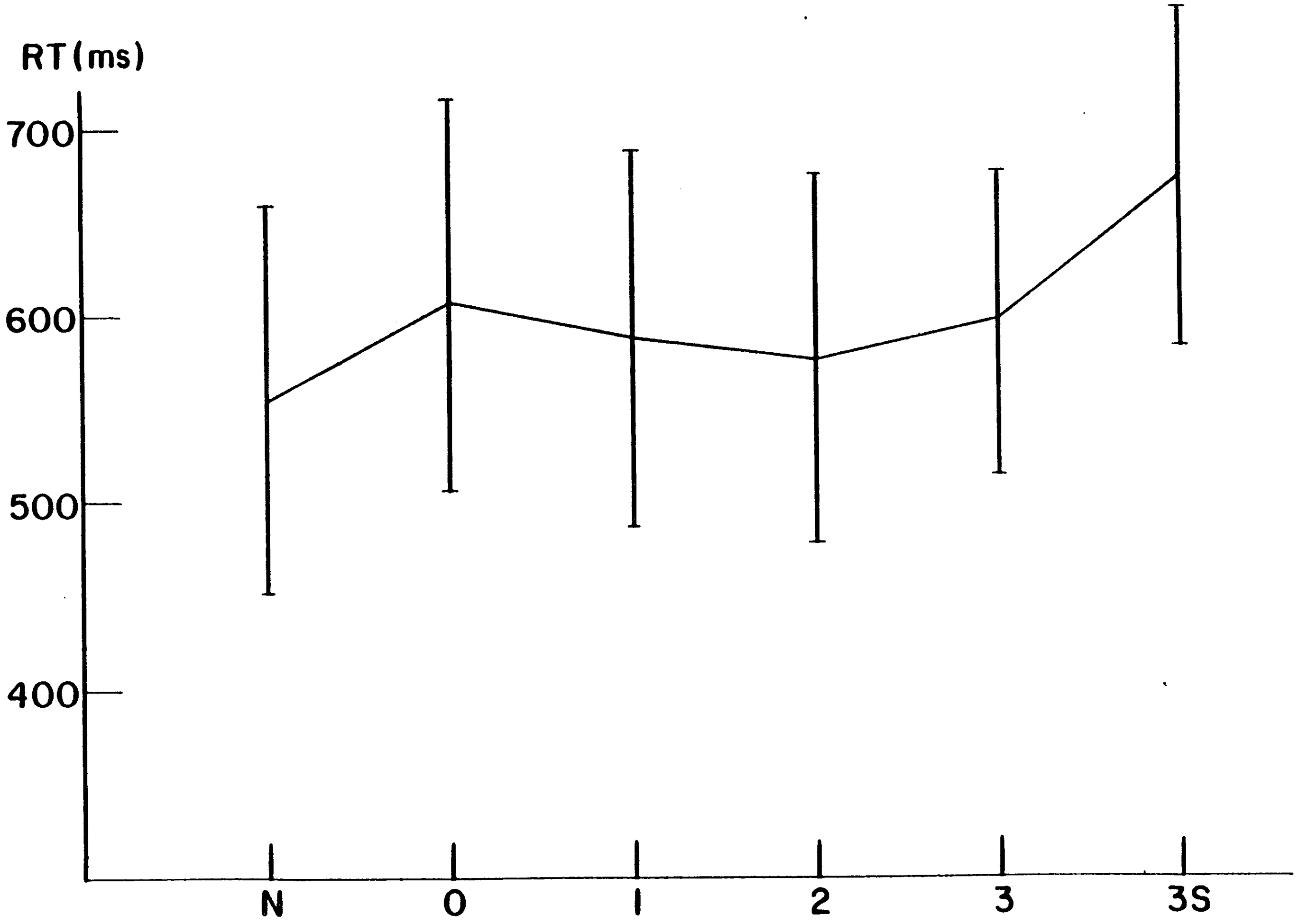
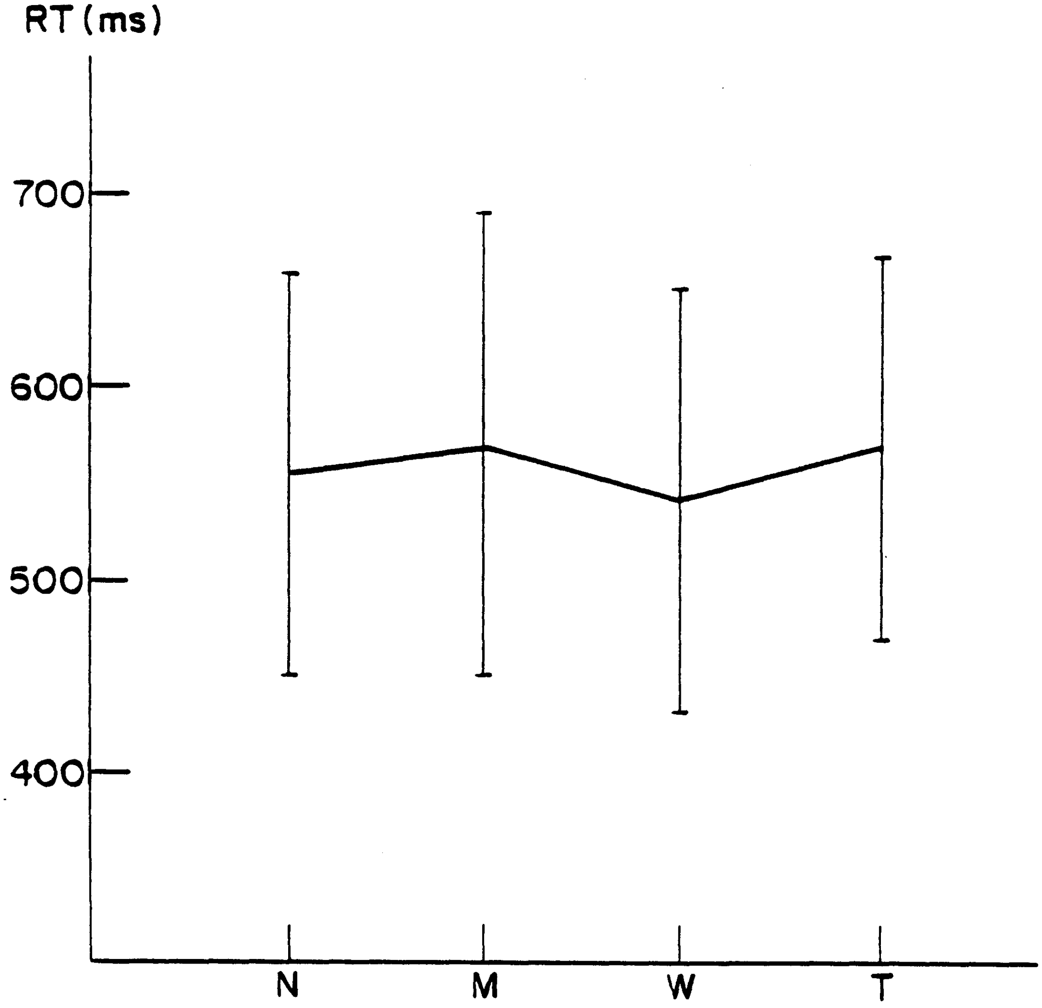


FIGURE 3.13 (3S)



AVERAGE REACTION TIME FOR INCREASINGLY DIFFICULT CENTRAL TASK LOAD

FIGURE 3.14



AVERAGE REACTION TIME FOR AUDIO INPUTS

FIGURE 3.15

CHAPTER 4

DISCUSSION

4.1 Peripheral Detectability

We have seen that the detectability of peripheral targets shows a significant rise as the central task load increases from no task to a difference of 2. This suggests that a greater demand of attention to the center task also increases detectability of flashed stimuli.

Experiments described in Chapter 2 were designed to measure mainly three parameters related to peripheral detection as a function of a central or primary task. One parameter is overall detectability (d') of the peripheral visual field (± 45 deg). This measures the probability of detecting a target in a random position of the peripheral visual field. The variable in these experiments is the complexity of the central task. According to the Yerkes-Dodson Law (Yerkes & Dodson, 1908) to move from a simple to a complex task keeping the same quality of performance, the level of arousal has to be increased, but the law does not contemplate secondary tasks so that it does not say how the increased level of arousal will meet the demand of the second task. However, Kahneman (1973) included this possibility in his electrical analogy (an electric generator plays the role of arousal or supply and several tasks are the load connected to it) and suggested that the increased arousal is only enough to compensate for the higher demand of the primary task (up to a limit), so that the spare capacity allocated to the secondary task will diminish and performance will deteriorate. According to this, detection of peripheral targets should drop when the central task demand increases. We have found (see Figure 3.1) the opposite up to a difference of 3. Kahneman's electrical analogy can be modified however to accommodate our finding by changing the shape of the "total supply" curve as shown in Figure 4.1.

This figure has been plotted from the overall detectability data (d') for central and peripheral tasks (see section 3.1). The x axis represents the central task load and the y axis the supply or arousal for a particular central task. The line "supply = load" indicates how much supply should increment when the central task becomes more demanding to keep the same performance. The lower curve represents the supply to the central task, the d' value for the central task performance was used to plot this curve. As long as d' for the central task does not change as the central task difficulty increases, the supply meets the demands of the central task and the curve coincides with the straight line "supply = load". When d' drops (for central task difficulty 3), the supply is not enought to meet the central task requirements and the curve diverges from the straight line "supply = load". The supply to the central task is not the total supply. The total supply consists of that to the central task plus the supply to any other tasks, in our case the peripheral task. Therefore if we add to the central task supply curve in Figure 4.1 the supply to peripheral task, we can plot the total supply. Detectability of peripheral targets (d') and supply to peripheral task are closely related, as supply increases detectability increases; therefore d' values were added directly

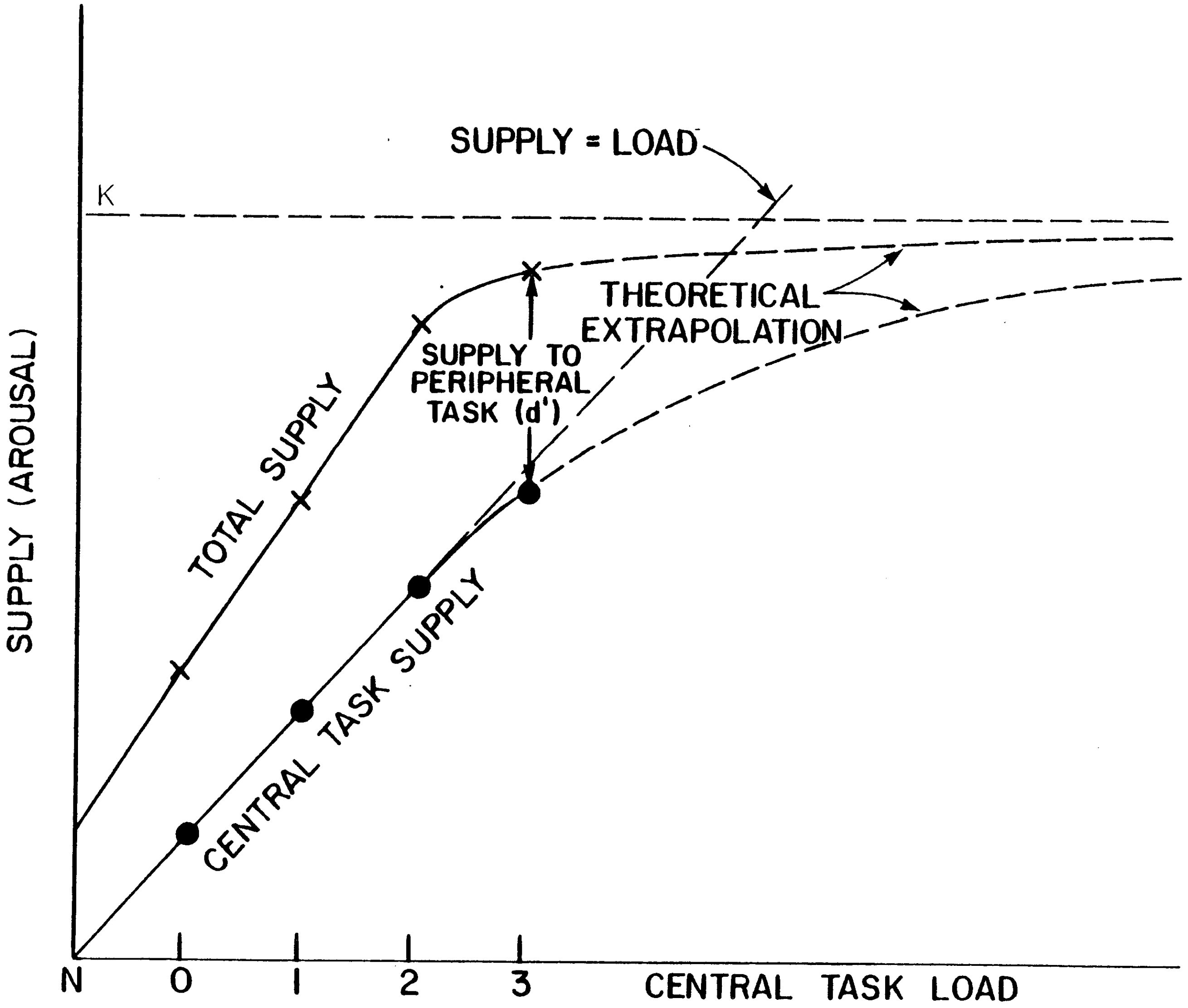

SUPPLY = LOAD
K
THEORETICAL EXTRAPOLATION
SUPPLY TO PERIPHERAL TASK (d')
TOTAL SUPPLY
CENTRAL TASK SUPPLY
SUPPLY (AROUSAL)
N
0
1
2
3
CENTRAL TASK LOAD

FIGURE 4.1

of d'. The curves plotted in Figure 4.1 this way have a remarkable resemblance to the hypothetical "performance resource function" proposed by Norman and Bobrow (see Wickens et al., 1980) and with Kahneman's (1973, p. 15) hypothesized curve. All curves, although using different names, plot capacity supplied to concurrent tasks versus capacity demanded by primary task.

The most interesting aspect of these curves is the vertical distance or substraction between total supply and central task supply, that is supply to the secondary task or peripheral task in our case. As Figure 4.1 shows, supply to the periphery increases faster than to the center; then for highly demanding tasks the supply starts to be insufficient for efficient accomplishment of the central task (around differences 2 and 3) and for the increasingly difficult central tasks all available supply is in the limit theorethicaly directed to the central task in detriment to the periphery.

What these results seem to indicate is that occupation in a primary task can improve performance as long as the compelxity of the primary task is not too high. It may be hard to say what task is easy or difficult. According to the scale of these experiments to detect when two changing (every 2 seconds) numbers were equal was an easy task while detecting when they were three digits apart (changing every second) began to make performance drop. Detecting difference 2 put peripheral performance at a maximum.

It is interesting to note that speech has the same effect as visual central task has as far as arousal and detectability are concerned (see Figure 3.10). Noise and music played at the same level as speech, however, did not show any arousal effect. Very loud noise has, though, been reported to be an effective arouser (Boggs and Simon, 1968; Broadbent, 1954; Hockey, 1970; Houston, 1968).

Another very interesting result has been obtained for the run with synchronized central and peripheral target onset. In this case, detectability of targets, either central or peripheral drops drastically (see Figure 3.10) indicating that two events happening very close in time (peripheral onset was 200 ms later than central) are very likely to pass undetected. As can be seen in Figure 3.10, the detectability in the periphery for this synchronized run is almost as low as when no task was presented, which points out how deteriorated peripheral detection of targets is when there is no central task. Vince (1948) found that whenever two signals followed one another within 0.5 seconds, the reaction to the second signal was markedly delayed. We have found not only this (see Section 4.3) but also a considerably lower detectability.

4.2 Narrowing of the Visual Field

The motivation of the experiments which are the subject of this thesis was to find out if the visual field narrows when the central task becomes demanding. No narrowing of the visual field has been found (see Figure 3.4), except when recorded speech was played while the subject was engaged in the peripheral task (see Figure 3.1). Bursill (1958) reported narrowing of his subjects' visual field or a "funnel effect" when they were exposed to extreme hot and humid conditions. Ikeda (1979) suggested that the visual field is smaller while detecting a figure in the central visual field. Therefore it would have been a reasonable guess to expect some narrowing in this experiment as the central task difficulty increases. It should be pointed out that the absence of a funnel effect has been observed when subjects were informed and expecting peripheral flashes. They should therefore allocate some of their attentional resources to the periphery. It should also be argued that in real life conditions such as flying a plane or driving a car, peripheral events can be expected as well. Narrowing of the visual field was however observed clearly and significantly in runs when subjects were asked to listen to recorded speech, as Figure 3.11 shows (T for talk or speech). The ratio of hit rate in the central field and in the periphery (beyond ±30 deg) increases from 2 without speech to 3 with speech. This narrower visual field is not accomplished at the expense of less detection, but rather the opposite, as Figure 3.10 depicts. The detectability for speech (T) is quite high. Translating the experimental conditions to real life situations, it could be predicted that the probability of detecting peripheral events while listening to a conversation or any other speech source will decay significantly. This effect can be important when flying a plane or driving, as detection of peripheral targets is necessary for efficient control of the vehicle. Auditory inputs may divert attention from visual events.

Another interesting finding, also related to audio inputs, was observed when plotting the C/P values for the right and left visual fields independently (Figure 3.5). It can be seen that all tasks involving audio inputs have a lower detection rate for the right visual field. The right field ends up in the left hemisphere of the visual cortex. It could be argued that as word processing is predominantly done in the left hemisphere, both visual and auditory tasks share processing in detriment to the visual (maybe also to the auditory) supporting the tendency observed in figure 3.5 in contrast with the opposite view which would predict a higher detection rate in the right visual field as the left hemisfere is more active or dominant than the right.

4.3 Reaction Time

Reaction time (RT) has been found to be longer in the periphery than in the center. Figure 3.13 showed that this increase in reaction time towards the peripheral is gradual and steady. This result was expected because it is known (Green and Swets, 1966) that reaction time is a sensitive and predictable measure of detectability that decreases as probability of detection increases.

We also know (Vince, 1948) that when two signals follow one another within 0.5 seconds, the reaction to the second signal is markedly - delayed. The RTs for the run with synchrony (flash 200 ms later than central change) confirms this rule, as can be checked in Figure 3.13 (3S), the RTs are considerably higher than the rest. It is interesting to note that the extreme periphery is not affected by this delay. This suggests that the center and periphery are processed independently, so that there is no possible synchronization between central task and periphery because they are processed by independent channels. Figure 3.3 confirms this finding; the hit rate for each angular position is plotted for difference three in the central task and difference three with synchrony. Central targets are much less detectable when the tasks are synchronized, however, the detection of peripheral targets is very little affected.

A parallel model of attention would easily explain these observations just assuming that central and peripheral vision are independent channels, however, we have also seen that speech makes peripheral targets less detectable, obviously speech and peripheral processing are different channels, so that there is no explanation for it in a parallel model, but in a serial model where processing capabilities are shared.

These results suggest that there are both a parallel and a serial stage in processing of information. A model with this feature will be proposed in the next section and how the model predicts results obtained so far and other observations will also be discussed.

4.4 Proposed Model of Attention

Two basic models of attention can be found in the literature. They are the parallel and serial models, already described in Section 1.1.3, and depicted in Figures 1.3 and 1.4. My proposed model takes features from both of them and adds new capabilities necessary to account for up to date observations. We have tried nevertheless to keep the model as simple as possible. Figure 4.2 depicts the model. Information from the

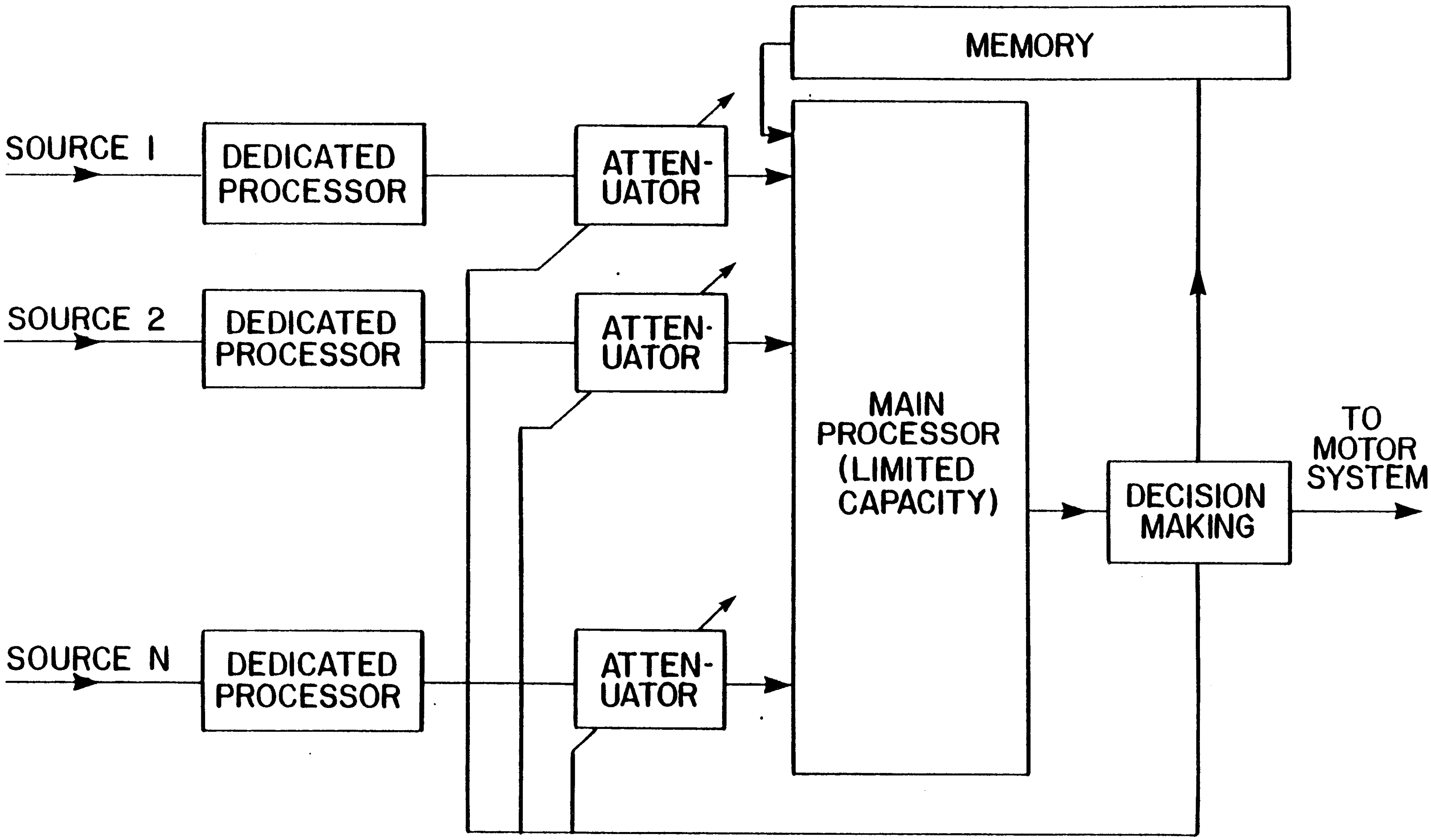

MEMORY
SOURCE 1
DEDICATED PROCESSOR
ATTEN-UATOR
SOURCE 2
DEDICATED PROCESSOR
ATTEN-UATOR
MAIN PROCESSOR (LIMITED CAPACITY)
TO MOTOR SYSTEM
DECISION MAKING
SOURCE N
DEDICATED PROCESSOR
ATTEN-UATOR

FIGURE 4.2

outside world coming from a variety of sources is processed, according to their nature in independent preprocessors. For example, central and peripheral visual fields could have independent preprocessing. These dedicated stages would work independently and no interference among them is possible. The main processor will then take care of preprocessed information. This box, labeled MAIN PROCESSOR in Figure 4.2, is capable of dealing with information which has passed the first stage simultaneously, for example central, peripheral visual field information and speech would be processed at the same time in this box as long as its capabilities are not exceeded. That the main processor is of limited capacity is in agreement with classical theory (Webster and Thompson, 1953, 1954; Webster and Solomon, 1955; Poulton, 1953, 1956; Broadbent, 1952, 1956). We shall further assume that this capacity is constant as there is no reason why this processing power should be reduced, and it is what the results of the experiments suggest (see level K in Figure 4.1).

The main consequence of a limited processing capacity is that it may not be enough to deal with all the information arriving from the dedicated preprocessors. The decision making stage is then in charge of deciding which sources of information should be favored and which attenuated to match the amount of information that the main processor can handle. The decision making stage also takes care of sending commands to the motor system to initiate a response to the stimuli. The main processor has other input apart from the ones from the sensory organs, which informs the processor of past experiences and is therefore coming from the box labeled MEMORY. Inputs from memory alone can trigger the motor system, for example, if we suddenly remember to make a telephone call, the main processor will receive this request from memory and after informing the decision making stage of this and the other inputs competing for a response, the decision making box will probably decide to move the arm to reach for the phone and dial the number. Again, the numbers sent from the memory are converted into finger movements. The decision making box will also send signals to the main processor to attenuate other inputs such as listening to a conversation.

The decision making stage has another important mission. There are stimuli to which we may not want to respond with the motor system, but may want to store in memory for future reference. The decision making box will then decide which information is considered useful for storage. This requires some processing as the decision will probably be based on comparisons with past experiences to make sure something new is stored. The main point is that the processor can be utilized to process external and internal information, the decision making stage decides what portion of the total capacity of the processor is dedicated to them. Let us illustrate this point with an example: If we are engaged in a very simple task, like watching a sunset, the decision making stage will detect the under utilization of the processor and will use the remaining capacity to organize internal information. This is what we call thinking and will attenuate information coming from the outside to prevent any interference. This example may help us understand why the peripheral detection is so low in the experiment described before when no central task is imposed on the subject. In fact, many subjects commented after the experiment that they could not concentrate because their imagination interfered.

There is a state in which stimuli from outside are almost completely ignored, that is sleep. It can be checked that the visual system is no exception with the following simple experiment: Open the eyes of a sleeping person with your fingers and put an object in front of his eyes, then hide the object, wake the person and ask him what it was. He will be unable to say. During sleep, therefore, the main processor is not occupied with external information, according to the model it must be processing internal information. Several authors, looking for a reason for sleep have proposed models that consider sleep as a state in which reprogramming takes place with the new information acquired in the day (Dewan, 1967; Newmann, 1965; Gaardner, 1966; Greenberg and Leiderman, 1966). This hypothesis fits very well in the model proposed. According to the model, sleep could be a situation in which channels bringing information from the outside are shut off to allow the main processor to organize the data collected and stored in memory. There is some evidence presented by Livingstone and Hubel (1981) to support this view. They recorded from individual cells in the visual cortex of sleeping cats. The recordings showed irregular bursts of spontaneous firing although images on a screen stimulated their retinas. As soon as they were awakened, the spontaneous firing (noise) was reduced and replaced by a smoother and more regular pattern,suggesting that visual signal transmision was blocked during sleep because of the increased signal to noise ratio. This experiment seems to suggest that the attenuators of Figure 4.2 are rather controllers of the signal to noise ratio.

4.5 Justification

Some examples have already been described that support the model proposed. However, the real justification of the model is in its superiority as compared to existing models to explain results obtained in many experiments. The serial or filter model first proposed by Broadbent fails to explain those experiments (Treisman, 1970; Treisman and Fearnley, 1971) in which division of attention to two or more sources is evidenced. The parallel model, associated with Deutsch and Deutsch (1963) assumes that each source is processed independently. This way attention can be divided, however, it cannot explain those experiments where selective attention to a source or task reduces performance on other tasks, because it would imply that the processing is not parallel or independent. In an attempt to solve the problem, the capacity model was formulated. It assumes that there is a general limit on man's capacity to perform mental work (Moray, 1967). The parallel model with this feature could be able to explain those cases of reduced performance in a secondary task due to load in a primary task as a simple overload of the processor. Very soon, however, a new problem arose with this capacity model. Experiments showed evidence that the total capacity was not constant whatsoever but varied with the difficulty of the task. The effort invested is determined by the intrinsic demands of the task (Kahneman et al., 1968). This apparently reasonable finding is actually quite puzzling. At an intermediate level of difficulty, the subject makes a significant number of errors. Yet he does not work as hard as he can, since he exerts greater effort when difficulty is further increased. Why, then does the subject not work harder at the initial level of difficulty and avoid all errors? The model proposed in this thesis answers that question. The total processing capabilities are constant for each subject, but they are not only utilized for processing external information but for internal processing also. No task (external or internal) has the privilege of exclusive use of the processor, but they all must share the available capabilities according to the subject's needs at that time.

CHAPTER 5

SUMMARY

The main objective of this thesis has been to assess the performance of the visual system under different attentional situations. As a starting point, Chapter 1 has reviewed the literature in selective attention revealing that the mechanisms involved are far from being understood. The coexistence of different attention models, discussed in this study, is evidence of our limited knowledge.

Experiments were designed and conducted to determine how subjects allocate their attentional resources when they must respond to a variety of tasks (Chapter 2). The experiments measured changes in peripheral sensitivity with increasing central attention and with audio inputs, accomplished by having subjects view a wide field display while fixating on a target in the center of the visual field. At a random time, an additional target appears in the periphery, and the subject's task is to detect it. The number of hits, misses and false alarms were used to indicate the performance of the subject and the peripheral visual field.

Results obtained from these experiments have double value: First, they are applicable to real life situations if we consider the experiment as a simulation of a particular activity. Peripheral detection is a function of the primary task. Knowing the shape of this function (Figure 3.1), we could change a variable central task to obtain a desired peripheral performance. For instance if we wanted to optimize the peripheral visual field detection of a pilot flying a plane, we should make sure he is engaged in a task that puts his peripheral detection in the peak of Figure 3.1. Experiments have shown that speech narrows the visual field; we can conclude that activities requiring peripheral target detection will be performed less effectively when simultaneously listening to speech. Thus it will not be desirable to listen to any speech source while engaged in a task that requires maximum peripheral detection, although it can be advantageous if the relevant task is in the central field.

Secondly these experiments have shown that selective attention is involved in visual perception although the performance of the visual system under various attentional situtations appears to be different from what could have been expected. We have therefore gained some knowledge of the attentional mechanisms themselves and a model of attention to account for these and previous experiments has been proposed in Chapter 4.

The use of the C/P ratio has shown a simple and effective way of measuring the narrowing of the visual field and we recommend its use in further experiments.

Several experiments have shown interesting although non-significant results, such as the effect of white noise and music in peripheral detection and the higher detectability of the left visual field when the subject is listening to any audio input. The lack of statisitcal significance could very well be due to the small population of subjects who participated in these audio experiments, therefore to design a collection of experiments with simultaneous audio and visual inputs for a larger population seems to be a future step.

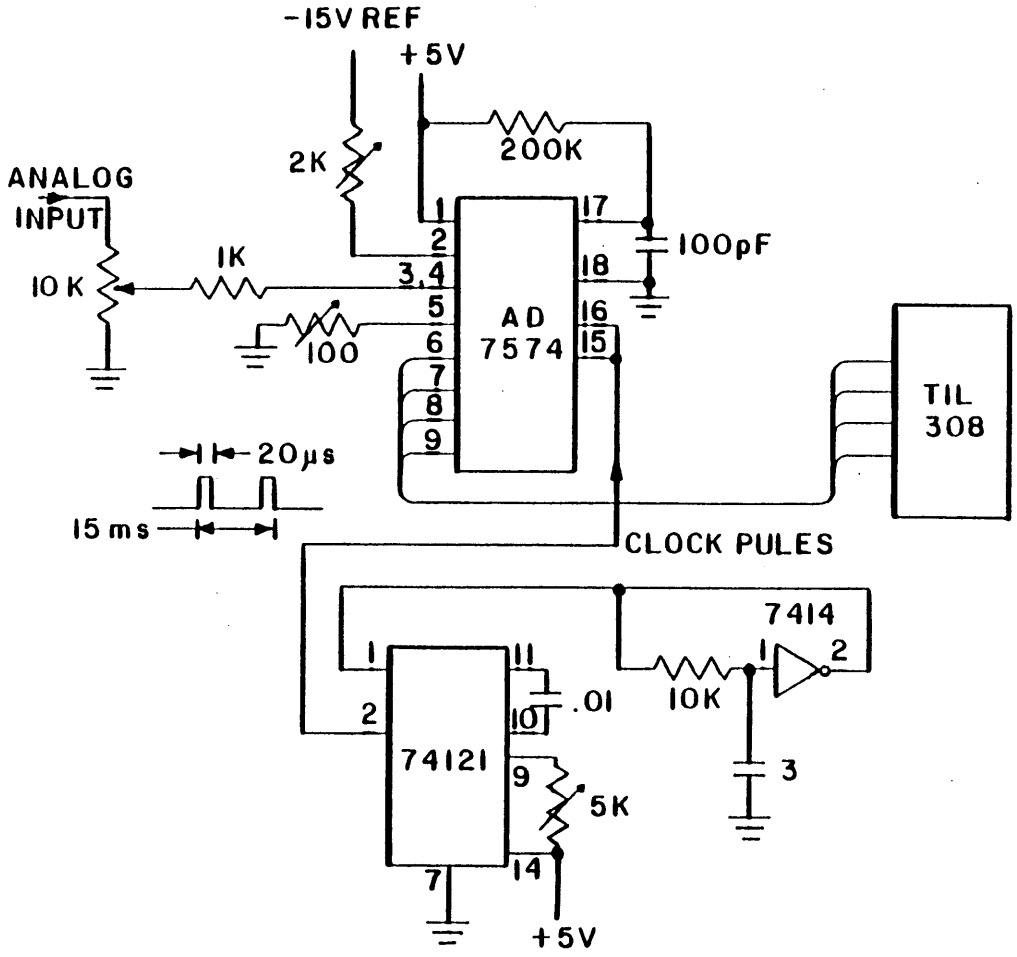
All experiments in this work have been conducted with static targets. It would also be very interesting to know what differences dynamic targets may introduce.

Also, before using the results of this work to predict performance in real life situations, an evaluation should be done with gradually increasing intensity targets, instead of the sudden onset used in the experiments and targets with different shapes should be used to adapt the experiment to particular cases.

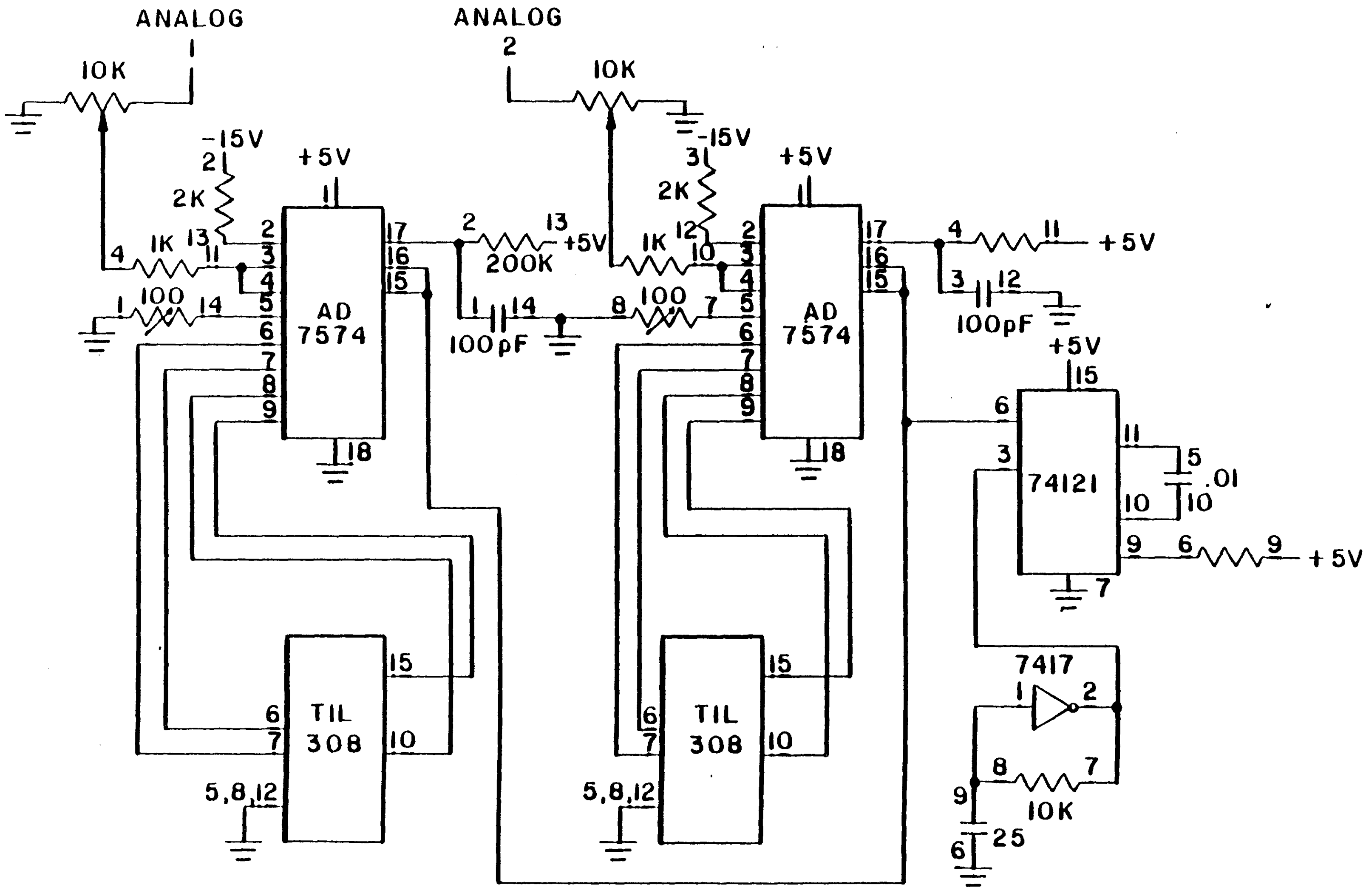
APENDIX I

SCHEMATICS

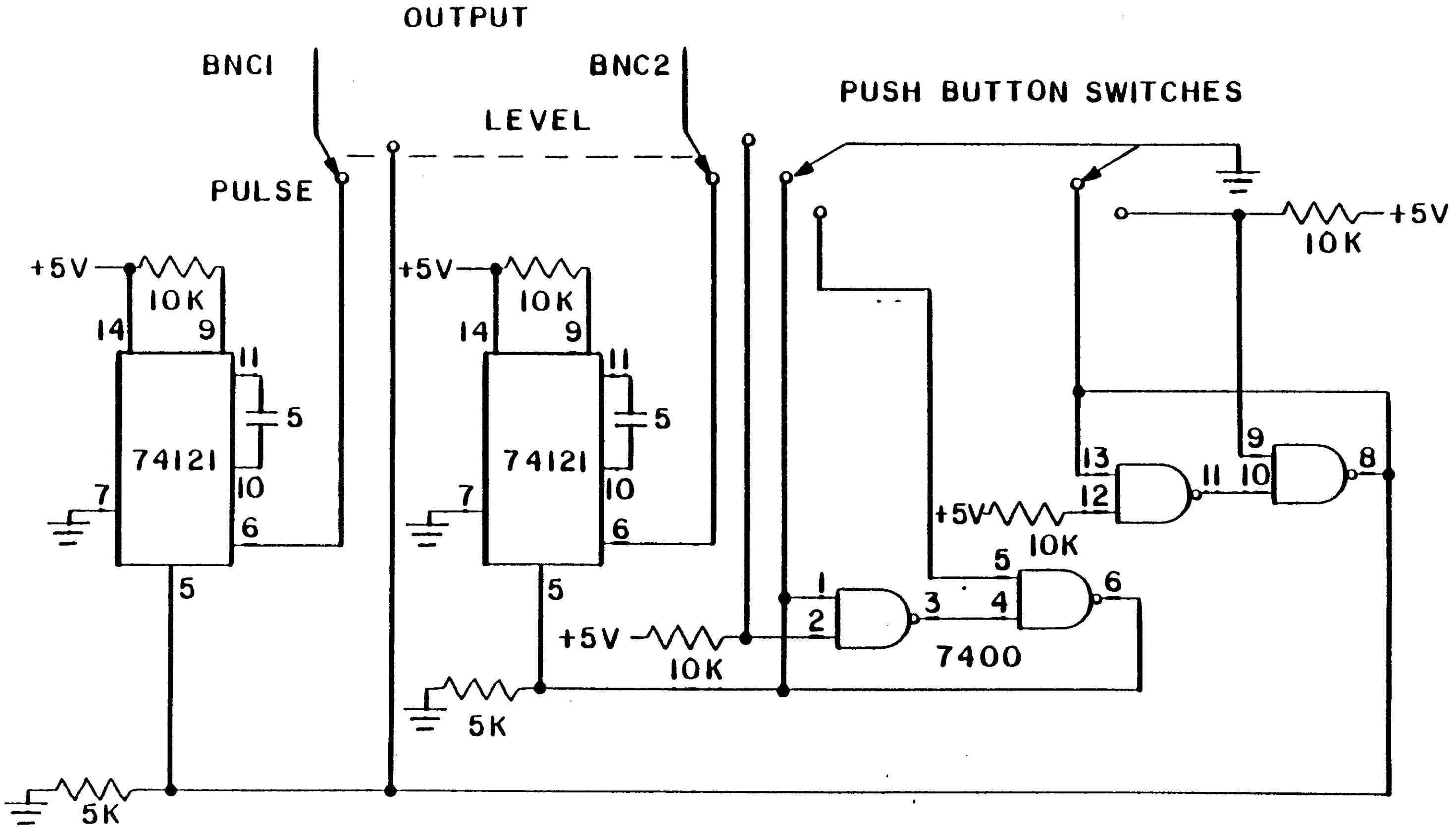
A device using an A/D converter was designed to illuminate the twin seven segment display. This device acepts any voltage between 0 and 15 volts and displays it in hexadecimal on the seven segment display. Any voltage in between two integer values is rounded to the nearest integer. The reason why the analog output of the computer was used for this purpose and therefore required A/D conversion, instead of using the digital outputs to drive the display directly, is that all the digital outputs are used to drive the peripheral LEDs. It can be seen in this block diagram and schematics that there is a single pulse generator for both D-7474 A/D converters. The purpose of this pulse is to start conversion (duration 15 ms). The display will be on till the next pulse arrives 15 microseconds later, and then another conversion takes place. Thus when the computer changes an output voltage, it will be displayed 15 microseconds later, maximum. The autput of the A/D converter is binary and the display requires BCD code; however when taking only the four most significant bits of the A/D conversion (see schematics), the autput is in BCD.



DUAL DISPLAY DRIVER DIAGRAM



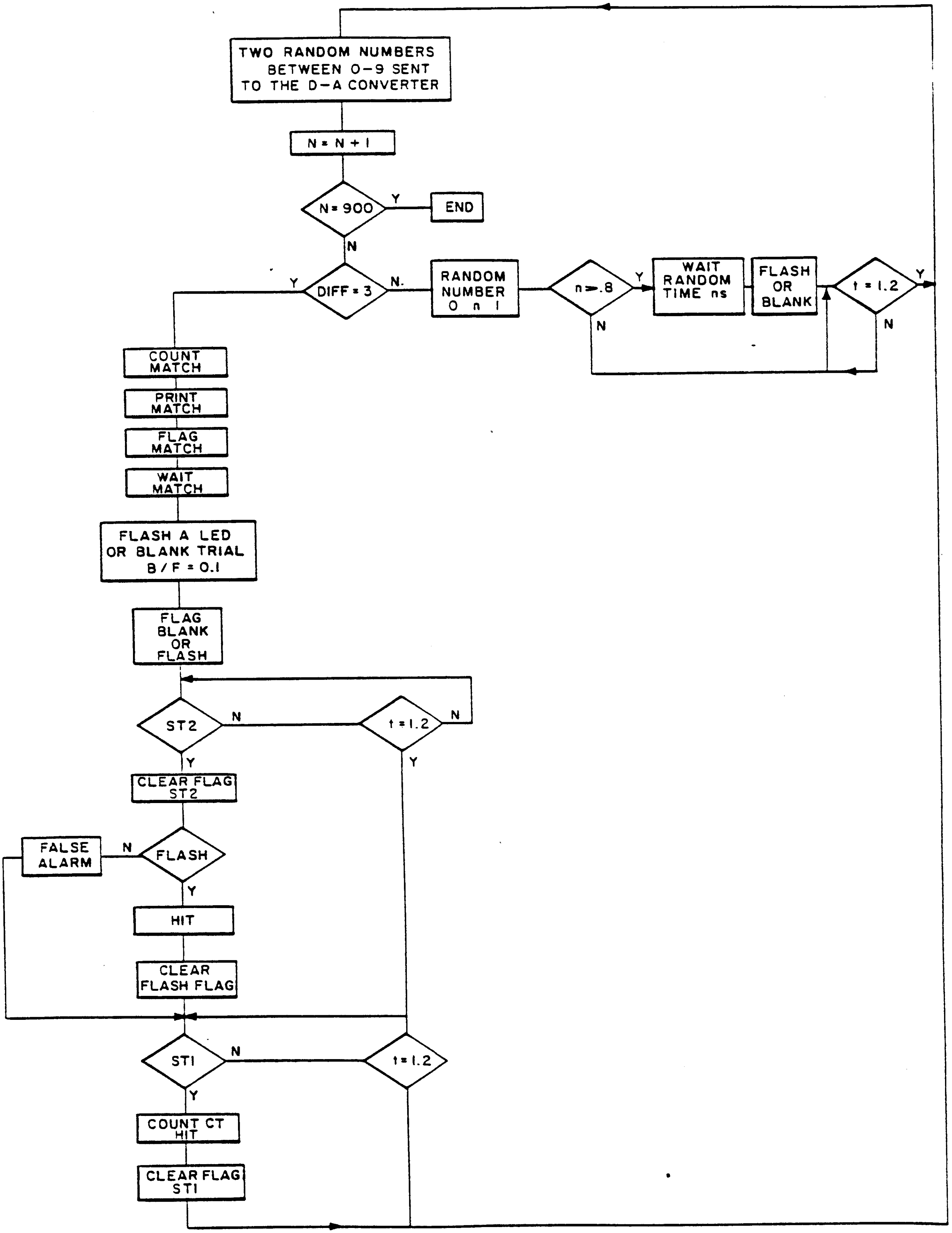
DUAL DISPLAY DRIVER SCHEMATIC



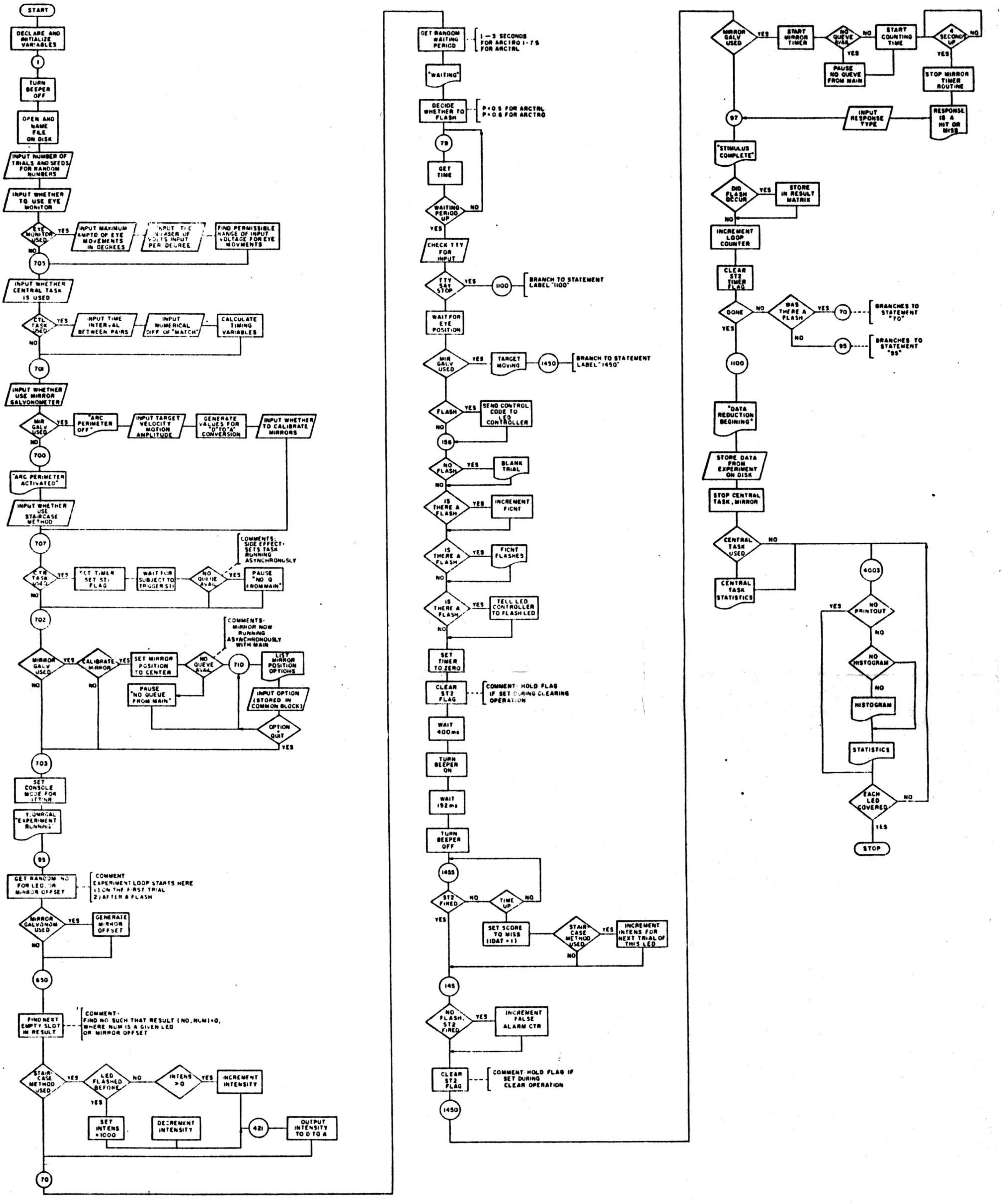
DUAL ONE SHOT & DEBOUNCER

APENDIX II

COMPUTER PROGRAMS



FLOW CHART FOR ARCSYN



FLOW CHART FOR ARCTRL

```
C
C       PROGRAM TO CONTROL THE LED ARC PERIMETER.
C               WRITTEN BY R.V. KENYON  FALL 81.
C
C       LINKING OBJECT FILES NEEDED ARE:
C       RVKLIB.OBJ - LIBRARY WRITTEN BY R.V. KENYON FOR LPS11.
C       LPSLIB.OBJ; - LPS11 LIBRARY WRITTEN BY DEC.
C
C       THIS PROGRAM WILL ILLUMINATE ONE LED ON THE ARC IN A
C       PSEUDO-RANDOM SEQUENCE AFTER WAITING BETWEEN FLASHES
C       SOME RANDOM TIME BETWEEN 1 AND 7.5 SECONDS.
C
C       CONCURRENTLY, AT A USER SPECIFIED INTERVAL THE CENTER DISPLAY
C       NUMBER WILL CHANGE VALUE PRODUCED BY A RANDOM NUMBER
C       GENERATOR.  THIS FEATURE IS IMPLEMENTED BY CONNECTING
C       D TO A CHANNEL #2 (DAC1) TO A DVM DISPLAY.
C
C       THE SUBJECT RESPONDS BY TRIGGERING ST2 WITH A PULSE
C       AT WHICH TIME THE REACTION TIME IS STORED IN A DATA ARRAY.
C       IF NO RESPONSE IS RECIEVED AFTER 3 SECONDS THE TRIAL IS
C       A MISS AND A 1 IS STORED IN THAT LOCATION.
C
C       A HIT WILL DECREMENT THAT TARGET INTENSITY BY A FIXED AMOUNT
C       WHILE A MISS WILL INCREMENT THAT SAME TARGET INTENSITY
C       BY THE SAME INCREMENTAL AMOUNT.  THUS EACH TARGET LOCATION
C       ON THE ARC WILL HAVE ITS OWN INTENSITY VALUE THAT WILL
C       CHANGE WITH THE NUMBER OF HITS AND MISSES. (STAIRCASE PARADIGM)
C
C       IF A RESPONSES IS RECIEVED BEFORE THE FLASH OCCURS AS SEEN
C       BY ST1, A FALSE ALARM IS SCORED.
C
C       AT THE END OF TRIALS, THE DATA IS STORED ON THE DISK:
C       REACTION TIME IN MILLISECONDS,
C       INTENSITY PROFILE FOR EACH LAMP AS FUNCTION OF TRIAL,
C       STATISTICAL AND HISTOGRAM RAW DATA.
C
C       OUTPUT LINES ARC:       D TO A 1===>VARIABLE LED FLASH INTENSITY
C                               D TO A 2===>CENTRAL LED DISPLAY #1
C                               D TO A 3===>CENTRAL LED DISPLAY #2
C                               D TO A 4===>GALVONOMETER CONTROL
C                               D TO A 5===>'BEEP' TONE CONTROL.
C
C       INPUT LINES ARE:        A TO D 0===>EYE POSITION.
C
C       KEYBOARD COMMANDS INCLUDE:
C               S-  STOP DATA ACQUISTION JUMP TO DATA PROCESSING.
C               H-  PRODUCE NO HISTOGRAMS
C               P-  INHIBIT ALL DATA PRINTOUT
C       COMMANDS MAY BE PUT IN BACK TO BACK:
C               SP<RET>-  STOP DATA ACQUISTION AND NO DATA PRINTOUT
C               SH<RET>-  STOP DATA ACQUISTION AND NO HISTOGRAMS
C
C       THE SUBROUTINES RUN ASYNCHRONOUSLY AND ARE CONTROLLED VIA
C       VARIABLES IN COMMON BLOCKS.
C
```

```fortran
      PROGRAM ARCCTL
C
C   DEFINE ARRAYS AND VARIABLES
C
      EXTERNAL BOOL,MIRROR,LEDGEN
      VIRTUAL RESULT(256,20),INTENS(256,20)
      INTEGER*4 ATIME,BTIME
      INTEGER IMAX,CHARTR(10),ST,H,P,BELLON(5),BELOFF(5)
      INTEGER NO,IEFLG,INH,IMISS,IHIT,NCOUT,TIMMER(4)
      INTEGER TARGET(6,20),INC,TIM,ICHAR,FICNT
      INTEGER FALSE,IOP,ICNT,TICK,JSW
      INTEGER IDAT(1),ILOW,ITOP,OUTPUT(6)
      REAL MTIME,R(2)
      REAL TIME,X,DTIME,FREQ(20),PCT(20),STAT(5),S(256),NLAT
      REAL UBO(3),BX,C(6),SECONS,PMAX,MX,DELX,EM,EMCAL,XY
      INTEGER IP(2),NUM,TMIRR(4),TICKR,ZTIME
      INTEGER NLFT,IVL,LEDFLS,LEDCNT,LEDMIS,RUN,IPFF(2)
      INTEGER IFLG,DIFF,CAL,PMIN,TOTHIT,TOTMIS
      LOGICAL*1 RGT,LFT,AUTO,QIMON,PASS,QCNTSK,QMRCAL,QSTAIR,QMRGAL,
      .NOPE,CTR,Y,Q,QOUTDV
      COMMON /TOALL/IP
      COMMON /CBOOL/IHIT,IMISS
      COMMON /CLGEN/TICK,TIM,LEDMIS,LEDFLS,LEDCNT,LEDHIT,DIFF,RUN,ID1
      COMMON /CMIR/TICKR,MX,DELX,PMAX,PMIN,CAL,ID2,OFF,SUBMRX
C
C   DEFAULT VALUES FOR EYE MOVEMENT WINDOW
C
      DATA ITOP/5000/ILOW/0/
C
    VALUES FOR MOVING TARGET JOB
C
      DATA CAL/409/TICKR/1/DELX/1.0/
C
C   VALUES FOR CONDITIONAL LOGIC
C
      DATA C/1.,3.,1.,1.,6.,1./
C
C   VALUES FOR UPPER,LOWER BOUNDS & INTERVALS
C
      DATA UBO/100.,20.,1000./
C
C   INCREMENT FOR LIGHT INTENSITY
C
      DATA INC/10/
C
C   DATA FOR KEYBOARD BRANCHING
C
      DATA BELLON(5)/3000/BELOFF(5)/2048/
      DATA RGT/82/LFT/76/AUTO/65/Y/89/NOPE/78/Q/81/CTR/67/
      DATA ST/83/H/72/P/80/
C
```

```
C   TARGET ARRAY: ROW NUMBERS CORRESPOND TO AN LED ON THE ARC PERIMETER,
C   AND ENTIRE ROWS ARE OUTPUT AT A TIME TO THE LED CONTROLLER.
C
        DATA TARGET/32383,-1,31767,-9,-1,-1,
       .32447,-1,31767,-9,-1,-1,
       .32479,-1,31767,-9,-1,-1,
       .32495,-1,31767,-9,-1,-1,
       .32503,-1,31767,-9,-1,-1,
       .32507,-1,31767,-9,-1,-1,
       .32509,-1,31767,-9,-1,-1,
       .32510,-1,31767,-9,-1,-1,
       .32511,-2049,31767,-9,-1,-1,
       .32511,-1025,31767,-9,-1,-1,
       .32511,-513,31767,-9,-1,-1,
       .32511,-257,31767,-9,-1,-1,
       .32511,-129,31767,-9,-1,-1,
       .32511,-65,31767,-9,-1,-1,
       .32511,-33,31767,-9,-1,-1,
       .32511,-17,31767,-9,-1,-1,
       .32511,-9,31767,-9,-1,-1,
       .32511,-5,31767,-9,-1,-1,
       .32511,-3,31767,-9,-1,-1,
       .32511,-2,31767,-9,-1,-1/
C
C   ZERO VIRTUAL DATA ARRAYS
C
        DO 1 I=1,20
        DO 2 N=1,50
2       INTENS(N,I)=0
        DO 1 J=1,256
1       RESULT(J,I)=0.0
        CALL DTOAX(BELOFF,1,5)
C
C   ENTER FILE NAME, A/D LIMITS FOR EYE MOVEMENTS, AND NUMBER OF TRIALS.
C
        TYPE 600
600     FORMAT(' ENTER NAME OF OUTPUT STORAGE FILE.',/)
601     FORMAT(A1)
        CALL   ASSIGN (3,'DUM',-1)
        OPEN (UNIT=3,TYPE ='NEW')
C
        TYPE *,'ENTER FLASH COUNT'
        ACCEPT *,NCOUT
C
        TYPE *,'ENTER TWO RANDOM NUMBERS (SINGLE DIGIT)'
        ACCEPT *,IP(1)
        ACCEPT *,IP(2)
C
        TYPE *,'DO YOU WISH TO MONITOR EYE POSITON?'
        ACCEPT 601,QIMON
        IF(QIMON.NE.Y)GOTO 705
```

```
        TYPE *,'ENTER AMPLITUDE OF PERMISSABLE EYE MOVEMENTS(DEGREES).'
        ACCEPT *,EM
        EM=ABS(EM)
        TYPE *,'HOW MANY VOLTS=5 DEGREES.'
        ACCEPT *,EMCAL
        EMCAL=ABS(EMCAL)
        EMCAL=5./EMCAL
        EM=(2048./EMCAL)*EM
        ITOP=2048+IFIX(EM)
        ILOW=2048-IFIX(EM)
C
705     TYPE *,'DO YOU WISH CENTRAL TASK?'
        ACCEPT 601,QCNTSK
        IF(QCNTSK.NE.Y)GOTO 701
        TYPE *,'CENTRAL TASK PARAMETERS INCLUDE:'
        TYPE *,'INTERVAL BETWEEN SUCCESSIVE NUMBERS(SEC).'
        ACCEPT *,SECONS
        TYPE *,'DIFFERENCE BETWEEN NUMERICAL PAIR(0->9)'
        ACCEPT *,DIFF
        TIM=IFIX(SECONS)
        TICK=IFIX(60.*(SECONS-FLOAT(TIM)))
        RUN=120/(TIM*60+TICK) !RUN IS TRIALS PER 2 SECONDS
C
701     TYPE *,'ARE YOU USING MIRROR GALVONOMETER?'
        ACCEPT 601,QMRGAL
        IF(QMRGAL.NE.Y)GOTO 700
        TYPE *.'***LED ARC PERIMETER CONTROLS DISABLED***'
        TYPE *,'VALUES FOR TARGET MOTION INCLUDE:'
        TYPE *,'VELOCITY OF TARGET (DEGREES/SEC).'
        ACCEPT *.MX
        TYPE *,'AMPLITUDE OF TARGET MOTION(DEGREES).'
        ACCEPT *,BX
C   CONVERT DEGREES TO PTS FOR DACS
        PMAX=(BX*40.96)
        MX=(MX*40.96)/60.
        TYPE *.'CALIBRATION OF MIRROR SYSTEM? (-10/0/10 DEG)'
        ACCEPT 601,QMRCAL
        GOTO 707
C
700     TYPE *.'***LED ARC PERIMETER CONTROL ACTIVATED***'
        TYPE *,'DO YOU NEED STAIRCASE PARADIGM FOR LED INTENSITY?'
        ACCEPT 601,QSTAIR
C
C   SET TIMER FOR 7 SEGMENT DISPLAY RUNNING ASYNCHRONOUSLY
C
707     IF(QCNTSK.NE.Y)GOTO 702
        ID1=1  !ID1=1 MEANS DO QUEUE CENTRAL TASK SUBROUTINE.
        CALL IPOKE('170404,0)
4500    IF(IPEEK('170404).GE.0)GOTO 4500 !WAIT FOR SUBJECT (ST1).
C       QUEUE LEDGEN SUBROUTINE.
        IF(ITIMER(0,0,TIM,TICK,TIMMER,1,LEDGEN).NE.0)PAUSE 'NO Q
        .ELEMENTS LEFT:: FROM MAIN PRG.' !Q=QUEUE, NO Q=CAN'T SCHEDULE
C   CENTRAL TASK IS NOW RUNNING.
```

```
C
C    FIND NEXT EMPTY SLOT IN DATA ARRAY FOR STORAGE.
C    NUM IS THE PERIPHERAL TARGET TO BE FLASHED.
650       NO=1
66        IF(RESULT(NO,NUM).EQ.0.0)GOTO 68
          NO=NO+1
          GOTO 66
68        IF(IMAX.LT.NO)IMAX=NO
C
C    DECIDE ON INCREMENT OR DECREMENT OF TARGET ILLUMINATION.
          IF(QSTAIR.NE.Y)GOTO 70
          IF(NO.EQ.1)GOTO 422
          IF(INTENS(NO,NUM).GT.0)GOTO 420
          INTENS(NO,NUM)=INTENS(NO-1,NUM)+INC
          GO TO 421
420       INTENS(NO,NUM)=INTENS(NO-1,NUM)-INC
          GOTO 421
422       INTENS(NO,NUM)=1000
C
C    OUTPUT VOLTAGE TO LED CONTROLLER FOR INTENSITY.
C         USE CHANNEL DAC1 FOR INTENSITY (D TO A #2 ON PATCH PANEL)
421       OUTPUT(1)=INTENS(NO,NUM)
          CALL DTOAX(OUTPUT,1,1)
C
C    GET RANDOM NUMBER FROM 1-> 3.0 SEC. FOR VARIABLE DELAY
C    BRANCH HERE AFTER BLANK TRIAL.
70        X=RAN(IP(1),IP(2))
          NLAT=X*3.0
          IF(NLAT.LT.1.)NLAT=1.0
C
C    WAIT VARIABLE TIME AND CHECK FOR FALSE ALARM (ST2 FIRED).
          TIME=SECNDS(0.0)
          TYPE *,'   WAITING'
C
C    WHILE WAITING, DECIDE IF THE NEXT TRIAL IS BLANK.
C    P=0.6 FOR ARCTRO, AS OPPOSED TO P=0.5 FOR ARCTRL.
          XY=RAN(IPFF(1),IPFF(2))
C
79        DTIME=SECNDS(TIME)
          IF(DTIME.LT.NLAT)GOTO 79
C
C    THEN CHECK FOR TTY INPUT FOR PROGRAM BRANCH.
C    STORE CHARACTERS IN ARRAY. USE ONLY THE FIRST CHARACTER.
          ICHAR=1
99        CHARTR(ICHAR)=ITTINR()
          IF(CHARTR(ICHAR).LT.0)GOTO 401
          ICHAR=ICHAR+1
          GOTO 99
```

```
C
C   IS THE GALVONOMETER BEING USED, AND IF SO DOES IT NEED CALIBRATION?
702     IF(QMRGAL.NE.Y)GOTO 703
        IF(QMRCAL.NE.Y)GOTO 703
C
C   CALIBRATION PROCEDURE
        PMIN=-1
        ID2=2         !OK TO QUEUE MIRROR ROUTINE
        TICKR=100
        IF(ITIMER(0,0,0,TICKR,TMIRR,2,MIRROR).NE.0)PAUSE 'NO Q
        .LEFT FOR MIRROR FROM MAIN'  !MIRROR IS QUEUED.
710     TYPE *,'CALIBRATION:C=CTR;R=RGT;L=LFT:A=AUTO;Q=QUIT'
        ACCEPT 601,PASS
C   COMMUNICATE WITH MIRROR ROUTINE VIA COMMON VARIABLE.
        IF(PASS.EQ.CTR)PMIN=-1
        IF(PASS.EQ.RGT)PMIN=-2
        IF(PASS.EQ.LFT)PMIN=-3
        IF(PASS.EQ.AUTO)PMIN=-4
C   WHEN DONE TURN OFF CAL.
        IF(PASS.NE.Q)GOTO 710
        PMIN=-1
        TICKR=1
        ID2=0            !STOP QUEUEING MIRROR ROUTINE.
C   WAIT
        TIME=SECNDS(0.0)
709     DTIME=SECNDS(TIME)
        IF(DTIME.LT.2.)GOTO 709
        PMIN=0
C
C   JSW=JOB STATUS WORD; SET BIT·6 TO INHIBIT CONSOLE WAIT STATE.
C
703     JSW=IPEEK('44)
        CALL IPOKE('44,'100.OR.JSW)
C
C   BEGIN EXPERIMENT CONTROL.
C       TYPE 601,Y,QMRGAL
        TYPE *,'EXPERIMENT RUNNING; YOU MAY ENTER KEYBOARD COMMANDS!'
C
C
C   EXPERIMENT LOOP BEGINS.
C
C   GET RANDOM NUMBER FROM 2- 18 FOR LED ILLUMINATION.
95      X=RAN(IP(1),IP(2))
        NUM=2+IFIX(X*18.)
C
C   SET UP OFFSET FOR MOVING TARGETS
        IF(QMRGAL.NE.Y)GOTO 650
        IF(NUM.GE.10)NUM=NUM+1
               IF(NUM.GE.20)NUM=19
        OFF=204.8*FLOAT(NUM)-FLOAT(PMAX/2)
        SUBMRX=0.0
```

```
C
C     HIT CHARACTER 'S' TO STOP DATA ACQUISTION.
401        IF(CHARTR(1).EQ.ST)GOTO 1100
C
C
C    WAIT TILL EYE POSITION IS WITHIN LIMITS
403        IVL=IADC(8)
           IF(IVL.GT.ITOP.OR.IVL.LT.ILOW)GOTO 403
           IF(QMRGAL.EQ.Y)TYPE *,'TARGET MOVING'
C
C
C    SKIP TO MOVING TARGET CONTROL SECTION
           IF(QMRGAL.EQ.Y)GOTO 1450
C
           IF(XY.GE.0.6)GOTO 156 !SKIP THE NEXT SECTION FOR A BLANK TRIAL.
C
C    TURN ON TARGET BY SENDING DATA TO LED CONTROLLER.
           DO 155,M=1,5
           CALL IDOR(,0,-1,TARGET(M,NUM))
155        CONTINUE
C
C
C    OUTPUT TRIAL TYPE TO CONSOLE, AND TURN OFF TARGET.
C
156        IF(XY.GE.0.6)TYPE *,'BLANK TRIAL'
           IF(XY.LT.0.6)FICNT=FICNT+1
           IF((QMRGAL.NE.Y).AND.(XY.LT.0.6))TYPE *,FICNT,'FLASHES'
           IF(XY.LT.0.6)CALL IDOR(,0,-1,TARGET(6,NUM))
C
C    SET TIMER TO ZERO FOR TIME-OUT CHECK OF MISS
           TIME=SECNDS(0.0)
C
C    WAIT FOR ST2 TO INDICATE DETECTION OF FLASH.
C
C    HIST READS TIME FROM CLOCK INTO IDAT, THE SETS IFLG TO -1
           CALL HIST(IDAT,1,1,IFLG,NLFT)
C
           IST1=IPEEK('170404)
           CALL SETR(4,3,0.,IEFLG)         !START TIMING. IEFLG=OVERFLOW FLAG
           CALL IPOKE('170404,IPEEK('170404).OR.('100000.AND.IST1))
C    BEEPER CONTROL
           CALL GTIM(ATIME)
           CALL JJCVT(ATIME)
           MTIME=AJFLT(ATIME)+25.
158        CALL GTIM(BTIME)
           CALL JJCVT(BTIME)
           IF((MTIME-AJFLT(BTIME)).GT.0.0)GOTO 158  !WAIT 400mS, THEN BEEP.
           CALL DTOAX(BELLON,1,5)
           CALL GTIM(ATIME)
           CALL JJCVT(ATIME)
           MTIME=AJFLT(ATIME)+12.
157        CALL GTIM(BTIME)
           CALL JJCVT(BTIME)
           IF((MTIME-AJFLT(BTIME)).GT.0.0)GOTO 157 !WAIT 192mS,THEN UNBEEP.
           CALL DTOAX(BELOFF,1,5)
```

```
C
1455     IF(IFLG.NE.0)GOTO 145 !IF TRIGGER IS SET STOP TIMING
C
C   IF NO RESPONSE IN 2 SECONDS SCORE AS MISS.
C
         DTIME=SECNDS(TIME)
         IF(DTIME.LT.1.0)GOTO 1455
         IDAT(1)=1                   !STORE 2 SECONDS AS R.T. (i.e. A MISS)
         IF(QSTAIR.NE.Y)GOTO 145
         INTENS(NO+1,NUM)=1
C
C   CHECK FOR FALSE ALARM
145      IF((XY.GE.0.6).AND.(IDAT(1).NE.1))FALSE=FALSE+1
C
C   CLEAR INTERRUPT BUT HOLD FOR FALSE ALARM.
         IST1=IPEEK('170404)
         CALL SETR(-1,,,)                               ! KILL TIMER FOR HIST
         CALL IPOKE('170404,IPEEK('170404).OR.(IST1.AND.'100000))
         NLFT=NLFT+1
C
C
C   CONTROL FOR SCORING MOVING TARGET RECOGNTION
C     IF CORRECT GIVE 2 IF WRONG GIVE 1
1450     IF(QMRGAL.NE.Y) GOTO 97
C   QUEUE MIRROR ROUTINE
         ID2=2      !LET THE MIRROR ROUTINE QUEUE ITSELF.
         IF(ITIMER(0,0,0,TICKR,TMIRR,2,MIRROR).NE.0)PAUSE 'NEED QS'
         TIME=SECNDS(0.0)
4150     DTIME=SECNDS(TIME)
         IF(DTIME.LT.4.0)GOTO 4150
         ID2=0      !DO NOT QUEUE MIRROR ANYMORE
         TYPE *,'RESPONSE IS HIT OR MISS'
         ACCEPT 601,PASS
         IF(PASS.EQ.H)IDAT(1)=2
         IF(PASS.NE.H)IDAT(1)=1
C
C
97       TYPE *,'   STIMULUS COMPLETE.'
C
C  STORE REACTION TIME AND CONTINUE EXPERIMENT IF COUNT NOT EXCEEDED.
C
         IF(XY.LT.0.6)RESULT(NO,NUM)=FLOAT(IDAT(1))
         ICNT=ICNT+1
         IFLG=0
         IF(ICNT.GE.NCOUT)GOTO 1100
         IF(XY.GE.0.6)GOTO 70
         GOTO 95
C   EXPERIMENT LOOP ENDS
C
1100     TYPE *,'  DATA REDUCTION BEGINING'
```

```
C   STOP TIMER ROUTINE FOR CENTRAL STIMULI.
C
        ID1=0
        ID2=0
C
C   STORE DATA ON DISK
C
452     FORMAT(I4)
45      WRITE(3,452)IMAX,FALSE
        WRITE(3,*)((RESULT(I,J),I=1,IMAX),J=1,20)
        WRITE(3,*)((INTENS(I,J),I=1,IMAX),J=1,20)
        WRITE(3,*)LEDCNT,LEDHIT,LEDMIS,LEDFLS
        IF(QCNTSK.NE.Y)GOTO 4003
        TYPE *,'*******CENTER TASK PERFORMANCE SUMMARY*********'
        TYPE *,LEDCNT,'(MAX POSSIBLE HITS)',LEDHIT,'(ACTUAL HITS)'
        TYPE *,LEDMIS,'(NUMBER OF MISSES)',LEDFLS,'(FALSE ALARMS)'
        TYPE *,'**********************************************'
C
C   PERFORM STATISTICAL ANALYSIS AND HISTOGRAMS.
C
4003    DO 4000 N=1,20
        N001=N
        C(1)=FLOAT(N001)
        C(2)=C(1)
        CALL SUBST(RESULT,C,R,BOOL,S,256,20,2)
        CALL TAB1(RESULT,S,N001,UBO,FREQ,PCT,STAT,256,20)
C
C   SAVE DATA FROM EACH ANALYSIS
C
        WRITE(3,*)N001,IHIT,IMISS,STAT,FREQ,PCT
        NP=IFIX(UBO(2))
C   WAS THERE A CONSOLE COMMAND TO STOP?
        IF((CHARTR(1).EQ.P).OR.(CHARTR(2).EQ.P))GOTO 4002
        IF((CHARTR(1).EQ.H).OR.(CHARTR(2).EQ.H))GOTO 4001
        IF(QMRGAL.NE.Y)CALL HISTG(N001,FREQ,NP)
4001    TYPE *,IHIT,'(HITS)',IMISS,'(MISSES)',FALSE,'(FALSE ALARMS)'
        IF(QMRGAL.EQ.Y)GOTO 4002
        TYPE *,STAT(2),'(AVERAGE)',STAT(3),'(STD)',STAT(1),'(TOTALS)'
        TYPE *,STAT(4),'(MIN)',STAT(5),'(MAX)'
4002    TOTHIT=TOTHIT+IHIT
        TOTMIS=TOTMIS+IMISS
        IMISS=0
4000    IHIT=0
C   OVERALL STATISTICS
        WRITE(3,452)TOTHIT,TOTMIS
        TYPE *,'TOTAL HITS=',TOTHIT,'TOTAL MISSES=',TOTMIS
150     CLOSE (UNIT=3)
        END
```

```
C    SUBROUTINE TO GENERATE VOLTAGES ON DAC TO CHANGE NUMBER
C       ON CENTRAL SEVEN SEGMENT DISPLAY.
C
        SUBROUTINE LEDGEN(ID)
        EXTERNAL LEDGEN
        INTEGER IP(2),ID,N,I,OUT(3),VOLTS(11),TIMMER(4),TICK,TIM,RUN
        INTEGER LEDMIS,LEDFLS,IST1,LEDCNT,SAMFLG,LEDHIT,DIFF
        INTEGER COUNT,ID1,SF
        REAL X
        COMMON /TOALL/IP
        COMMON /CLGEN/TICK,TIM,LEDMIS,LEDFLS,LEDCNT,LEDHIT,DIFF.RUN,ID1
C
C   VALUES FOR DAC TO GENERATE 7 SEGMENT DISPLAY NUMBERS
C
        DATA VOLTS/2048,2252,2457,2662,2867.3072,3276,3481;3686,3891,
        .2048/
C
C   CHECK FOR DATA EQUAL RECOGNITION
C
        IF(SAMFLG.NE.1)GOTO 44
        COUNT=COUNT+1
        IST1=IPEEK('170404)
        IF(IST1.LT.0)GOTO 45       !IF SEEN CLR FLG
        IF(COUNT.LT.RUN)GOTO 46
        TYPE *,'                         MISS'
        LEDMIS=LEDMIS+1
        GOTO 43
45      LEDHIT=LEDHIT+1
        TYPE *,'                         HIT'
        CALL IPOKE('170404.'077777.AND.IST1)     !CLR ST1 FLG
43      COUNT=0
        SF=1
        LEDCNT=LEDCNT+1
        GOTO 46
C
C   CHECK FOR FALSE ALARM
C
44      IST1=IPEEK('170404)        !CHECK FOR FALSE TRIG
        IF(IST1.GE.0)GOTO 46
        LEDFLS=LEDFLS+1            !INC FLASE ALRAM
        CALL IPOKE('170404,'077777.AND.IST1)
C
C    GENERATE RANDOM NUMBER FOR CENTRAL DISPLAY.
C              THIS IS FOR FIRST NUMBER.
C
46      X=RAN(IP(1),IP(2))
        IJ=IFIX(X*10.)+1
        OUT(2)=VOLTS(IJ)
C
```

```
C                THIS IS FOR SECOND NUMBER
C
        X=RAN(IP(1),IP(2))
        I=IFIX(X*10.)+1
        OUT(3)=VOLTS(I)
C
C     OUTPUT VOLTAGE 0=>9 FOR CENTRAL LED SEGMENT NUMBER.
C
        IF((SAMFLG.EQ.1).AND.(IABS(I-IJ).EQ.DIFF))OUT(3)=VOLTS(I+1)
        CALL DTOAX(OUT,2,2)
        IF((SAMFLG.EQ.1).OR.(IABS(I-IJ).NE.DIFF))GOTO 40
        TYPE *,'                              A MATCH'
        SAMFLG=1
C
C    KILL TIMED EVENT IF ID1<>1.
C
40      IF(ID1.NE.1)GOTO 41
C
C    IF NOT RESCHEDULE EVENT.
C
        IF(SF.NE.1)GOTO 49
        SF=0
        SAMFLG=0
49      IF(ITIMER(0,0,TIM,TICK,TIMMER,1,LEDGEN).NE.0)PAUSE 'MORE Q
        . ELEMENTS NEEDED:: FROM COMPLETION RT.'
41      RETURN
        END

C
C     SUBROUTINE TO ASSESS NUMBER OF HITS AND MISSES
C        GIVEN UPPER AND LOWER VAULES IN UBO.
C
        SUBROUTINE BOOL(R,T)
        DIMENSION R(2)
        COMMON /CBOOL/IHIT,IMISS
C
C     R(1) IS 1 IF RESULT=1; THUS SUBJECT MISSED.
C
        IF(R(1).EQ.1.)IMISS=IMISS+1
C
C     R(2) IS 1 IF RESULT=1; THUS SUBJECT DETECTED FLASH.
C
        IF(R(2).EQ.1.)IHIT=IHIT+1
C
C     RETURN NEEDED VALUE TO CALLING PROGRAM.
C
        T=R(2)
        RETURN
        END
```

```
C
C    SUBROUTINE TO OSCILLATE MIRROR GALVONOMETER
C
         SUBROUTINE MIRROR(ID)
         EXTERNAL MIRROR
         INTEGER TMIRR(4),OUT(6),ID,TICKR,INCAL
         INTEGER ZERO,OFFIN,CNT,IP(2),CAL,ID2,PMIN
         REAL MX,PMAX,SUBMRX,DELX,OUTW,OFF
         COMMON /TOALL/IP
         COMMON /CMIR/TICKR,MX,DELX,PMAX,PMIN,CAL,ID2,OFF,SUBMRX
         DATA ZERO/2048/
C
C    CHECK FOR CALIBRATION
C
C        TYPE *,PMIN,OUT(4),CAL
         IF(PMIN.GE.0)GOTO 3
C
C    START CAL AS CENTER,RIGHT,LEFT,AND AUTO
C
         INCAL=IABS(CAL)
         IF(PMIN.EQ.-1)OUT(4)=2048         !CENTER
         IF(PMIN.EQ.-2)OUT(4)=2048+INCAL   !RIGHT 10
         IF(PMIN.EQ.-3)OUT(4)=2048-INCAL   !LEFT 10
         IF(PMIN.NE.-4)GOTO 4              !AUTO 10/0/-10
         OUT(4)=ZERO+CAL
         ZERO=OUT(4)
         IF(OUT(4).LT.2048)CAL=-CAL
         IF(OUT(4).GT.2048)CAL=-CAL
4        CALL DTOAX(OUT,1,4)
         GOTO 5
C
C    CALCULATE TRIANGLE WAVEFORM
C
3        OUTW=MX*SUBMRX
         OUT(4)=IFIX(OUTW+OFF)
         CALL DTOAX(OUT,1,4)
C
         IF((OUTW+MX.GE.PMAX).OR.(OUTW-MX.LT.-MX))DELX=-DELX
C
C    INCREMENT COUNTER BY DELTA
C
         SUBMRX=SUBMRX+DELX
5        IF(ID2.NE.2)GOTO 100
         IF(ITIMER(0,0,0,TICKR,TMIRR,2,MIRROR).NE.0)PAUSE 'MORE
         .Q NEEDED AT MIRROR'
100      RETURN
         END
```

APENDIX III

d' TABLES

VALUES OF d' FOR THE YES-NO PROCEDURE

$P_N(A)$	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10
$P_{SN}(A)$										
.01	0	−.27	−.44	−.57	−.68	−.77	−.85	−.92	−.98	−1.04
.02	.27	0	−.17	−.30	−.41	−.50	−.58	−.65	−.71	−.77
.03	.44	.17	0	−.13	−.24	−.33	−.41	−.48	−.54	−.60
.04	.57	.30	.13	0	−.11	−.20	−.28	−.35	−.41	−.47
.05	.68	.41	.24	.11	0	−.09	−.17	−.24	−.30	−.36
.06	.77	.50	.33	.20	.09	0	−.08	−.15	−.21	−.27
.07	.85	.58	.41	.28	.17	.08	0	−.07	−.13	−.19
.08	.92	.65	.48	.35	.24	.15	.07	0	−.06	−.12
.09	.98	.71	.54	.41	.30	.21	.13	.06	0	−.06
.10	1.04	.77	.60	.47	.36	.27	.19	.12	.06	0
.11	1.09	.82	.65	.52	.41	.32	.24	.17	.11	.05
.12	1.14	.88	.70	.58	.46	.38	.30	.22	.16	.10
.13	1.19	.92	.75	.62	.51	.42	.34	.27	.21	.15
.14	1.24	.97	.80	.67	.56	.47	.39	.32	.26	.20
.15	1.28	1.01	.84	.71	.60	.51	.43	.36	.30	.24
.16	1.33	1.06	.89	.76	.65	.56	.48	.41	.35	.29
.17	1.37	1.10	.93	.80	.69	.60	.52	.45	.39	.33
.18	1.40	1.14	.96	.84	.72	.64	.56	.48	.42	.36
.19	1.44	1.17	1.00	.87	.76	.67	.59	.52	.46	.40
.20	1.48	1.21	1.04	.91	.80	.71	.63	.56	.50	.44
.21	1.52	1.24	1.08	.94	.84	.74	.66	.60	.54	.48
.22	1.55	1.28	1.11	.98	.87	.78	.70	.63	.57	.51
.23	1.58	1.31	1.14	1.01	.90	.81	.73	.66	.60	.54
.24	1.62	1.34	1.18	1.04	.94	.84	.76	.70	.64	.58
.25	1.64	1.38	1.20	1.08	.96	.88	.80	.72	.66	.60
.26	1.68	1.41	1.24	1.11	1.00	.91	.83	.76	.70	.64
.27	1.71	1.44	1.27	1.14	1.03	.94	.86	.79	.73	.67
.28	1.74	1.47	1.30	1.17	1.06	.97	.89	.82	.76	.70
.29	1.76	1.50	1.32	1.20	1.08	1.00	.92	.84	.78	.72
.30	1.80	1.52	1.36	1.22	1.12	1.02	.94	.88	.82	.76
.31	1.82	1.54	1.38	1.24	1.14	1.04	.96	.90	.84	.78
.32	1.85	1.58	1.41	1.28	1.17	1.08	1.00	.93	.87	.81
.33	1.88	1.61	1.44	1.31	1.20	1.11	1.03	.96	.90	.84
.34	1.91	1.64	1.47	1.34	1.23	1.14	1.06	.99	.93	.87
.35	1.94	1.66	1.50	1.36	1.26	1.16	1.08	1.02	.96	.90
.36	1.96	1.69	1.52	1.39	1.28	1.19	1.11	1.04	.98	.92
.37	1.99	1.72	1.55	1.42	1.31	1.22	1.14	1.07	1.01	.95
.38	2.02	1.74	1.58	1.44	1.34	1.24	1.16	1.10	1.04	.98
.39	2.04	1.77	1.60	1.47	1.36	1.27	1.19	1.12	1.06	1.00
.40	2.06	1.80	1.62	1.50	1.38	1.30	1.22	1.14	1.08	1.02
.41	2.09	1.82	1.65	1.52	1.41	1.32	1.24	1.17	1.11	1.05
.42	2.12	1.85	1.68	1.55	1.44	1.35	1.27	1.20	1.14	1.08
.43	2.14	1.87	1.70	1.57	1.46	1.37	1.29	1.22	1.16	1.10
.44	2.17	1.90	1.73	1.60	1.49	1.40	1.32	1.25	1.19	1.13
.45	2.19	1.92	1.75	1.62	1.51	1.42	1.34	1.27	1.21	1.15
.46	2.22	1.95	1.78	1.65	1.54	1.45	1.37	1.30	1.24	1.18
.47	2.24	1.98	1.80	1.68	1.56	1.48	1.40	1.32	1.26	1.20
.48	2.27	2.00	1.83	1.70	1.59	1.50	1.42	1.35	1.29	1.23
.49	2.30	2.02	1.86	1.72	1.62	1.52	1.44	1.38	1.32	1.26
.50	2.32	2.05	1.88	1.75	1.64	1.55	1.47	1.40	1.34	1.28

$P_N(A)$	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10
$P_{SN}(A)$										
.51	2.34	1.08	1.90	1.78	1.66	1.58	1.50	1.42	1.36	1.30
.52	2.37	2.10	1.93	1.80	1.69	1.60	1.52	1.45	1.39	1.33
.53	2.40	2.12	1.96	1.82	1.72	1.62	1.54	1.48	1.42	1.36
.54	2.42	2.15	1.98	1.85	1.74	1.65	1.57	1.50	1.44	1.38
.55	2.45	2.18	2.01	1.88	1.77	1.68	1.60	1.53	1.47	1.41
.56	2.47	2.20	2.03	1.90	1.79	1.70	1.62	1.55	1.49	1.43
.57	2.50	2.23	2.06	1.93	1.82	1.73	1.65	1.58	1.52	1.46
.58	2.52	2.25	2.08	1.95	1.84	1.75	1.67	1.60	1.54	1.48
.59	2.55	2.28	2.11	1.98	1.87	1.78	1.70	1.63	1.57	1.51
.60	2.58	2.30	2.14	2.00	1.90	1.80	1.72	1.66	1.60	1.54
.61	2.60	2.33	2.16	2.03	1.92	1.83	1.75	1.68	1.62	1.56
.62	2.62	2.36	2.18	2.06	1.94	1.86	1.78	1.70	1.64	1.58
.63	2.65	2.38	2.21	2.08	1.97	1.88	1.80	1.73	1.67	1.61
.64	2.68	2.41	2.24	2.11	2.00	1.91	1.83	1.76	1.70	1.64
.65	2.70	2.44	2.26	2.14	2.02	1.94	1.86	1.78	1.72	1.66
.66	2.73	2.46	2.29	2.16	2.05	1.96	1.88	1.81	1.75	1.69
.67	2.76	2.49	2.32	2.19	2.08	1.99	1.91	1.84	1.78	1.72
.68	2.79	2.52	2.35	2.22	2.11	2.02	1.94	1.87	1.81	1.75
.69	2.82	2.56	2.38	2.26	2.14	2.06	1.98	1.90	1.84	1.78
.70	2.84	2.58	2.40	2.28	2.16	2.08	2.00	1.92	1.86	1.80
.71	2.88	2.60	2.44	2.30	2.20	2.10	2.02	1.96	1.90	1.84
.72	2.90	2.63	2.46	2.33	2.22	2.13	2.05	1.98	1.92	1.86
.73	2.93	2.66	2.49	2.36	2.25	2.16	2.08	2.01	1.95	1.89
.74	2.96	2.69	2.52	2.39	2.28	2.19	2.11	2.04	1.98	1.92
.75	3.00	2.72	2.56	2.42	2.32	2.22	2.14	2.08	2.02	1.96
.76	3.02	2.76	2.58	2.46	2.34	2.26	2.18	2.10	2.04	1.98
.77	3.06	2.79	2.62	2.49	2.38	2.29	2.21	2.14	2.08	2.02
.78	3.09	2.82	2.65	2.52	2.41	2.32	2.24	2.17	2.11	2.05
.79	3.12	2.86	2.68	2.56	2.44	2.36	2.28	2.20	2.14	2.08
.80	3.16	2.89	2.72	2.59	2.48	2.39	2.31	2.24	2.18	2.12
.81	3.20	2.93	2.76	2.63	2.52	2.43	2.35	2.28	2.22	2.16
.82	3.24	2.96	2.80	2.66	2.56	2.46	2.38	2.32	2.26	2.20
.83	3.27	3.00	2.83	2.70	2.59	2.50	2.42	2.35	2.29	2.23
.84	3.31	3.04	2.87	2.74	2.63	2.54	2.46	2.39	2.33	2.27
.85	3.36	3.09	2.92	2.79	2.68	2.59	2.51	2.44	2.38	2.32
.86	3.40	3.13	2.96	2.83	2.72	2.63	2.55	2.48	2.42	2.36
.87	3.45	3.18	3.01	2.88	2.77	2.68	2.60	2.53	2.47	2.41
.88	3.50	3.22	3.06	2.92	2.82	2.72	2.64	2.58	2.52	2.46
.89	3.55	3.28	3.11	2.98	2.87	2.78	2.70	2.63	2.58	2.51
.90	3.60	3.33	3.16	3.03	2.92	2.83	2.75	2.68	2.62	2.56
.91	3.66	3.39	3.22	3.09	2.98	2.89	2.81	2.74	2.68	2.62
.92	3.72	3.45	3.28	3.15	3.04	2.95	2.87	2.80	2.74	2.68
.93	3.79	3.52	3.35	3.22	3.11	3.02	2.94	2.87	2.81	2.75
.94	3.87	3.60	3.43	3.30	3.19	3.10	3.02	2.95	2.89	2.83
.95	3.96	3.69	3.52	3.39	3.28	3.19	3.11	3.04	2.98	2.92
.96	4.07	3.80	3.63	3.50	3.39	3.30	3.22	3.15	3.09	3.03
.97	4.20	3.93	3.76	3.63	3.52	3.43	3.35	3.28	3.22	3.16
.98	4.37	4.10	3.93	3.80	3.69	3.60	3.52	3.45	3.39	3.33
.99	4.64	4.37	4.20	4.07	3.96	3.87	3.79	3.72	3.66	3.60

$P_{SN}(A)$ \ $P_N(A)$	.11	.12	.13	.14	.15	.16	.17	.18	.19	.20
.01	−1.09	−1.14	−1.19	−1.24	−1.28	−1.33	−1.37	−1.40	−1.44	−1.48
.02	− .82	− .88	− .92	− .97	−1.01	−1.06	−1.10	−1.14	−1.17	−1.21
.03	− .65	− .70	− .75	− .80	− .84	− .89	− .93	− .96	−1.00	−1.04
.04	− .52	− .58	− .62	− .67	− .71	− .76	− .80	− .84	− .87	− .91
.05	− .41	− .46	− .51	− .56	− .60	− .65	− .69	− .72	− .76	− .80
.06	− .32	− .38	− .42	− .47	− .51	− .56	− .60	− .64	− .67	− .71
.07	− .24	− .30	− .34	− .39	− .43	− .48	− .52	− .56	− .59	− .63
.08	− .17	− .22	− .27	− .32	− .36	− .41	− .45	− .48	− .52	− .56
.09	− .11	− .16	− .21	− .26	− .30	− .35	− .39	− .42	− .46	− .50
.10	− .05	− .10	− .15	− .20	− .24	− .29	− .33	− .36	− .40	− .44
.11	0	− .06	− .10	− .15	− .19	− .24	− .28	− .32	− .35	− .39
.12	.06	0	− .04	− .10	− .14	− .18	− .22	− .26	− .30	− .34
.13	.10	.04	0	− .05	− .09	− .14	− .18	− .22	− .25	− .29
.14	.15	.10	.05	0	− .04	− .09	− .13	− .16	− .20	− .24
.15	.19	.14	.09	.04	0	− .05	− .09	− .12	− .16	− .20
.16	.24	.18	.14	.09	.05	0	− .04	− .08	− .11	− .15
.17	.28	.22	.18	.13	.09	.04	0	− .04	− .07	− .11
.18	.32	.26	.22	.16	.12	.08	.04	0	− .04	− .08
.19	.35	.30	.25	.20	.16	.11	.07	.04	0	− .04
.20	.39	.34	.29	.24	.20	.15	.11	.08	.04	0
.21	.42	.37	.32	.28	.24	.18	.14	.11	.08	.04
.22	.46	.40	.36	.31	.27	.22	.18	.14	.11	.07
.23	.49	.44	.39	.34	.30	.25	.21	.18	.14	.10
.24	.52	.47	.42	.38	.34	.28	.24	.21	.18	.14
.25	.56	.50	.46	.40	.36	.32	.28	.24	.20	.16
.26	.59	.54	.49	.44	.40	.35	.31	.28	.24	.20
.27	.62	.56	.52	.47	.43	.38	.34	.30	.27	.23
.28	.65	.60	.55	.50	.46	.41	.37	.34	.30	.26
.29	.68	.62	.58	.52	.48	.44	.40	.36	.32	.28
.30	.70	.65	.60	.56	.52	.46	.42	.39	.36	.32
.31	.72	.67	.62	.58	.54	.48	.44	.41	.38	.34
.32	.76	.70	.66	.61	.57	.52	.48	.44	.41	.37
.33	.79	.74	.69	.64	.60	.55	.51	.48	.44	.40
.34	.82	.76	.72	.67	.63	.58	.54	.50	.47	.43
.35	.84	.79	.74	.70	.66	.60	.56	.53	.50	.46
.36	.87	.82	.77	.72	.68	.63	.59	.56	.52	.48
.37	.90	.84	.80	.75	.71	.66	.62	.58	.55	.51
.38	.92	.87	.72	.78	.74	.68	.64	.61	.58	.54
.39	.95	.90	.85	.80	.76	.71	.67	.64	.60	.56
.40	.98	.92	.88	.82	.78	.74	.70	.66	.62	.58
.41	1.00	.94	.90	.85	.81	.76	.72	.68	.65	.61
.42	1.03	.98	.93	.88	.84	.79	.75	.72	.68	.64
.43	1.05	1.00	.95	.90	.86	.81	.77	.74	.70	.66
.44	1.08	1.02	.98	.93	.89	.84	.80	.76	.73	.69
.45	1.10	1.04	1.00	.95	.91	.86	.82	.78	.75	.71
.46	1.13	1.08	1.03	.98	.94	.89	.85	.82	.78	.74
.47	1.16	1.10	1.06	1.00	.96	.92	.88	.84	.80	.76
.48	1.18	1.12	1.08	1.03	.99	.94	.90	.86	.83	.79
.49	1.20	1.15	1.10	1.06	1.02	.96	.92	.89	.86	.82
.50	1.23	1.18	1.13	1.08	1.04	.99	.95	.92	.88	.84

$P_N(A)$ / $P_{SN}(A)$	.11	.12	.13	.14	.15	.16	.17	.18	.19	.20
.51	1.26	1.20	1.16	1.10	1.06	1.02	.98	.94	.90	.86
.52	1.28	1.22	1.18	1.13	1.09	1.04	1.00	.96	.93	.89
.53	1.30	1.25	1.20	1.16	1.12	1.06	1.02	.99	.96	.92
.54	1.33	1.28	1.23	1.18	1.14	1.09	1.05	1.02	.98	.94
.55	1.36	1.30	1.26	1.21	1.17	1.12	1.08	1.04	1.01	.97
.56	1.38	1.32	1.28	1.23	1.19	1.14	1.10	1.06	1.03	.99
.57	1.41	1.36	1.31	1.26	1.22	1.17	1.13	1.10	1.06	1.02
.58	1.43	1.38	1.33	1.28	1.24	1.19	1.15	1.12	1.08	1.04
.59	1.46	1.40	1.36	1.31	1.27	1.22	1.18	1.14	1.11	1.07
.60	1.48	1.43	1.38	1.34	1.30	1.24	1.20	1.17	1.14	1.10
.61	1.51	1.46	1.41	1.36	1.32	1.27	1.23	1.20	1.16	1.12
.62	1.54	1.48	1.44	1.38	1.34	1.30	1.26	1.22	1.18	1.14
.63	1.56	1.50	1.46	1.41	1.37	1.32	1.28	1.24	1.21	1.17
.64	1.59	1.54	1.49	1.44	1.40	1.35	1.31	1.28	1.24	1.20
.65	1.62	1.56	1.52	1.46	1.42	1.38	1.34	1.30	1.26	1.22
.66	1.64	1.58	1.54	1.49	1.45	1.40	1.36	1.32	1.29	1.25
.67	1.67	1.62	1.57	1.52	1.48	1.43	1.39	1.36	1.32	1.28
.68	1.70	1.64	1.60	1.55	1.51	1.46	1.42	1.38	1.35	1.31
.69	1.74	1.68	1.64	1.58	1.54	1.50	1.46	1.42	1.38	1.34
.70	1.76	1.70	1.66	1.60	1.56	1.52	1.48	1.44	1.40	1.36
.71	1.78	1.73	1.68	1.64	1.60	1.54	1.50	1.47	1.44	1.40
.72	1.81	1.76	1.71	1.66	1.62	1.57	1.53	1.50	1.46	1.42
.73	1.84	1.78	1.74	1.69	1.65	1.60	1.56	1.52	1.49	1.45
.74	1.87	1.82	1.77	1.72	1.68	1.63	1.59	1.56	1.52	1.48
.75	1.90	1.85	1.80	1.76	1.72	1.66	1.62	1.59	1.56	1.52
.76	1.94	1.88	1.84	1.78	1.74	1.70	1.66	1.62	1.58	1.54
.77	1.97	1.92	1.87	1.82	1.78	1.73	1.69	1.66	1.62	1.58
.78	2.00	1.94	1.90	1.85	1.81	1.76	1.72	1.68	1.65	1.61
.79	2.04	1.98	1.94	1.88	1.84	1.80	1.76	1.72	1.68	1.64
.80	2.07	2.02	1.97	1.92	1.88	1.83	1.79	1.76	1.72	1.68
.81	2.11	2.06	2.01	1.96	1.92	1.87	1.83	1.80	1.76	1.72
.82	2.14	2.09	2.04	2.00	1.96	1.90	1.86	1.83	1.80	1.76
.83	2.18	2.12	2.08	2.03	1.99	1.94	1.90	1.86	1.83	1.79
.84	2.22	2.16	2.12	2.07	2.03	1.98	1.94	1.90	1.87	1.83
.85	2.27	2.22	2.17	2.12	2.08	2.03	1.99	1.96	1.92	1.88
.86	2.31	2.26	2.21	2.16	2.12	2.07	2.03	2.00	1.96	1.92
.87	2.36	2.30	2.26	2.21	2.17	2.12	2.08	2.04	2.01	1.97
.88	2.40	2.35	2.30	2.26	2.22	2.16	2.12	2.09	2.06	2.02
.89	2.46	2.40	2.36	2.31	2.27	2.22	2.18	2.14	2.11	2.07
.90	2.51	2.46	2.41	2.36	2.32	2.27	2.23	2.20	2.16	2.12
.91	2.57	2.52	2.47	2.42	2.38	2.33	2.29	2.26	2.22	2.18
.92	2.63	2.58	2.53	2.48	2.44	2.39	2.35	2.32	2.28	2.24
.93	2.70	2.64	2.60	2.55	2.51	2.46	2.42	2.38	2.35	2.31
.94	2.78	2.72	2.68	2.63	2.59	2.54	2.50	2.46	2.43	2.39
.95	2.87	2.82	2.77	2.72	2.68	2.63	2.59	2.56	2.52	2.48
.96	2.98	2.92	2.88	2.83	2.79	2.74	2.70	2.66	2.63	2.59
.97	3.11	3.06	3.01	2.96	2.92	2.87	2.83	2.80	2.76	2.72
.98	3.28	3.22	3.18	3.13	3.09	3.04	3.00	2.96	2.93	2.89
.99	3.55	3.50	3.45	3.40	3.36	3.31	3.27	3.24	3.20	3.16

$P_N(A)$	.21	.22	.23	.24	.25	.26	.27	.28	.29	.30
$P_{SN}(A)$										
.01	−1.52	−1.55	−1.58	−1.62	−1.64	−1.68	−1.71	−1.74	−1.76	−1.80
.02	−1.24	−1.28	−1.31	−1.34	−1.38	−1.41	−1.44	−1.47	−1.50	−1.52
.03	−1.08	−1.11	−1.14	−1.18	−1.20	−1.24	−1.27	−1.30	−1.32	−1.36
.04	−.94	−.98	−1.01	−1.04	−1.08	−1.11	−1.14	−1.17	−1.20	−1.22
.05	−.84	−.87	−.90	−.94	−.96	−1.00	−1.03	−1.06	−1.08	−1.12
.06	−.74	−.78	−.81	−.84	−.88	−.91	−.94	−.97	−1.00	−1.02
.07	−.66	−.70	−.73	−.76	−.80	−.83	−.86	−.89	−.92	−.94
.08	−.60	−.63	−.66	−.70	−.72	−.76	−.79	−.82	−.84	−.88
.09	−.54	−.57	−.60	−.64	−.66	−.70	−.73	−.76	−.78	−.82
.10	−.48	−.51	−.54	−.58	−.60	−.64	−.67	−.70	−.72	−.76
.11	−.42	−.46	−.49	−.52	−.56	−.59	−.62	−.65	−.68	−.70
.12	−.37	−.40	−.44	−.47	−.50	−.54	−.56	−.60	−.62	−.65
.13	−.32	−.36	−.39	−.42	−.46	−.49	−.52	−.55	−.58	−.60
.14	−.28	−.31	−.34	−.38	−.40	−.44	−.47	−.50	−.52	−.56
.15	−.24	−.27	−.30	−.34	−.36	−.40	−.43	−.46	−.48	−.52
.16	−.18	−.22	−.25	−.28	−.32	−.35	−.38	−.41	−.44	−.46
.17	−.14	−.18	−.21	−.24	−.28	−.31	−.34	−.37	−.40	−.42
.18	−.11	−.14	−.18	−.21	−.24	−.28	−.30	−.34	−.36	−.39
.19	−.08	−.11	−.14	−.18	−.20	−.24	−.27	−.30	−.32	−.36
.20	−.04	−.07	−.10	−.14	−.16	−.20	−.23	−.26	−.28	−.32
.21	0	−.04	−.06	−.10	−.13	−.16	−.20	−.22	−.25	−.28
.22	.04	0	−.03	−.06	−.10	−.13	−.16	−.19	−.22	−.24
.23	.06	.03	0	−.04	−.06	−.10	−.13	−.16	−.18	−.22
.24	.10	.06	.04	0	−.03	−.06	−.10	−.12	−.15	−.18
.25	.13	.10	.06	.03	0	−.04	−.06	−.10	−.12	−.15
.26	.16	.13	.10	.06	.04	0	−.03	−.06	−.08	−.12
.27	.20	.16	.13	.10	.06	.03	0	−.03	−.06	−.08
.28	.22	.19	.16	.12	.10	.06	.03	0	−.02	−.06
.29	.25	.20	.18	.15	.12	.08	.06	.02	0	−.03
.30	.28	.24	.22	.18	.15	.12	.08	.06	.03	0
.31	.30	.26	.24	.20	.17	.14	.10	.08	.05	.02
.32	.34	.30	.27	.24	.20	.17	.14	.11	.08	.06
.33	.36	.33	.30	.26	.24	.20	.17	.14	.12	.08
.34	.40	.36	.33	.30	.26	.23	.20	.17	.14	.12
.35	.42	.38	.36	.32	.29	.26	.22	.20	.17	.14
.36	.44	.41	.38	.34	.32	.28	.25	.22	.20	.16
.37	.48	.44	.41	.38	.34	.31	.28	.25	.22	.20
.38	.50	.46	.44	.40	.37	.34	.30	.28	.25	.22
.39	.52	.49	.46	.42	.40	.36	.33	.30	.28	.24
.40	.55	.52	.48	.45	.42	.38	.36	.32	.30	.27
.41	.58	.54	.51	.48	.44	.41	.38	.35	.32	.30
.42	.60	.57	.54	.50	.48	.44	.41	.38	.36	.32
.43	.62	.59	.56	.52	.50	.46	.43	.40	.38	.34
.44	.66	.62	.59	.56	.52	.49	.46	.43	.40	.38
.45	.68	.64	.61	.58	.54	.51	.48	.45	.42	.40
.46	.70	.67	.64	.60	.58	.54	.51	.48	.46	.42
.47	.73	.70	.66	.63	.60	.56	.54	.50	.48	.45
.48	.76	.72	.69	.66	.62	.59	.56	.53	.50	.48
.49	.78	.74	.72	.68	.65	.62	.58	.56	.53	.50
.50	.80	.77	.74	.70	.68	.64	.61	.58	.56	.52

$P_{SN}(A)$ \ $P_N(A)$	.21	.22	.23	.24	.25	.26	.27	.28	.29	.30
.51	.83	.80	.76	.73	.70	.66	.64	.60	.58	.55
.52	.86	.82	.79	.76	.72	.69	.66	.63	.60	.58
.53	.88	.84	.82	.78	.75	.72	.68	.66	.63	.60
.54	.90	.87	.84	.80	.78	.74	.71	.68	.66	.62
.55	.94	.90	.87	.84	.80	.77	.74	.71	.68	.66
.56	.96	.92	.89	.86	.82	.79	.76	.73	.70	.68
.57	.98	.95	.92	.88	.86	.82	.79	.76	.74	.70
.58	1.00	.97	.94	.90	.88	.84	.81	.78	.76	.72
.59	1.04	1.00	.97	.94	.90	.87	.84	.81	.78	.76
.60	1.06	1.02	1.00	.96	.93	.90	.86	.84	.81	.78
.61	1.08	1.05	1.02	.98	.96	.92	.89	.86	.84	.80
.62	1.11	1.08	1.04	1.01	.98	.94	.92	.88	.86	.83
.63	1.14	1.10	1.07	1.04	1.00	.97	.94	.91	.88	.86
.64	1.16	1.13	1.10	1.06	1.04	1.00	.97	.94	.92	.88
.65	1.19	1.16	1.12	1.09	1.06	1.02	1.00	.96	.94	.91
.66	1.22	1.18	1.15	1.12	1.08	1.05	1.02	.99	.96	.94
.67	1.24	1.21	1.18	1.14	1.12	1.08	1.05	1.02	1.00	.96
.68	1.28	1.24	1.21	1.18	1.14	1.11	1.08	1.05	1.02	1.00
.69	1.31	1.28	1.24	1.21	1.18	1.14	1.12	1.08	1.06	1.03
.70	1.33	1.30	1.26	1.23	1.20	1.16	1.14	1.10	1.08	1.05
.71	1.36	1.32	1.30	1.26	1.23	1.20	1.16	1.14	1.11	1.08
.72	1.38	1.35	1.32	1.28	1.26	1.22	1.19	1.16	1.14	1.10
.73	1.42	1.38	1.35	1.32	1.28	1.25	1.22	1.19	1.16	1.14
.74	1.44	1.41	1.38	1.34	1.32	1.28	1.25	1.22	1.20	1.16
.75	1.48	1.44	1.42	1.38	1.35	1.32	1.28	1.26	1.23	1.20
.76	1.51	1.48	1.44	1.41	1.38	1.34	1.32	1.28	1.26	1.23
.77	1.54	1.51	1.48	1.44	1.42	1.38	1.35	1.32	1.30	1.26
.78	1.58	1.54	1.51	1.48	1.44	1.41	1.38	1.35	1.32	1.30
.79	1.61	1.58	1.54	1.51	1.48	1.44	1.42	1.38	1.36	1.33
.80	1.64	1.61	1.58	1.54	1.52	1.48	1.45	1.42	1.40	1.36
.81	1.68	1.65	1.62	1.58	1.56	1.52	1.49	1.46	1.44	1.40
.82	1.72	1.68	1.66	1.62	1.59	1.56	1.52	1.50	1.47	1.44
.83	1.76	1.72	1.69	1.66	1.62	1.59	1.56	1.53	1.50	1.48
.84	1.80	1.76	1.73	1.70	1.66	1.63	1.60	1.57	1.54	1.52
.85	1.84	1.81	1.78	1.74	1.72	1.68	1.65	1.62	1.60	1.56
.86	1.88	1.85	1.82	1.78	1.76	1.72	1.69	1.66	1.64	1.60
.87	1.94	1.90	1.87	1.84	1.80	1.77	1.74	1.71	1.68	1.66
.88	1.98	1.94	1.92	1.88	1.85	1.82	1.78	1.76	1.73	1.70
.89	2.04	2.00	1.97	1.94	1.90	1.87	1.84	1.81	1.78	1.76
.90	2.08	2.05	2.02	1.98	1.96	1.92	1.89	1.86	1.84	1.80
.91	2.14	2.11	2.08	2.04	2.02	1.98	1.95	1.92	1.90	1.86
.92	2.20	2.17	2.14	2.10	2.08	2.04	2.01	1.98	1.96	1.92
.93	2.28	2.24	2.21	2.18	2.14	2.11	2.08	2.05	2.02	2.00
.94	2.36	2.32	2.29	2.26	2.22	2.19	2.16	2.13	2.10	2.08
.95	2.44	2.41	2.38	2.34	2.32	2.28	2.25	2.22	2.20	2.16
.96	2.56	2.52	2.49	2.46	2.42	2.39	2.36	2.33	2.30	2.28
.97	2.68	2.65	2.62	2.58	2.56	2.52	2.49	2.46	2.44	2.40
.98	2.86	2.82	2.79	2.76	2.72	2.69	2.66	2.63	2.60	2.58
.99	3.12	3.09	3.06	3.02	3.00	2.96	2.93	2.90	2.88	2.84

$P_{SN}(A)$ \ $P_N(A)$	.31	.32	.33	.34	.35	.36	.37	.38	.39	.40
.01	−1.82	−1.85	−1.88	−1.91	−1.94	−1.96	−1.99	−2.02	−2.04	−2.06
.02	−1.54	−1.58	−1.61	−1.64	−1.66	−1.69	−1.72	−1.74	−1.77	−1.80
.03	−1.38	−1.41	−1.44	−1.47	−1.50	−1.52	−1.55	−1.58	−1.60	−1.62
.04	−1.24	−1.28	−1.31	−1.33	−1.36	−1.39	−1.42	−1.44	−1.47	−1.50
.05	−1.14	−1.17	−1.20	−1.23	−1.26	−1.28	−1.31	−1.34	−1.36	−1.38
.06	−1.04	−1.08	−1.11	−1.14	−1.16	−1.19	−1.22	−1.24	−1.27	−1.30
.07	− .96	−1.00	−1.03	−1.06	−1.08	−1.11	−1.14	−1.16	−1.19	−1.22
.08	− .90	− .93	− .96	− .99	−1.02	−1.04	−1.07	−1.10	−1.12	−1.14
.09	− .84	− .87	− .90	− .93	− .96	− .98	−1.01	−1.04	−1.06	−1.08
.10	− .78	− .81	− .84	− .87	− .90	− .92	− .95	− .98	−1.00	−1.02
.11	− .72	− .76	− .79	− .82	− .84	− .87	− .90	− .92	− .95	− .98
.12	− .67	− .70	− .74	− .76	− .79	− .82	− .84	− .87	− .90	− .92
.13	− .62	− .66	− .69	− .72	− .74	− .77	− .80	− .82	− .85	− .88
.14	− .58	− .61	− .64	− .67	− .70	− .72	− .75	− .78	− .80	− .82
.15	− .54	− .57	− .60	− .63	− .66	− .68	− .71	− .74	− .76	− .78
.16	− .48	− .52	− .55	− .58	− .60	− .63	− .66	− .68	− .71	− .74
.17	− .44	− .48	− .51	− .54	− .56	− .59	− .62	− .64	− .67	− .70
.18	− .41	− .44	− .48	− .50	− .53	− .56	− .58	− .61	− .64	− .66
.19	− .38	− .41	− .44	− .47	− .50	− .52	− .55	− .58	− .60	− .62
.20	− .34	− .37	− .40	− .43	− .46	− .48	− .51	− .54	− .56	− .58
.21	− .30	− .34	− .36	− .40	− .42	− .44	− .48	− .50	− .52	− .55
.22	− .26	− .30	− .33	− .36	− .38	− .41	− .44	− .46	− .49	− .52
.23	− .24	− .27	− .30	− .33	− .36	− .38	− .41	− .44	− .46	− .48
.24	− .20	− .24	− .26	− .30	− .32	− .34	− .38	− .40	− .42	− .45
.25	− .17	− .20	− .24	− .26	− .29	− .32	− .34	− .37	− .40	− .42
.26	− .14	− .17	− .20	− .23	− .26	− .28	− .31	− .34	− .36	− .38
.27	− .10	− .14	− .17	− .20	− .22	− .25	− .28	− .30	− .33	− .36
.28	− .08	− .11	− .14	− .17	− .20	− .22	− .25	− .28	− .30	− .32
.29	− .05	− .08	− .12	− .14	− .17	− .20	− .22	− .25	− .28	− .30
.30	− .02	− .06	− .08	− .12	− .14	− .16	− .20	− .22	− .24	− .27
.31	0	− .04	− .06	− .10	− .12	− .14	− .18	− .20	− .22	− .25
.32	.04	0	− .03	− .06	− .08	− .11	− .14	− .16	− .19	− .22
.33	.06	.03	0	− .03	− .06	− .08	− .11	− .14	− .16	− .18
.34	.10	.06	.03	0	− .02	− .05	− .08	− .10	− .13	− .16
.35	.12	.08	.06	.02	0	− .02	− .06	− .08	− .10	− .13
.36	.14	.11	.08	.05	.02	0	− .03	− .06	− .08	− .10
.37	.18	.14	.11	.08	.06	.03	0	− .02	− .05	− .08
.38	.20	.16	.14	.10	.08	.06	.02	0	− .02	− .05
.39	.22	.19	.16	.13	.10	.08	.05	.02	0	− .02
.40	.25	.22	.18	.16	.13	.10	.08	.05	.02	0
.41	.28	.24	.21	.18	.16	.13	.10	.08	.05	.02
.42	.30	.27	.24	.21	.18	.16	.13	.10	.08	.06
.43	.32	.29	.26	.23	.20	.18	.15	.12	.10	.08
.44	.36	.32	.29	.26	.24	.21	.18	.16	.13	.10
.45	.38	.34	.31	.28	.26	.23	.20	.18	.15	.12
.46	.40	.37	.34	.31	.28	.26	.23	.20	.18	.16
.47	.43	.40	.36	.34	.31	.28	.26	.23	.20	.18
.48	.46	.42	.39	.36	.34	.31	.28	.26	.23	.20
.49	.48	.44	.42	.38	.36	.34	.30	.28	.26	.23
.50	.50	.47	.44	.41	.38	.36	.33	.30	.28	.26

$P_{SN}(A)$ \ $P_N(A)$	.31	.32	.33	.34	.35	.36	.37	.38	.39	.40
.51	.53	.50	.46	.44	.41	.38	.36	.33	.30	.28
.52	.56	.52	.49	.46	.44	.41	.38	.36	.33	.30
.53	.58	.54	.52	.48	.46	.44	.40	.38	.36	.33
.54	.60	.57	.54	.51	.48	.46	.43	.40	.38	.36
.55	.64	.60	.57	.54	.52	.49	.46	.44	.41	.38
.56	.66	.62	.59	.56	.54	.51	.48	.46	.43	.40
.57	.68	.65	.62	.59	.56	.54	.51	.48	.46	.44
.58	.70	.67	.64	.61	.58	.56	.53	.50	.48	.46
.59	.74	.70	.67	.64	.62	.59	.56	.54	.51	.48
.60	.76	.72	.70	.66	.64	.62	.58	.56	.54	.51
.61	.78	.75	.72	.69	.66	.64	.61	.58	.56	.54
.62	.81	.78	.74	.72	.69	.66	.64	.61	.58	.56
.63	.84	.80	.77	.74	.72	.69	.66	.64	.61	.58
.64	.86	.83	.80	.77	.74	.72	.69	.66	.64	.62
.65	.89	.86	.82	.80	.77	.74	.72	.69	.66	.64
.66	.92	.88	.85	.82	.80	.77	.74	.72	.69	.66
.67	.94	.91	.88	.85	.82	.80	.77	.74	.72	.70
.68	.98	.94	.91	.88	.86	.83	.80	.78	.75	.72
.69	1.01	.98	.94	.92	.89	.86	.84	.81	.78	.76
.70	1.03	1.00	.96	.94	.91	.88	.86	.83	.80	.78
.71	1.06	1.02	1.00	.96	.94	.92	.88	.86	.84	.81
.72	1.08	1.05	1.02	.99	.96	.94	.91	.88	.86	.84
.73	1.12	1.08	1.05	1.02	1.00	.97	.94	.92	.89	.86
.74	1.14	1.11	1.08	1.05	1.02	1.00	.97	.94	.92	.90
.75	1.18	1.14	1.12	1.08	1.06	1.04	1.00	.98	.96	.93
.76	1.21	1.18	1.14	1.12	1.09	1.06	1.04	1.01	.98	.96
.77	1.24	1.21	1.18	1.15	1.12	1.10	1.07	1.04	1.02	1.00
.78	1.28	1.24	1.21	1.18	1.16	1.13	1.10	1.08	1.05	1.02
.79	1.31	1.28	1.24	1.22	1.19	1.16	1.14	1.11	1.08	1.06
.80	1.34	1.31	1.28	1.25	1.22	1.20	1.17	1.14	1.12	1.10
.81	1.38	1.35	1.32	1.29	1.26	1.24	1.21	1.18	1.16	1.14
.82	1.42	1.38	1.36	1.32	1.30	1.28	1.24	1.22	1.20	1.17
.83	1.46	1.42	1.39	1.36	1.34	1.31	1.28	1.26	1.23	1.20
.84	1.50	1.46	1.43	1.40	1.38	1.35	1.32	1.30	1.27	1.24
.85	1.54	1.51	1.48	1.45	1.42	1.40	1.37	1.34	1.32	1.30
.86	1.58	1.55	1.52	1.49	1.46	1.44	1.41	1.38	1.36	1.34
.87	1.64	1.60	1.57	1.54	1.52	1.49	1.46	1.44	1.41	1.38
.88	1.68	1.64	1.62	1.58	1.56	1.54	1.50	1.48	1.46	1.43
.89	1.74	1.70	1.67	1.64	1.62	1.59	1.56	1.54	1.51	1.48
.90	1.78	1.75	1.72	1.69	1.66	1.64	1.61	1.58	1.56	1.54
.91	1.84	1.81	1.78	1.75	1.72	1.70	1.67	1.64	1.62	1.60
.92	1.90	1.87	1.84	1.81	1.78	1.76	1.73	1.70	1.68	1.66
.93	1.98	1.94	1.91	1.88	1.86	1.83	1.80	1.78	1.75	1.72
.94	2.06	2.02	1.99	1.96	1.94	1.91	1.88	1.86	1.83	1.80
.95	2.14	2.11	2.08	2.05	2.02	2.00	1.97	1.94	1.92	1.90
.96	2.26	2.22	2.19	2.16	2.14	2.11	2.08	2.06	2.03	2.00
.97	2.38	2.35	2.32	2.29	2.26	2.24	2.21	2.18	2.16	2.14
.98	2.56	2.52	2.49	2.46	2.44	2.41	2.38	2.36	2.33	2.30
.99	2.82	2.79	2.76	2.73	2.70	2.68	2.65	2.62	2.60	2.58

$P_N(A)$ $P_{SN}(A)$	.41	.42	.43	.44	.45	.46	.47	.48	.49	.50
.01	−2.09	−2.12	−2.14	−2.17	−2.19	−2.22	−2.24	−2.27	−2.30	−2.32
.02	−1.82	−1.85	−1.87	−1.90	−1.92	−1.95	−1.98	−2.00	−2.02	−2.05
.03	−1.65	−1.68	−1.70	−1.73	−1.75	−1.78	−1.80	−1.83	−1.86	−1.88
.04	−1.52	−1.55	−1.57	−1.60	−1.62	−1.65	−1.68	−1.70	−1.72	−1.75
.05	−1.41	−1.44	−1.46	−1.49	−1.51	−1.54	−1.56	−1.59	−1.62	−1.64
.06	−1.32	−1.35	−1.37	−1.40	−1.42	−1.45	−1.48	−1.50	−1.52	−1.55
.07	−1.24	−1.27	−1.29	−1.32	−1.34	−1.37	−1.40	−1.42	−1.44	−1.47
.08	−1.17	−1.20	−1.22	−1.25	−1.27	−1.30	−1.32	−1.35	−1.38	−1.40
.09	−1.11	−1.14	−1.16	−1.19	−1.21	−1.24	−1.26	−1.29	−1.32	−1.34
.10	−1.05	−1.08	−1.10	−1.13	−1.15	−1.18	−1.20	−1.23	−1.26	−1.28
.11	−1.00	−1.03	−1.05	−1.08	−1.10	−1.13	−1.16	−1.18	−1.20	−1.23
.12	− .94	− .98	−1.00	−1.02	−1.04	−1.08	−1.10	−1.12	−1.15	−1.18
.13	− .90	− .93	− .95	− .98	−1.00	−1.03	−1.06	−1.08	−1.10	−1.13
.14	− .85	− .88	− .90	− .93	− .95	− .98	−1.00	−1.03	−1.06	−1.08
.15	− .81	− .84	− .86	− .89	− .91	− .94	− .96	− .99	−1.02	−1.04
.16	− .76	− .79	− .81	− .84	− .86	− .89	− .92	− .94	− .96	− .99
.17	− .72	− .75	− .77	− .80	− .82	− .85	− .88	− .90	− .92	− .95
.18	− .68	− .72	− .74	− .76	− .78	− .82	− .84	− .86	− .89	− .92
.19	− .65	− .68	− .70	− .73	− .75	− .78	− .80	− .83	− .86	− .88
.20	− .61	− .64	− .66	− .69	− .71	− .74	− .76	− .79	− .82	− .84
.21	− .58	− .60	− .62	− .66	− .68	− .70	− .73	− .76	− .78	− .80
.22	− .54	− .57	− .59	− .62	− .64	− .67	− .70	− .72	− .74	− .77
.23	− .51	− .54	− .56	− .59	− .61	− .64	− .66	− .69	− .72	− .74
.24	− .48	− .50	− .52	− .56	− .58	− .60	− .63	− .66	− .68	− .70
.25	− .44	− .48	− .50	− .52	− .54	− .58	− .60	− .62	− .65	− .68
.26	− .41	− .44	− .46	− .49	− .51	− .54	− .56	− .59	− .62	− .64
.27	− .38	− .41	− .43	− .46	− .48	− .51	− .54	− .56	− .58	− .61
.28	− .35	− .38	− .40	− .43	− .45	− .48	− .50	− .53	− .56	− .58
.29	− .32	− .36	− .38	− .40	− .42	− .46	− .48	− .50	− .53	− .56
.30	− .30	− .32	− .34	− .38	− .40	− .42	− .45	− .48	− .50	− .52
.31	− .28	− .30	− .32	− .36	− .38	− .40	− .43	− .46	− .48	− .50
.32	− .24	− .27	− .29	− .32	− .34	− .37	− .40	− .42	− .44	− .47
.33	− .21	− .24	− .26	− .29	− .31	− .34	− .36	− .39	− .42	− .44
.34	− .18	− .21	− .23	− .26	− .28	− .31	− .34	− .36	− .38	− .41
.35	− .16	− .18	− .20	− .24	− .26	− .28	− .31	− .34	− .36	− .38
.36	− .13	− .16	− .18	− .21	− .23	− .26	− .28	− .31	− .34	− .36
.37	− .10	− .13	− .15	− .18	− .20	− .23	− .26	− .28	− .30	− .33
.38	− .08	− .10	− .12	− .16	− .18	− .20	− .23	− .26	− .28	− .30
.39	− .05	− .08	− .10	− .13	− .15	− .18	− .20	− .23	− .26	− .28
.40	− .02	− .06	− .08	− .10	− .12	− .16	− .18	− .20	− .23	− .26
.41	0	− .03	− .05	− .08	− .10	− .13	− .16	− .18	− .20	− .23
.42	.03	0	− .02	− .05	− .07	− .10	− .12	− .15	− .18	− .20
.43	.05	.02	0	− .03	− .05	− .08	− .10	− .13	− .16	− .18
.44	.08	.05	.03	0	− .02	− .05	− .08	− .10	− .13	− .15
.45	.10	.07	.05	.02	0	− .03	− .06	− .08	− .10	− .13
.46	.13	.10	.08	.05	.03	0	− .02	− .05	− .08	− .10
.47	.16	.12	.10	.08	.06	.02	0	− .02	− .05	− .08
.48	.18	.15	.13	.10	.08	.05	.02	0	− .02	− .05
.49	.20	.18	.16	.13	.10	.08	.05	.02	0	− .02
.50	.23	.20	.18	.15	.13	.10	.08	.05	.02	0

$P_N(A)$ $P_{SN}(A)$	.41	.42	.43	.44	.45	.46	.47	.48	.49	.50
.51	.26	.22	.20	.18	.16	.12	.10	.08	.05	.02
.52	.28	.25	.23	.20	.18	.15	.12	.10	.08	.05
.53	.30	.28	.26	.22	.20	.18	.15	.12	.10	.08
.54	.33	.30	.28	.25	.23	.20	.18	.15	.12	.10
.55	.36	.33	.31	.28	.26	.23	.20	.18	.16	.13
.56	.38	.35	.33	.30	.28	.25	.22	.20	.18	.15
.57	.41	.38	.36	.33	.31	.28	.26	.23	.20	.18
.58	.43	.40	.38	.35	.33	.30	.28	.25	.22	.20
.59	.46	.43	.41	.38	.36	.33	.30	.28	.26	.23
.60	.48	.46	.44	.40	.38	.36	.33	.30	.28	.26
.61	.51	.48	.46	.43	.41	.38	.36	.33	.30	.28
.62	.54	.50	.48	.46	.44	.40	.38	.36	.33	.30
.63	.56	.53	.51	.48	.46	.43	.40	.38	.36	.33
.64	.59	.56	.54	.51	.49	.46	.44	.41	.38	.36
.65	.62	.58	.56	.54	.52	.48	.46	.44	.41	.38
.66	.64	.61	.59	.56	.54	.51	.48	.46	.44	.41
.67	.67	.64	.62	.59	.57	.54	.52	.49	.46	.44
.68	.70	.67	.65	.62	.60	.57	.54	.52	.50	.47
.69	.74	.70	.68	.66	.64	.60	.58	.56	.53	.50
.70	.76	.72	.70	.68	.66	.62	.60	.58	.55	.52
.71	.78	.76	.74	.70	.68	.66	.63	.60	.58	.56
.72	.81	.78	.76	.73	.71	.68	.66	.63	.60	.58
.73	.84	.81	.79	.76	.74	.71	.68	.66	.64	.61
.74	.87	.84	.82	.79	.77	.74	.72	.69	.66	.64
.75	.90	.88	.86	.82	.80	.78	.75	.72	.70	.68
.76	.94	.90	.88	.86	.84	.80	.78	.76	.73	.70
.77	.97	.94	.92	.89	.87	.84	.82	.79	.76	.74
.78	1.00	.97	.95	.92	.90	.87	.84	.82	.80	.77
.79	1.04	1.00	.98	.96	.94	.90	.88	.86	.83	.80
.80	1.07	1.04	1.02	.99	.97	.94	.92	.89	.86	.84
.81	1.11	1.08	1.06	1.03	1.01	.98	.96	.93	.90	.88
.82	1.14	1.12	1.10	1.06	1.04	1.02	.99	.96	.94	.92
.83	1.18	1.15	1.13	1.10	1.08	1.05	1.02	1.00	.98	.95
.84	1.22	1.19	1.17	1.14	1.12	1.09	1.06	1.04	1.02	.99
.85	1.27	1.24	1.22	1.19	1.17	1.14	1.12	1.09	1.06	1.04
.86	1.31	1.28	1.26	1.23	1.21	1.18	1.16	1.13	1.10	1.08
.87	1.36	1.33	1.31	1.28	1.26	1.23	1.20	1.18	1.16	1.13
.88	1.40	1.38	1.36	1.32	1.30	1.28	1.25	1.22	1.20	1.18
.89	1.46	1.43	1.41	1.38	1.36	1.33	1.30	1.28	1.26	1.23
.90	1.51	1.48	1.46	1.43	1.41	1.38	1.36	1.33	1.30	1.28
.91	1.57	1.54	1.52	1.49	1.47	1.44	1.42	1.39	1.36	1.34
.92	1.63	1.60	1.58	1.55	1.53	1.50	1.48	1.45	1.42	1.40
.93	1.70	1.67	1.65	1.62	1.60	1.57	1.54	1.52	1.50	1.47
.94	1.78	1.75	1.73	1.70	1.68	1.65	1.62	1.60	1.58	1.55
.95	1.87	1.84	1.82	1.79	1.77	1.74	1.72	1.69	1.66	1.64
.96	1.98	1.95	1.93	1.90	1.88	1.85	1.82	1.80	1.78	1.75
.97	2.11	2.08	2.06	2.03	2.01	1.98	1.96	1.93	1.90	1.88
.98	2.28	2.25	2.23	2.20	2.18	2.15	2.12	2.10	2.08	2.05
.99	2.55	2.52	2.50	2.47	2.45	2.42	2.48	2.37	2.34	2.32

APENDIX IV

TABLES OF NORMALIZED d' AND C/P VALUES

TABLE OF NORMALIZED d' VALUES FOR ALL TASKS

	TASK								
SUBJECT #	M	W	T	N	0	1	2	3	S
1				1.9	2.0	2.0	2.1	1.8	
2				1.8	2.1	1.9	2.0	2.0	
3				1.9	2.1	2.0	2.0	2.0	
4				1.8	2.1	2.0	2.0	2.0	
5					1.6	1.6	1.6	1.7	
6					1.5	1.7	1.8	1.7	
7				1.6	1.9	2.0	2.3	2.0	
8				1.7	2.1	2.1	2.1	1.8	
9				1.8	2.2	2.0	1.9	1.9	
10				1.5	1.8	2.2	2.5	1.6	
11				1.9	1.8	2.1	2.0	2.1	
12	1.5	1.6	1.6	1.5				1.6	
13			1.9	1.6	1.4	1.6	1.8	2.0	1.3
14			1.2	1.7	1.6	1.4	1.6	1.8	1.9
15			2.0	1.1	1.5	1.7	1.8	2.0	1.4
16			2.0	1.6	1.8	1.7	1.7	1.7	1.4
17		1.2	1.4	1.7					
18	1.6		1.6						
19	1.6			1.6					
20			1.8	1.3					
21	1.6		1.8	1.2	1.8	1.8	1.8	1.8	1.7
MEAN :	1.56	1.38	1.67	1.53	1.65	1.70	1.78	1.74	1.54

TABLE OF C/P VALUES FOR ALL TASKS

	TASK								
SUBJECT #	M	W	T	N	0	1	2	3	S
1				2.8	2.3	2.5	2.7	2.2	
2				2.3	2.8	2.3	2.3	2.7	
3				2.5	2.3	2.2	3.2	2.2	
4				2.4	1.4	2.4	3.0	2.8	
5					0.6	1.2	1.7	1.5	
6					1.1	1.3	1.5	1.1	
7				6.3	2.8	1.8	0.8	2.6	
8				1.8	0.9	2.6	4.8	1.2	
9				3.7	3.5	2.1	1.6	2.1	
10				3.8	3.4	1.9	1.6	2.2	
11				2.7	2.6	2.5	2.4	2.5	
12	1.2	-.3	4.8	0.9					
13			2.7	7.9	0.9	0.9	0.9	1.0	2.4
14			3.4	1.1	4.8	2.6	2.3	1.4	1.7
15			2.7	1.8	2.2	2.4	2.5	2.7	2.1
16			2.6	2.2	2.4	2.3	2.3	2.3	2.0
17		2.9	2.8	2.0					
18	3.1		2.0						
19	1.8			1.8					
20			2.8	2.9					
21	2.1		2.3	2.6	2.5	2.4	2.3	2.2	1.7
MEAN :	2.09	1.29	3.06	2.31	2.10	2.10	2.27	2.56	1.98

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