SELECTIVE ATTENTION IN VISION: HEMIRETINAL

FIELDS USED AS CHANNELS FOR DICHOPTIC VIEWING

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by

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Abstract

A survey of modes of stimulus presentation used in studies
of selective attention, in both vision and audition, suggests that
the two eyes or the two visual fields, considered as separate input
channels, process information differently than the two ears. The
difference between modalities can be attributed to the decussation
of the optic nerve. Whereas each ear can be considered a separate
channel to a respective contralateral hemisphere, each eye is better
conceived as two channels, one to an ipsilateral and the other to a
contralateral hemisphere. In order to study the conceptualization
of the hemiretinal fields as channels, a new design for dichoptic
viewing apparatus was developed, based on the horopter. The data
were analyzed by Contralateral Contingent Event Analysis. When
visual stimuli are considered in terms of input to hemiretinal
fields, results similar to those for auditory stimuli are obtained.
It was concluded that, not only are the hemiretinal fields analogous
to the ears as separate input channels, but the apparatus was
feasible for dichoptic viewing tasks in selective attention.

CHAPTER I

Introduction

Theories of Selective Attention

Selective attention is primarily concerned with the division of attention among "concurrent streams of mental activity" (Kahneman, 1973). Whether or not attention is divisible is pertinent to the argument of this thesis.

There are two anecdotal observations that bear on the problem of divisibility of attention. One of these observations is that often one does multiple overt activities simultaneously, such as talking while driving. One apparently divides his attention between the concurrent activities. A second observation is that, when two or more overt stimuli are presented simultaneously, often only one of them elicits a response and the others evoke no response. If all the stimuli elicit responses, the responses typically appear to be successive rather than simultaneous. To account for the apparent divisibility of attention, a number of theories have been developed.

Broadbent's filter theory. Broadbent's (1958) model of attention assumed a sequence of three elements: a short-term storage (S-system), a selective filter, and a limited capacity channel (P-system). Concurrent stimuli enter into the S-system in parallel, and are analyzed there for physical features. More elaborate perceptual analyses are carried out in the P-system. This system deals serially with those stimuli selected by the filter. The amount of time spent on each stimulus depends on the amount of information that the stimulus conveys. When the P-system has cleared, the filter allows a new stimulus to enter. Thus, when two stimuli are presented simultaneously, they can be handled successively, but only if the processing of the first is completed before the record of the other in the S-system has decayed.

Filter theory implies that attention cannot be divided between

two stimuli at the same time because the P-system performs no
parallel processing of discrete stimuli. The apparent division of
attention in performance of concurrent activities is mediated by
alternation between channels, defined as any physical characteristic
for which the filter can be set, or between responses. According to
Broadbent (1958), the rate of alternation is slow (the minimum
dwell-time, the amount of time that the filter must remain on one
channel before it can switch to another channel, of the filter being
about 300- to 500-msec.). The processing of simultaneous complex
messages fails when the processing of the first message that enters
the P-system is so prolonged that the traces of the other message
are lost from the S-system before they can be retrieved.

Although the model is based on the entire experimental
evidence reviewed in Perception and Communication (Broadbent, 1958),
the major experiment is the split-span experiment (Broadbent, 1954).
Three simultaneous pairs of digits, or other signals, are presented
to a subject, who is required to recall them. Typically, one of
each pair is presented to one ear simultaneously with the presentation
to the other ear of the other half of the pair. The criterion is the
percentage of lists completely correct. Broadbent found that recall
by ear (left-left-left-right-right-right [LLLRRR] or RRRLLL) was
much superior (90% of the total number of lists correct as compared
to less than 20%) to alternating recall by ear (LRLRLR or RLRLRL).
He, thus, suggested that the only information that got through the
filter was that from the accepted channel. Since subjects in the
alternating recall task could give some correct lists, it is pos-
sible that some information from rejected messages does bypass the
the filter.

In 1953, Cherry introduced the technique of speech shadowing,
the technique of asking a subject to verbally repeat a continuous
message while hearing it. Cherry requested the subject to repeat
a message through one ear while he played a different, distracting

message into the other. He found that the subjects could repeat the accepted message, the message to be shadowed as designated by the experimenter. Although the subject was unable to recall the semantic content or the language of the rejected message (the distracting message), he could distinguish some general physical characteristics (e.g., whether or not the rejected message was words or music, was a prose passage or a list, or was spoken by a male or by a female). With a similar experimental task, Moray (1959) found that a subject's name could cause a shift in attention. Apparently, some information in rejected messages is able to bypass the filter. It appears, then, that selection is not an all-or-none process as Broadbent proposed.

Treisman's attentuation theory. In order to account for the fact that at least some of the rejected message does get past the filter, Treisman proposed a modification of Broadbent's (1958) theory. She suggested that the filtering was not all-or-none: the rejected message was merely attenuated, not eradicated. In her model, information enters the system through a number of parallel channels. At the level of a preprocessor, the messages are analyzed for crude physical properties, such as loudness, pitch, and spatial location. This information is available to conscious perception, and for re- porting by the subject, regardless of what happens to the message beyond this point. The preprocessor can also act to attenuate the signal strength depending upon whether or not the signal has the requisite characteristic (e.g., a particular loudness, a particular pitch, or a particular spatial location). This means that the out- put from the preprocessor is differentially weighted.

The attenuated (rejected) messages and the one unattenuated (accepted) message pass deeper into the nervous system until they reach the main processor (the dictionary). At this level, according to Treisman, a message activates hypothetical "dictionary units" in memory. Each unit has a threshold that must be exceeded for per- ception to occur. The thresholds for highly significant stimuli

(e.g., one's name) are permanently lowered. The threshold for a stimulus that the context makes probable is lowered temporarily. Even if such signals have been attenuated, they will trigger the appropriate dictionary units and perception will occur. Neutral attentuated signals are not able to trigger their appropriate dictionary units because their signal strength has been attenuated by the filter. However, unattenuated signals are able to do so and, hence, the message is perceived. In general, rejected signals do not activate the corresponding dictionary units, except when the threshold of one of these units is exceptionally low.

A postulate of the preceding two models is that there is a mechanism that receives the input in parallel and converts it to sequential form for processing. The parallel to sequential conversion suggests the image of a bottleneck, a stage at which information flow is restricted. It may be that the postulate of a structural bottleneck is not warranted.

Capacity theory. A capacity theory of attention provides an alternative to theories that explain man's limitations by assuming the existence of structural bottlenecks (i.e., the conversion from parallel to sequential processing). Instead of such bottlenecks, a capacity theory (as described by Kahneman, 1973) assumes that there is a general limit on man's capacity to perform work. It also assumes that this limited capacity can be allocated with considerable freedom among concurrent activities (Moray, 1967). To explain man's limited ability to carry out multiple tasks at the same time, a capacity theory assumes that the absolute amount of attention that can be deployed at any time is limited.

Both types of theory (structural and capacity) predict that concurrent activities are likely to be mutually interfering, but they ascribe the interference to different causes. In a structural model, interference occurs when the same mechanism (e.g., the filter) is required to carry out two incompatible operations simultaneously. In

a capacity model, interference occurs when the demands of two con-
current activities exceed available capacity. Thus, a structural
model implies that interference between tasks is specific (Kahneman,
1973), and depends on the degree to which the tasks call for the same
mechanisms. In a capacity model, interference is nonspecific
(Kahneman, 1973), and depends only on the demands of both tasks.

The capacity model would account for any physically possible
behavior that is within the capacity limitations of the organism. Un-
fortunately, capacity limitation is the only real restriction of the
model. Because this model can account for any physically or mentally
possible behavior within the capacity limitations of the organism,
including hypothetical behaviors that do not occur, the model is less
useful for predicting behavior than the structural models, which are
more restrictive in concept.

Moray's switching theory. Once the input has entered the system
in parallel, it encounters an unspecified structural bottleneck that
reduces the processing to a sequential format. Moray, Fitter, Ostry,
Favreau, and Nagy (1975) say that it does not matter whether the
selective mechanism (the bottleneck) is a discontinuous (Broadbent,
1958) or a continuous (Treisman, 1960) filtering device; what matters
is the proposition that sequential processing occurs. Moray et al.
(1975) do not discuss whether or not the switching speed can change,
but they do say that the amount of time spent on any one channel varies
directly with the amount of time required to make a decision about the
input. Thus, indirectly, the switching rate varies with decision time.
In the situation in which Moray et al. (1975) were concerned, different
pitch tone burst series, each series composed of both targets and
nontargets, are presented to each of the ears. They describe the en-
suing decision state:

> As soon as the first burst has been processed to the point
> at which the observer can decide whether to say "yes" or
> "no", processing of the first burst stops and processing
> of the second burst or its trace begins. Either when the

second has been processed to a point where a decision can
be made, or when time runs out and a decision, however,
unsatisfactory to the observer, must be made the observer
presses (or refrains from pressing, for a "no") the
appropriate buttons. Since nontargets are more frequent
than targets, they will be associated with a shorter
decision time that the latter (Hyman, 1953): so short in
fact that correctly to process a nontarget leaves enough
time thoroughly to process the second burst, as though it
alone had been processed. The longer decision time
associated with the rarer target cuts down the time
available for processing the second burst, and also
results in processing a weakened trace for short bursts,
and the detectability of the second target therefore
falls (pp. 14-15).

There are two points in emphasize in the above statement.
First, what Moray et al. (1975) refer to as the "second burst" is
in in reality presented simultaneously with the "first burst." It
is called the second burst because it is the second input to be pro-
cessed. This occurs merely because the switch is not set for the
particular channel on which that burst occurs. Because both bursts
are presented simultaneously, processing of the second burst will
always be on the trace of the second burst.

Second, the amount of time spent processing the second burst
varies directly with the amount of time available after the completion
of processing on the first burst. If the first burst does not re-
quire much processing time for a decision to be made, more time is
available to process the second burst. As the amount of time re-
quired by the first burst to make a decision increases, the amount
of time available for processing the second burst decreases. Thus,
at least with the simple signals used by Moray et al. (1975), the
first burst is always completely processed. The second burst may
or may not be completely processed, depending on the amount of time
taken by the first burst.

An analysis of this model shows that there is a structural
bottleneck, which could be similar to either Broadbent's (1958)
discontinuous or Treisman's (1960) continuous filter. Once past this

bottleneck the processing is sequential. However, dwell-time on any one channel is construed as variable. The variability depends upon the amount of time that is taken to make a decision abount the stimulation on that channel. The variability of the switch dwell-time brings the switching theory more in line with the selective attention data. In a later section, differences in predictions between the four theories will be discussed.

The concept of channels. One of the assumptions of the above four models is the notion of a channel. As noted previously, a channel is defined as any physical characteristic for which the selecting device (or allocator in the case of the capacity models) can be set. Examples of channels include such manifest physical characteristics as spatial location, pitch, intensity, voice qualities, and timbre. In other words, the notion of channels assumes that the stimulus field is partitioned into segments or groups. The Gestalt laws of grouping would describe the operation of this stage; for example, successive sounds that originate in the same place would be more likely to be grouped as a unit than sounds from different places.

The concept of channels is very important to attention. It has been noted that effective search is possible only when all potential targets share a physical characteristic that permits these targets to be grouped together (Williams, 1966; von Wright, 1968, 1970). Kahneman (1973) states that "the properties that provide strong units also allow for the effective control of attention, because attention is most easily directed toward a natural unit" (p. 74) or Gestalten.

Experimenters in auditory selective attention have almost unanimously used different spatial locations as the stimulus input channels. Stimuli are typically presented dichotically in shadowing tasks or monitoring tasks, a task in which the subject is to respond to target stimuli within a continuous stream of nontarget stimuli no matter on which channel the target occurs. The stimulation presented to each ear is assumed to be processed separately. That is, there is no

mixing of the auditory stimulation, presented to separate ears, along the ascending sensory pathways until the stimulation reaches the cortex.

With respect to the visual system, an interesting anatomical point is that each retina is functionally divided into two regions, which receive input from the left and right visual fields. The right visual field is mediated by both the right nasal hemiretina and the left temporal hemiretina. Similarly, the left visual field is mediated by both the left nasal and right temporal hemiretina. Correspondingly, ganglion cell axons from the right nasal and the left temporal hemi-retinae project to the left cerebral hemisphere and ganglion cell axons from the left nasal and the right temporal hemiretinae project to the right cerebral hemisphere. There are interhemispheric con-nections through the commissure fibers crossing the corpus callosum, but there is no known interaction between the neural pathways of the two eyes at any level more pheripheral than the thalamic geniculates.

Before the two modalities can be appropriately compared, there is a question of whether or not there is an approriate visual analogue to auditory input channels. When the two modalities are compared, it becomes apparent that some methods of stimulus presentation in vision may be more analogous to dichotic stimulus presentation in audition than other methods of presentation. The first possible appropriate analogue is the conceptualization of each eye as an input channel. A second appropriate analogue is the consideration of the right and left visual fields as the input channels. The final conceptualization of visual input channels is the hemiretinal fields. Each hemiretinal field would be considered a separate channel. It is submitted that the most appropriate conceptualization of visual input channels is that of the hemiretinal fields.

Experimental Survey of Visual Input Channels

In the last section, it was suggested that the concept of the hemiretinal fields as input channels was the most appropriate

analogue to the concept of the ears as separate input channels. This
suggestion would be much stronger if it were supported by the findings
in the literature.

Before exploring the literature, however, the definition of
"visual field" should be clarified. Sanders (1963) has made a
relevant distinction among three orthogonal types or subdivisions
of the visual field: the headfield, that part of the visual field
that can be sampled by moving the head; the eyefield, that part of
the visual field that can be sampled by moving the eyes, but with
the head held stationary; and the stationary field, that region that
can be sampled while holding both head and eyes stationary.

Sander's distinctions provide a useful division for work on
visual attention. Moving the head may totally prevent visual input
from some parts of the environment, but it changes merely the
direction of auditory stimuli relevant to the ears. Moving the
eyes will affect the retinal location of the stimulus. The auditory
receptors cannot be moved independently of head movement. The
stationary field seems to be more relevant to visual selective
attention than either the headfield or the eyefield, especially
since dichotic stimuli are typically presented to the separate
ears via stereophonic earphones, which ensure that moving the head
will not affect the perception of the direction of the stimulation.
All of the following studies have controlled for head and eye
movement (i.e., have used the stationary field).

Sampson and his colleagues (Sampson, 1964; Sampson & Horrocks,
1967; Sampson & Spong, 1961a, 1961b) conducted a series of studies
using a slide projector to back-project stimuli onto a screen. An
opaque division prevented the left eye from seeing the right side
of the field and the right eye from seeing the left side of the
field. In some of the experiments (Sampson & Spong, 1961a, 1961b)
fixation points were provided. By fusing them, a standard direction
of gaze was maintained. They used the split-span method of pre-

sentation, in which signals were presented simultaneously to each
eye. The subjects were required to recall the signals after the
entire series had been presented. Although, in the original
split-span experiments in audition, Broadbent (1954) had found
that listeners tended to recall all the stimuli from one ear
followed by all those from the other ear, Sampson and Spong (1961a,
1961b) did not find this. They found that viewers tended to recall
the presented digits as simultaneous pairs, not separated by eye.
This result does not seem surprising, however, since, it two digits
appear side by side in the visual field, reading bias alone would
give a tendency for them to be read as single two-digit numbers.
To read them otherwise might be expected to require practice.

     In order to overcome the positive effects of reading bias,
Sampson (1964) presented digits to one eye and colored patches to
the other. Although there were great individual differences, at
least some of the subjects tended to report all digits together
and then all colors together rather than pairing digits and colors.
In addition, digits were recalled with fewer errors than colors,
and had a shorter response time.

     One possible interpretation of these results is that response
factors were involved rather than attentional ones. Most people
have probably had greater practice at naming numbers than color
patches in everyday life, and, thus, perhaps show a reduced latency
for numbers (Moray, 1970). Sampson did not control for this effect.

     In 1967, Sampson and Horrocks explored the importance of
the different regions of the visual field in more detail. The
method of presentation was the same as in the earlier experiments
(Sampson, 1964; Sampson & Spong, 1961a, 1961b), but the arrangement
of the stimuli in the first of their series of experiments was as
shown in Figure 1. They found that the most frequent pairing of
responses was upper-lower; that is, the upper of a pair was given
before the lower. The only exception was the last condition in

which the left side (lower) was given before the right side (upper).
The subjects spontaneously reported in pairs. Again, as in the
previous studies, these results appear to show the effects of
reading bias.

. . . .
Insert Figure 1 about here
. . . .

In a second experiment, reported in the same paper, they
investigated the effect of partially overlapping the stimuli,
either binocularly or monocularly (Figure 2). Recall was more
accurate when viewing monocularly overlapped stimuli than when
the overlapping was caused by binocular fusion. The stimuli
tended to be recalled pair by pair, the left hand digit first.
This tendency was more marked in the monocular recall condition.

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Insert Figure 2 about here
. . . .

A final experiment investigated the possible role of
binocular rivalry. Slides, similar to the binocular overlapping
condition of the previous experiment (Figure 2), were presented
and viewers were asked to call out after each slide what they had
seen. The stimuli presented to the left eye were recalled with a
level of accuracy of 74.2% and those to the right eye with 85%.
These stimuli apparently were viewed using no designated fixation
points because there were no differences in accuracy of recall
between the eyes in those conditions in which the subjects were
required to fixate binocularly. Implicit in the Sampson studies
(Sampson, 1964; Sampson & Horrocks, 1967; Sampson & Spong, 1961a,
1961b) was that there was an appropriate analogy between perception
in the auditory system and perception in the visual system. They
considered each eye as an input channel. In other words, the eyes
were conceived as functioning simultaneously as independent in-
formation sources.

Two difficulties with apparatus design, however, tend to

Figure 1.   Stimulus display from Sampson and Horrocks (1967).

Stimulus Array

Percept

3
4

3
4

Left Monocular

2
6

2
6

Right Monocular

7

5

7
5
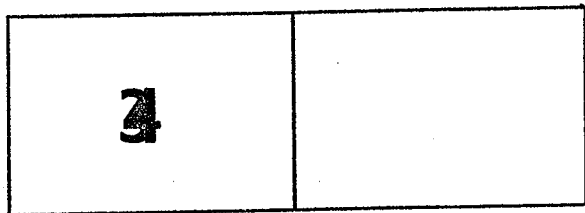
Binocular Left-upper

8

1

8

1

Binocular Right-upper

Figure 2.   Partially overlapping displays from Sampson and Horrocks (1967).

Stimulus Array

Percept
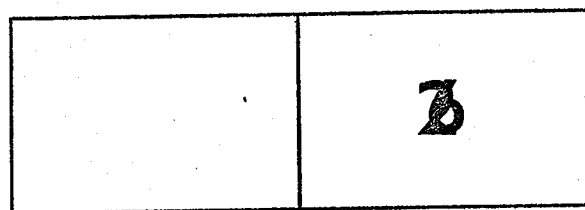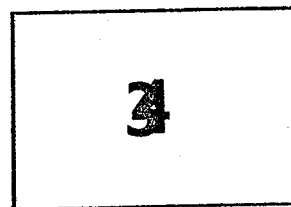
Left Monocular

Right Monocular
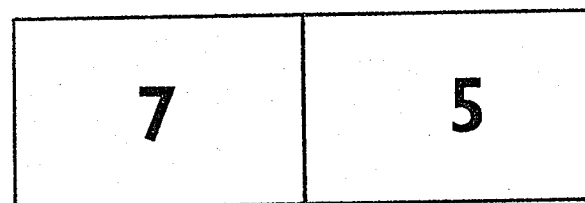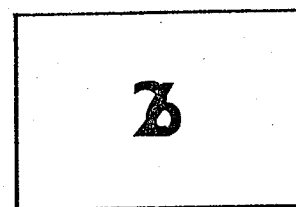
Binocular
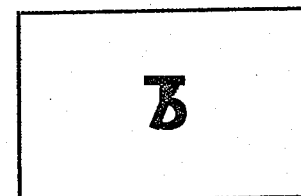
cast doubt on this suggestion. For one thing, there was no control
kept on eye movements. The duration of each of the stimuli was
300 msec. and the interstimulus interval was 800 msec. Changes
of fixation were possible, especially since fixation points were
not provided (Moray, 1970). In addition, stimuli were of the
order of 41' of arc wide and $1°11'$ high, and appear to have been
presented at about $20°$ angular separation. Nevertheless, the
experimenters did not appear to attempt to see whether acuity was
symmetrical about the fixation point.

A second problem concerned the optics of the experimental
situation. Sampson and Horrocks (1967) say that the eyes of the
viewers probably overconverged for the display. The separation
of the centers of the display was slightly greater than the
average interpupillary distance and was not adjusted for the
individual subject; then, there could be an unknown degree of
fusion and changes in convergence, accommodation, and brightness.
This would introduce large individual variations in acuity between
subjects (Moray, 1970).

Jeeves and Dixon (1970) investigated differences between
the cerebral hemispheres. Response latency to visual stimuli was
the dependent variable. The subjects were to respond simultaneously
with both hands when the stimulus appeared. The stimulus was a
signal presented to either the nasal or the temporal part of the
retina. In the nasal condition, bright point sources of light,
well above threshold at a distance of 17 1/2 cm. and at an angle
of $70°$ to the midline (presumably, the visual axis), flashed on
for 2 msec. For the temporal stimulation condition, subjects
wore a black plastic spectacle frame with lights embedded within
the frame so that only the temporal part of the retina was stimu-
lated when the lights flashed on.

The results from the Jeeves and Dixon (1970) study show
a tendency for the response latencies from the stimuli directed

to the right cerebral hemisphere to be less than those from the stimuli directed to the left cerebral hemisphere. In addition, Jeeves and Dixon (1970) ranked the response latencies from fast response time to slow response time: (1) right hemisphere receiving (left visual field), left hemisphere initiating response (right hand responding); (2) right hemisphere receiving, right hemisphere initiating response (left hand responding); (3) left hemisphere receiving (right visual field), left hemisphere initiating response (right hand responding); and (4) left hemisphere receiving, right hemisphere initiating response (left hand responding). If the nasal and temporal conditions are separated and then ranked by the Jeeves and Dixon criterion, the constancy of the above ordering is maintained (Table 1).

. . . .
Insert Table 1 about here
. . . .

However, the ranking of the Jeeves and Dixon (1970) data is not consistent with the findings from studies done by Dimond (1970) and Dimond and Beaumont (1971a). Dimond (1970) reported an attempt to assess the relative efficiency of the hemispheres and their relationship in performance on complex reaction time tasks. A divided visual field was used to direct signals to the temporal or nasal hemiretina of each eye (Figure 3). The signals could be presented to any of the four hemiretinae alone, or simultaneously in pairs.

. . . .
Insert Figure 3 about here
. . . .

When the signals were presented singly, there were no overall significant differences between any of the four signal conditions. Furthermore, there were no significant differences between the response of the right and the left hand in the four signal conditions. However, there was some tendency for errors of commission (i.e., responses with the incorrect hand) to be

Hemisphere receiving	Hemisphere responding	Jeeves and Dixon (1970)	
		N^a	T^a
Right	left	247.7(1)	232.7(1)
	right	247.9(2)	234.6(2)
Left	left	251.3(3)	237.7(3)
	right	256.2(4)	242.5(4)
		Dimond(1970)	
		N^a	T^a
Right	left	654.7(3)	636.7(2)
	right	679.3(4)	656.0(4)
Left	left	597.3(2)	651.3(3)
	right	580.0(1)	629.3(1)
		Isseroff et al. (1974)	
		NO^a	MI^a
Right	left	342(4)	388(3)
	right	333(3)	391(4)
Left	left	306(2)	339(1)
	right	302(1)	343(2)

Note. All RTs are measured in msec.

[a] Values in parentheses represent the rank of that RT.

Table 1. Mean RTs and rank associated with each experiment. N is the nasal hemiretina, T is the temporal hemiretina, NO is normal words, and MI are mirror-image words.

Figure 3. Schematic diagram of apparatus and visual pathways,
from Dimond (1970). The fixation point is at the
midpoint between the two screens on the same plane
as the stimulus light sources. RN is right nasal,
RT is right temporal, LN is left nasal, and LT is
left temporal hemiretinae.

Eyes

RN
LT
RT
LN
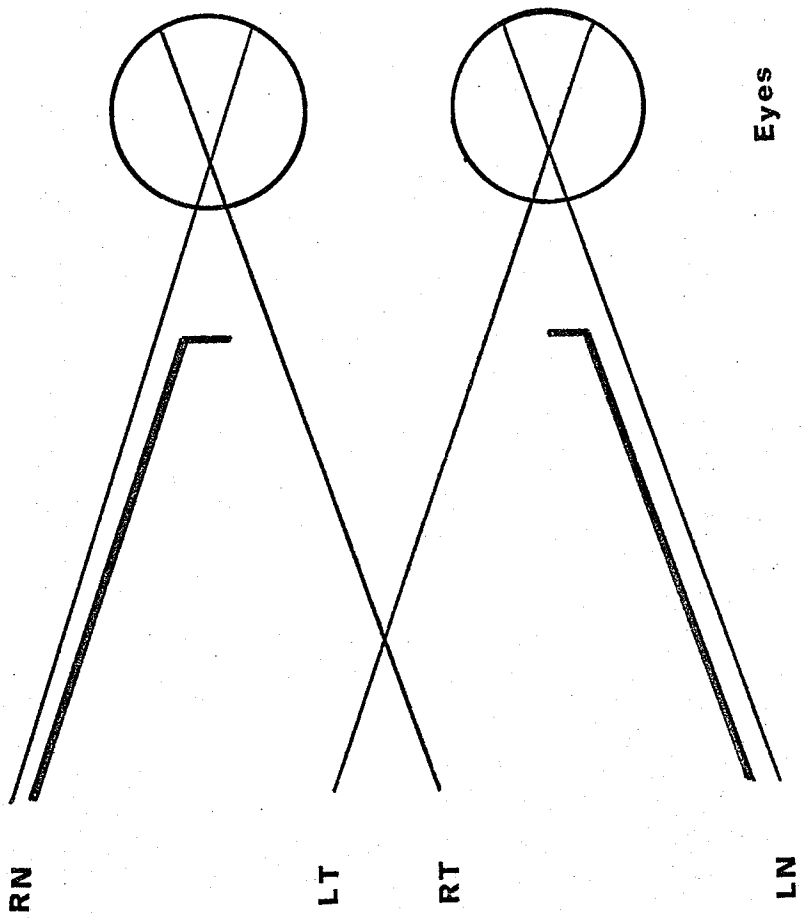
more frequent when the hemisphere to which the signal was sent and the hemisphere from which the response originated were the same (e.g., a signal sent to the right temporal hemiretina and a response required by the left hand).

In the simultaneous double condition, when pairs of signals were directed to both hemispheres, one signal through one eye and the other signal through the other eye, the combined response times of the hemispheres were lowest (fast RT). When signals were directed to different hemispheres through the same eye, one through the temporal and the other through the nasal hemiretina, the reaction times increased significantly (p less than .05). When both signals were directed through different eyes to the same hemisphere, response times were highest (slow RT). While the response times of each hemisphere show a distinct lengthening when both signals were directed to it simultaneously, the right hemisphere showed a greater lengthening than the left.

Dimond and Beaumont (1971a) studied the detection of visual stimuli by the cerebral hemispheres during a vigilance task. They used apparatus similar to that used in the Dimond (1970) study. Signals were present equally and randomly at the four signal sources (Figure 3). Each signal occurred at a random point within a 100 msec. period. They found no significant differences between the performance of the right and the left hemispheres in the detection of the signals. However, the left hemisphere consistently produced more errors of commission than the right hemisphere. In addition, more signals presented to the temporal hemiretinae were detected than to the nasal hemiretinae, irregardless of the hemisphere to which the signals were directed.

The results of the Dimond (1970) and the Dimond and Beaumont (1971a) studies show that at least some of the processing of information within hemispheres appears to be sequential. If the processing was not sequential (i.e., in parallel), the response

times for the three simultaneous presentation conditions would
have been the same. In addition, Dimond's (1970) result, that
the right hemisphere showed a greater latency of response times
than the left hemisphere when two signals were directed to it
simultaneously, appears opposite to the results of Jeeves and
Dixon (1970), who found faster response times for the right hemi-
sphere than for the left hemisphere. However, Dimond and Beaumont
(1971a) found that the left hemisphere consistently produced more
errors of commission than the right. One possibility is a speed-
accuracy tradeoff. What Dimond's subjects made up for in speed,
they lost in accuracy.

On the other hand, most studies have found a right visual
field (left hemisphere) superiority. Isseroff, Carmon, and
Nachson (1974) discussed the idea that recognition of Latin letters
presented to one visual field at a time is faster in the right
field than in the left field. The slight prolongation of response
times to Latin letters presented as stimuli in the left visual
field is attributed to a time delay due to a necessary trans-
callosal transmission of the verbal content of the letters from
the right to the left hemisphere, which is dominant for speech.
The superior accuracy of the right visual field in recognition
of verbal material has been explained in terms of cerebral dominance.
However, when stimuli containing verbal information was presented
simultaneously to the two fields, the left field had superior
recognition. These differences might be attributed to a directional
reading bias. Mishkin and Forgays (1952) and Orbach (1953) have
reported that Hebrew and Yiddish, which are scanned in the opposite
direction to English words, are identified better from the left
field in unilateral tachistoscopic exposures. These data are
contrary to a directional reading bias hypothesis. Isseroff et
al. (1974) attempted to clarify whether right visual field su-
periority (i.e., the short latencies to verbal material) transcends

the directional scanning tendencies associated with the stimulus.

Two sets of English words were used as stimuli: Normal (NO) and mirror-image (MI) words. The stimuli were back-projected onto a screen equipped with a central fixation light. The subjects responded verbally, calling out the word that they saw, tripping a voice-key.

The results showed that response times were faster for stimuli exposed in the left hemisphere (right visual field) than for stimuli exposed in the right hemisphere. Response times to NO words were faster than response times to MI words.

The results from this experiment could be explained in other ways than speed of processing time. The processing speed could be the same speed for each hemisphere, but verbal responses could be generated more quickly when the left hemisphere is stimulated directly (i.e., no transcallosal transmission). In other words, because speech is localized in the left hemisphere, any stimuli directed towards the right hemisphere must be transmitted to the left hemisphere before a response can be generated. This indirect transmission through the right hemisphere to the left may be enough to account for the increased latency of stimuli in the left visual field. A second experiment (Isseroff et al., 1974) investigated this possibility by measuring the speed of manual responses to the verbal stimuli employed in the previous experiment. If the right visual field superiority, manifested in faster response times, is due to verbal response, it would be expected than manual response times would be similar for stimuli exposed in either the right or left visual fields. However, a left hemisphere (right visual field) superiority in terms of faster manual response times was found for both stimulus presentation categories (NO and MI words), and was maintained for both right- and left-hand responses. This evidence also fails to support the Jeeves and Dixon (1970) finding of right cerebral hemisphere superiority.

Jeeves and Dixon (1970) had rank ordered the hemispheres by direction from which the stimulation arrived (left and right visual fields) and the side from which a motor response was required (left or right hand response). If the results of Dimond (1970) and of Isseroff et al. (1974) are also ranked according to the categories of Jeeves and Dixon, an interesting relationship emerges (Table 1). The ranking for the Jeeves and Dixon data between the nasal and the temporal hemiretinae are the same. However, the ranking of the results from Dimond gives a strong negative correlation with those of Jeeves and Dixon, especially for the nasal condition (rho equals -.80 for the nasal condition and -.40 for the temporal condition). Considering the different tasks required of the subjects, it appears that the results from the Isseroff et al. (1974) study are closer to those of Dimond than to those of Jeeves and Dixon, again especially for the nasal condition (rho equals +.80 for the nasal condition and +.50 for the temporal condition when compared to Dimond's results).

Much of the difficulty, both within and between all the studies discussed to this point, can be attributed to apparatus. The apparatus used by Jeeves and Dixon (1970) is inconsistent in the presentation of stimuli to the nasal and temporal hemiretinae. The nasal and temporal presentation were completely different from each other. There was no allowance for convergence nor accommodation. No mention was made of the intensity of the stimuli other than that the nasal point sources were well above threshold. Neither was the ambient illumination discussed. Thus, afterimages could be confounding the results. In addition, there was no control over the detection of a stimulus, directed to one hemiretina, by the adjacent hemiretina in the same eye.

The apparatus used in the experiments by Sampson and his colleagues (Sampson, 1964; Sampson & Horrocks, 1967; Sampson &

Spong, 1961a, 1961b) fares no better. There was no control kept on eye movements. There were difficulties with overconvergence, accommodation, and control of brightness.

Whelan (1968) overcame some of the problems of equipment design. He designed his apparatus so that it could be adjusted for each observer. Allowances were made for individual interocular distances. His early experiments were done using ciné film. The later ones used a computer generated display with on-line control, so that onet and termination times and intersignal duration could be varied within a run and were accurate and reproducible to a millisecond. One part of the display could be altered while another could be left on. Typically, many stimuli were presented during one run, with the observers reading off stimuli as they appeared. The apparatus allowed control of convergence and brightness to suit the individual subject. However, the visual displays were similar to those used in some of the Sampson studies (Sampson, 1964; Sampson & Spong, 1961a, 1961b).

Both Sampson and Whelan presented their stimuli on a flat screen (e.g., Figure 4). The stimuli presented to one eye were generally directly in front of that eye, a few degrees to the right or left of the center of the display, for presentation to the temporal and nasal sides of the eye. This method of presentation creates a problem in perception of the stimuli. The experimenter does not have precise control over the retinal location stimulated. Because two stimuli are an equal number of degrees on either side of a fixation point does not necessarily mean that they will stimulate retinal locations an equal number of degrees from the fovea. Even when symmetrical retinal locations are stimulated, difficulties with factors affecting accommodation are encountered. These points will be expanded upon in a later section.

. . . .
Insert Figure 4 about here
. . . .

Dimond (1970, 1971; Dimond & Beaumont, 1971a, 1971b)
attempted to overcome these difficulties (Figure 3). He attempted
to control the accommodation factors. However, although the stimulus
points are equidistant from the eyes relative to each other, they
are not equidistant from the eyes relative to the fixation point.
The fixation point is closer to the eyes than are the stimulus
points. In addition, the stimuli do not stimulate the retinae
at points symmetrical about the foveae. With the eyes focused on
the fixation point, the stimuli striking the temporal hemiretinae
are closer to the foveae than those striking the nasal hemiretinae.
The assymmetry about the foveae of the stimulation locations on
the retinae might account for the differences in detection between
the temporal and nasal hemiretinae.

There is variation in accuracy of report of stimuli across
the retina. Typically, it is found that the farther from the fovea
that a stimulus strikes, the less accurate is the subject's report.
Dallenbach (1923) stated that those positions to the left of and
those above the fovea have an attentional advantage. The most
advantageous position of all is the position to the left and
below the point of fixation. Lefton and Haber (1974) found that
there was a change in response time associated with changes in
the retinal location of the stimuli: with increases in retinal
eccentricity from fixation, judgements required more time. In
addition, they found no difference between judgements with respect
to visual field of presentation.

At several different locations in the periphery of the
retina, Edwards and Goolkasian (1974) compared the performance
of different processing tasks (detection, positional recognition,
letter identification, and word categorization). Their results
demonstrated a decrease in performance as the position on the

Figure 4. Arrangement of stimuli from Whelan (1968).
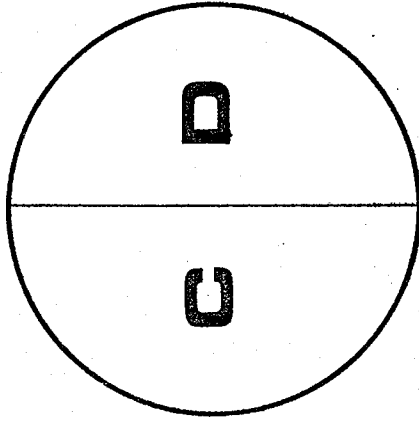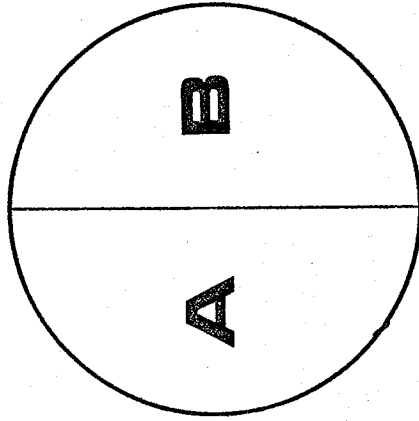
Left

Right

retina where a stimulus was presented moved from the foveal
region.   In the far peripheral region of the retina, the subject
was able to make only accurate detection judgements.   Edwards
and Goolkasian suggest that the retina consists of at least three
areas, based upon processing abilities, with no sharp dividing
line between them.

Senders, Webb, and Baker (1955) found, however, that
observers, once they had some idea of what to observe, were
able to make more than usual use of the periphery of the visual
field.   An example of this is the fact that people, when reading,
actually look ahead a considerable distance (Lawson, 1961; Morton,
1964).   This looking ahead appears related to levels of difficulty
in reading statistical approximations to English (Taylor & Moray,
1960).   As the order of approximation to English decreases, the
level of difficulty of reading increases.   Lawson (1961) and
Morton (1964) have found that the eye-voice span (i.e., the amount
that a person looks ahead when reading aloud) increases with in-
creasing redundancy of the material read.   In addition, Morton
(1964) found no change in the fixation time as a function of the
order of approximation.   Senders et al. (1955), while finding
that the frequency of fixations varied with the frequency of the
signal, also ascertained that the duration of fixations did not.
It appears, thus, that information can be seen over a wider visual
angle when it is predictable.

Summary

There are a number of major theories of selective attention.
All of these theories are based on findings from experiments on
audition, which conceptualize the ears as separate input channels.

Difficulties arise, however, when experimenters attempt
to employ the auditory models in relation to vision research in
selective attention.   Two possible reasons, relevant
to this discussion, for this;   (1) the models are not applicable

to vision; or (2) the experimenters have conceptualized the visual system input channels incorrectly for the selective attention models. Obviously, the peripheral receptors of the two modalities can be regarded as different. For example, the auditory receptors are most sensitive to a specific range of pressure fluctuations acting upon the hair cells in the cochlea and the adequate visual stimulus is a specific range of electromagnetic radiation acting upon the photosensitive cells of the retina. However, the selective attention models describe functions that are considered central in nature. There is no a priori reason to believe that, once stimulation from one modality has entered the association areas of the cortex, it is processed differently than stimulation from another modality. If this is the case, then it can be assumed that the models are applicable to all modalities. This means that any difficulty in applying the selective attention models to vision lies in the conceptualization of the visual input channels.

There are at least three possible visual analogues to auditory input channels (disregarding each modality itself as an input channel). One possible conceptualization of a visual input channel is each eye. The right and left eyes would each be considered an input channel. The results of attempts to formulate visual input channels this way (Sampson, 1964; Sampson & Horrocks, 1967; Sampson & Spong, 1961a, 1961b) demonstrate that it is very difficult, if at all, to obtain visual results that are similar to the findings from audition, using each eye as a separate channel.

A second possible conception is that each visual field (i.e., the right visual field and the left visual field) is an input channel. An anatomical analysis of the visual system shows that input from one visual field projects unilaterally to the cerebrum. However, there is no known interaction between the two eyes at any level more peripheral than the thalamic geni-

culates. Yet there is processing of the stimuli at the retinal
level. According to Uttal (1973), there is some processing of
stimulus information at the synaptic connections between the
photoreceptors and the bipolar cells, the bipolar cells and the
ganglion cells, and, probably, between the amacrine or horizontal
cells and the cells of their respective layers. The fact that
the input to the two eyes is processed separately prior to the
lateral geniculates means that one should be aware of the pos-
sible effects that this separate pregeniculate processing may
have on the results.

A third possible conception is that the separate input
channels are the hemiretinal fields. An anatomical analysis
shows that half of each eye is unilateral to the hemispheres.
Although the inputs to different eyes from a visual field do
project to the same hemisphere, there is separate processing
prior to the lateral geniculate nuclei. Typically, there is
preservation of an anatomical point-to-point correspondence
throughout the entire pathway (Geldard, 1972). This means that
the separate inputs to the visual field may project separately,
with no or little interaction, to the cortex. If this is true,
then it would support the conception of the hemiretinal fields
as separate input channels analogous to the ears. The research
of Jeeves and Dixon (1970) and Dimond (Dimond, 1970, 1971;
Dimond & Beaumont, 1971a, 1971b) demonstrate the use of this
notion. Unfortunately, these studies, in the opinion of this
writer, did not provide an adequate empirical study of the con-
sequences of this manner of modelling because of certain con-
founding attributes of the instrumentation used.

CHAPTER II

Dichoptic Viewing Apparatus

As noted in the preceding criticism of apparatus used in
the various studies, there are at least three major factors that
should be controlled in designing dichoptic viewing apparatus:
convergence, accommodation, and retinal disparity. If these
factors are controlled, then other minor difficulties (e.g.,
an allowance for interocular variation between subjects) are also
regulated. Convergence can be controlled by the simple expedient
of fixating a single fixation point with both eyes. This is what
is typically done in any vision research that requires a stationary
eye field.

Although discriminations of depth differences based on
accommodation are neither precise nor accurate over distances
greater than a meter or two (Graham, 1965), accommodation should
be regulated so that biasing effects of depth differences are
controlled and can be accounted for. The easiest method for
regulating accommodation is to ensure that all the stimuli are
equidistant from the retina. Most experimenters do attempt to
regulate accommodation. However, as was discussed with respect
to the apparatus used by Dimond (1970), difficulties arise if
all the stimuli are situated along a horizontal plane placed
in front of the eyes. The difficulty lies in the fact that,
as the visual angle between the fixation point and the stimuli
increases, so does the distance of the stimuli from the eye.
Thus, it is possible that a viewer would perceive a depth dif-
ference between the fixation point and stimuli that are x degrees
(where $x \neq 0$) from the fixation point.

The third factor to be regulated is retinal disparity.
When an observer looks at a scene, each eye does not see the
same configuration of objects within that scene. This variation

between the scene perceived by each eye is based on the fact
that the two eyes are situated in slightly different positions
with respect to the scene. Thus, each eye receives slightly
different images of the same external objects. This factor is
a major component of depth perception (Baird, 1970; Carr, 1935;
Graham, 1965; Helmholtz, 1962).

Corresponding Retinal Points

Corresponding points have been defined as "points on the
visual globes of the two eyes [that] are apparently in the same
position with respect to the point of fixation, so that they
coicide with each other in the common field of view" (Helmholtz,
1962, p.403). To illustrate (from Carr, 1935), an object is
placed in the median plane at a distance x. If this object is
fixated, it stimulates a small area in each retina. This area
is located in the same place in each eye, the fovea, and the
object is seen as single. All such pairs of areas are corre-
sponding retinal areas.   A second object is now placed at
a distance of x-y units in front of the eyes. The first object
(at distance x) is fixated and the second (at distance x-y) is
observed. The second object will be seen as double if the dis-
parity between it and the first is great enough, or, if the
disparity is not great, the object will be seen as single, but
as nearer or farther away than the first. The second object
stimulates an area in each retina, but, unlike the first, the
retinae are stimulated in different places. All such pairs
are known as noncorresponding or disparate retinal areas.

To be precise, any object is not seen as single or double
because it stimulates corresponding or disparate areas respectively.
Instead, the correspondence or disparity relation of the two
retinal areas involved is a postulate from the observable data:
an object is perceived as single when it occupies certain positions
with respect to the two eyes and is perceived as double when it

occupies certain other positions.

Horopter

The horopter is defined as the locus of all points in space falling on corresponding points in the two eyes, with a constant degree of convergence. All other locations are non-horopteric positions. One example of a horopter is the Vieth-Muller horopter circle (Figure 5). The Vieth-Muller horopter circle is a circle that passes through the fixation point and the first nodal points of each eye.

. . . .
Insert Figure 5 about here
. . . .

There are difficulties in determining the horopter empirically. For example, the stimulating object always has a certain size, and the two images often overlap in space: in indirect vision, it is difficult to distinguish between exact coincidence of the two images and the smaller degrees of doubling. There is a large amount of guess work involved in any statement of the positions at which the objects must be located in order to ensure exact correspondence. In addition, the two blind spots must be allowed for. If they are not allowed for, a single percept of the object may result although the object is not on the horopter.

Construction of a horopter (from Carr, 1935). If the eyes fixate a point (FP), lines drawn through FP to the fovea of each eye will be continuations of the visual axis of the eyes. If an object is placed in the horizontal plane of the binocular field and moved about, various phenomena can be observed. When the object is nearer than FP, it will be perceived as heteronymous double images (i.e., the image directed to the right eye is located on the left side of FP and the image directed to the left eye is located on the right). When the object is more distant than FP, the images will be homonymous double images

Figure 5.   The Vieth-Muller horopter circle.   Only if the points

P, Q, and R lie on a circle will their images fall on

corresponding points in the two retinae.   The proof

is given in Graham, 1965.
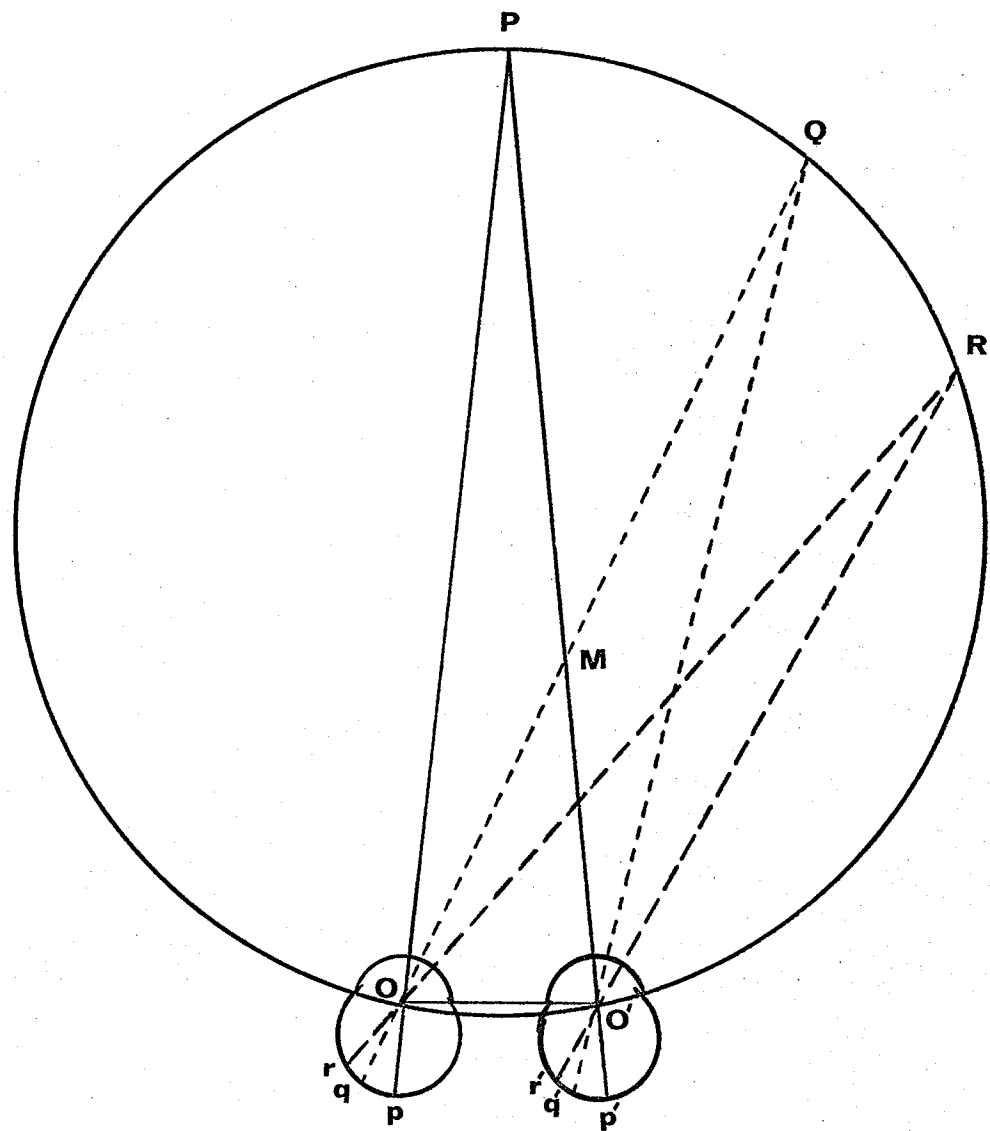
(i.e., the image to the right eye is on the right side of FP, and the image to the left eye is on the left). At a specific distance from the eyes, the object is perceived as single.

More generally, as a near object is moved away from the eyes, the heteronymous double images gradually approach each other. After acquiring spatial unity, they become homonymous double images. A line drawn through the series of locations that give a percept of spatial unity and FP will be an arc. The continuation of this arc theoretically will pass through the first nodal points of the eyes. The circle, formed thusly, is a horopter circle.

Once the horopter has been formed, the retinal positions of pairs of corresponding areas can be determined. A straight line is drawn from any position of the horopter through the first nodal point of each eye. The extensions of these two lines on their respective retinae fall upon a pair of corresponding points.

Dichoptic Viewing Apparatus Design

A stimulus source at any point on the circumference of a circle that passes through the first nodal points of the eyes, a horopter circle, will stimulate areas of the two retinae (Figure 6). Although the two stimulated retinal areas will be equidistant from the fovea of their respective eye, one area will be on the nasal side of one eye and the other area will be on the temporal side of the other eye. For example, a stimulus source, which is located x degrees to the right of the fixation point, will strike the left temporal and the right nasal hemiretinae. A second stimulus source, symmetrical to the first stimulus (i.e., x degrees to the left of the fixation point) on the circumference of the horopter circle, will stimulate the left nasal and the right temporal hemiretinae.

. . . .
Insert Figure 6 about here
. . . .

Figure 6.   Dichoptic apparatus schema.   The eyes are fixated on
            the fixation point.   Points B and C are stimulus sources,
            intersecting at X on the horopter circle, that stimulate
            corresponding points on the retinae.

Eyes

R

L

Arc L

Arc R

S

S

C

X

B

FP
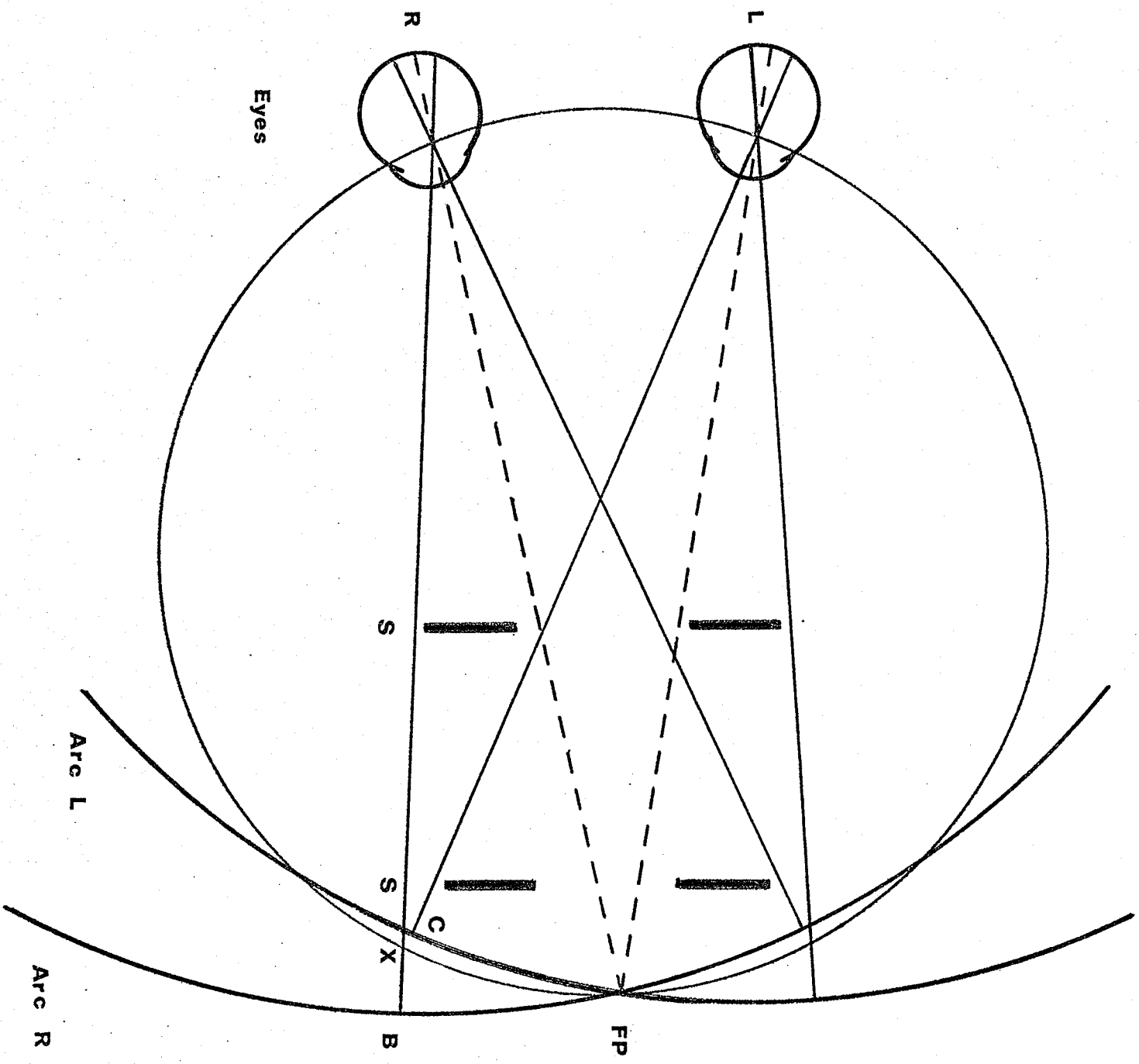
At this point the retinal locations of the stimuli are
regulated, but accommodation of the eyes is not. If point X,
on the horopter circle (Figure 6), is considered, it can be
noticed that the distance between point X and the left eye is
greater than the distance between point X and the right eye.
In addition, the distance between the fixation point (FP) and
the eyes is not equal to the distance between point X and the
eyes. To overcome these difficulties, one merely draws an arc
for each eye that passes through FP. The center of each arc
would be the first nodal point of the respective eye. To locate
the stimuli on the arcs, one continues the pathways from the
retinae to the stimulus sources on the horopter circle. The
sources for the left eye would be located at the intersection
of the pathways from that eye and the arc drawn from its nodal
point. Similarly, the source locations for the right eye would
be the intersections of the pathways from that eye and the arc
drawn from its nodal point. Screens are placed so that a source
directed at one hemiretina is prevented from stimulating another
hemiretina. Each source is now the same distance from its res-
pective hemiretina and each stimulates corresponding retinal
areas. Convergence is controlled by the viewer fixating the
fixation point.

In summary, a point X is a point on the horopter circle.
A stimulus source at this point would stimulate points R and L,
both of which are retinal points the same distance from the
fovea of their respective eyes (i.e., corresponding points).
However, the distance XL is greater than XR. Arc R and arc L
are drawn with their centers at the first nodal point of the
right and left eye respectively and with equal radii. If the
pathway XR is extended to point B on arc R and XL extended to
point C on arc L and stimulus sources placed at these points,
the sources will still stimulate points R and L, and the distances

from the sources will be the same (i.e., distance BR equals distance CL). Similarly, points can be found that stimulate the right temporal and left nasal hemiretinae and that are equi-distant from these points. Screens prevent a source projected to one hemiretina from stimulating another hemiretina.

This design for dichoptic viewing apparatus solves the problems of eye accommodation and locus of stimulation on the retina. It is suggested that this design has better control and more precision than typical apparatus in dichoptic viewing situations.

CHAPTER III

Experiment

Introduction

The review of the literature suggested that the most appro-
priate analogy to auditory input channels is the hemiretinal
fields. It also disclosed a paucity of apparatus that could sub-
stantiate the hemiretinae as input channels. As there is a lack
of good apparatus for dichoptic viewing using the hemiretinae, a
new design for dichoptic viewing apparatus is being suggested in
this study. The major purpose of this study, then, was to con-
struct and validate this apparatus with respect to the hemiretinal
fields as input channels.

In order to ensure that there are few biasing effects from
the experimental paradigm, a methodology used in auditory selective
attention (Appendix A) has been used. It was thought that semantic
content of the stimuli might possibly confound any discussion of
the findings and that more quantitative studies should be ini-
tiated. Thus, the methodology used was one that "aimed hopefully
towards establishing a quantitative basis for theory in [selective
attention]" (Moray, 1970b, p.1071).

It was hypothesized that subjects would be able to perceive
information directed to the hemiretinae. Furthermore, the subjects
would be able to discriminate between inputs directed to two hemi-
retinae simultaneously. The predicted order of results was, from
easiest to most difficult in discrimination between targets: (1)
the condition in which only one input was presented; (2) the
condition in which targets were presented simultaneously to both
hemiretinae, although subjects only respond to one channel;
(3) the condition in which targets were presented to only one
hemiretina (although signals were sent to two), to which the
subject was to respond; (4) the condition in which targets were
presented nonsimultaneously to both channels, although subjects

were to respond only to one channel; (5) the condition in which
subjects were to respond to only one channel although targets
were presented to either or both channels; and (6) the condition
in which responses were required to all targets, which occurred on
either or both channels. If these results were obtained, then it
could be assumed that this apparatus is feasible for more inten-
sive research on visual selective attention.

Method

Subjects. The subjects were two unpaid volunteers from
the undergraduate program at the University of Manitoba. One
subject was male, the other was female. Both were 19 years of
age. The male had normal vision (i.e., he did not require cor-
rective lenses). The vision of the female was corrected to
normal by corrective lenses.

Apparatus. The conceptualization of the apparatus has
been discussed in Chapter II. However, the pertinent factors
of the apparatus will be briefly summarized at this point. There
are two major difficulties with respect to construction of di-
choptic viewing apparatus. One, in order to overcome the dif-
ficulty of matching the placement of stimuli on the retina (i.e.,
to ensure that the stimuli stimulate the corresponding points
on the hemiretinae) the apparatus is designed using a Vieth-
Muller horopter circle. Any image lying on this circle will
fall on corresponding points on the two retinae (Carr, 1935;
Graham, 1965; Helmholtz, 1962).

Another major difficulty is that of accommodation: a
stimulus must be the same distance away from the eye as is the
fixation point and any other stimuli. If stimuli are placed
on arcs passing through the fixation point, measured from the
first nodal points for each eye, no matter where on the arc
they are, they would maintain a fixed distance from the eye.
To ensure that corresponding points are stimulated from stimuli

located equidistant from the eyes, the stimuli are located at
the intersection of the pathways that pass through a single
specific location on the horopter circle, and the arc drawn from
the first nodal point of the respective eye. Screens are placed
so that a stimulus source cannot stimulate other hemiretinae.
These ideas are incorporated schematically in Figure 6 (see
Chapter II).

Response buttons, situated on each side of the viewing
apparatus within easy reach of the subjects, were employed to
signal the perception by subjects of targets in the appropriate
channel. Since targets were presented, at most, on only two
channels at any one time, only two response buttons were neces-
sary. One response button each was required for the two channels.
To signal the presence of targets on both channels simultaneously,
it was necessary to depress both buttons at the same time.

The responses, targets, and nontargets were recorded on
an event recorder. The signal duration, target duration, and
interstimulus interval (ISI) were controlled by Hunter timers
(model 110-C). The experimenter controlled the onset of the
targets by a pushbutton switch. To eliminate distractions by
extraneous noise, white noise was played through earphones to
the subjects during the sessions.

Stimuli. The nontarget stimuli were bursts of light of
.10 microWatts/cm^2 as measured by a Hewlett-Packard radiant flux
meter (model 8330A). The targets were increments in intensity
over nontargets to .35 microWatts/cm^2. Both stimulus sources
were monochromatic red (approximately 650 millimicrons). Each
stimulus source subtended 1.43° of visual angle vertically and
.72° of visual angle horizontally at a distance of 20 inches
(50.8 cm.) from the eye. The intersection on the horopter circle
of the stimulus pathways from the same visual field was 13.61°
of visual angle from the fixation point. The fixation point

was a yellow dot that subtended .10° of visual angle.

Each burst of light was 100 msec. in duration with an
ISI of 400 msec. between bursts. The ambient irradiance was
.05 microWatts/cm^2. In all conditions, the onset and offset
of signals was synchronized for both channels.

Design. Runs of 500 signals per channel were presented
at a rate of two signals per channel per second. The conditions
of attention required were Single channel (S) mode, Select (St)
mode, Dedicated (D) mode, and Time-shared (TS) mode.

In S mode signals were sent to only one hemiretina at
any one time. No signals were presented to the other hemiretinae
at that time. Because there are four hemiretinae (two hemiretinae
per eye) in this condition, there were four different stimulus
presentations.

The St mode was subdivided into two subconditions: in
one, targets were presented to only one hemiretina (St1), although
nontarget signals were presented to two channels simultaneously.
In the other subconditions, targets were presented simultaneously
to both channels (St2). In either target presentation, the
subjects were required to attend to only one of the channels.
The experimenter informed the subjects at the beginning of a
session to which channel to attend. There were twelve (12)
different presentations for each of St1 and St2.

In D mode, similar to St mode, responses were required
for only one channel. D mode was also subdivided into two sub-
conditions. One, the targets never occurred simultaneously
even though they were presented to both channels (D1). Two,
one-half of the targets from both channels did occur simultaneously
while the other half of the targets from both channels occurred
nonsimultaneously (D2). In other words, 25 of the targets on a
channel occurred coinstantaneously with targets on the second
channel. The other 25 targets were nonsimultaneous with targets

on the second channel. In both D1 and D2 modes there were twelve (12) different presentations.

Time-shared mode was the condition in which sets of signals were sent to each channel with targets occurring on either channel of simultaneously on both channels. Responses were required whenever a target occurred. That is, if targets occurred singly on either channel or simultaneously on both, a response was required. Both channels were to be considered as equally important. The number of completely different stimulus presentations was six.

Ten percent of the signals on each channel were targets. This means that there were 50 targets per channel of 500 signals. The targets were randomly located in the signal stream, except that no targets were able to occur sooner than the third signal after the last ipsilateral or contralateral target. The duration between the onset of a signal and the onset of the third signal following was called a window, which allowed time for a subject to respond. In the D2 and TS modes, half of the targets occurred simultaneously, so that there were 25 single targets on one channel, 25 single targets on the other channel, and 25 simultaneous targets per run.

Procedure. The data collection occurred in one to two hour sessions. There was a five minute break after every block of 500 trials, each of which took approximately five minutes to run. Approximately six blocks of trials were run in an hour. The first two blocks in a session were considered warmup trials and were not included in the results.

Before data collection of a condition began, however, subjects were practiced to asymptote. The subjects were judged to have reached asymptote when their measure of sensitivity ($\underline{d}'$) between targets and nontargets was constant over two blocks of trials. It was found that to reach asymptote required between

10 to 15 hours of practice per condition. During the practice
sessions, subjects were exposed to all stimuli presentations
within the condition equally and randomly. This ensured that
the subjects were not overpracticed on one type of stimulus
presentation and unexposed to other possible presentations within
the condition. The results from the practice sessions were not
included in the final computations. In both the practice sessions
and the data collection sessions, the subjects were told to detect
(and respond to) as many of the targets as possible. At the
same time, they were to attempt to not respond to nontargets.
It was thought that these instructions would maximize the hit
rate (correct responses to a target) and minimize the false
alarms (responses to nontargets).

Scoring methodology. After a target occurred on a channel
(or two targets simultaneously on both channels) no targets were
able to occur sooner than the third signal following. This
interval (the minimum target spacing), in which no more than
one target (or set of simultaneous targets) could occur, was
called a window (Figure 7). A response anytime within a window
counted as a hit, provided the response was ipsilateral with
the target. A contralateral response within the window counted
as a false alarm for the contralateral channel and a miss for
the ipsilateral channel. Except for the simultaneous targets
in D2 and TS modes, if two responses occurred within a window,
the ipsilateral response counted as a hit and the contralateral
one as a false alarm. If no response occurred in a window con-
taining a target, a miss was recorded for the ipsilateral chan-
nel. Correct rejections were recorded for those windows that
contained no targets and that received no response.

. . . .
Insert Figure 7 about here
. . . .

The method of analysis that was used is called Contralateral

Figure 7.   Interaction mode of presentation and scoring criterion.
            D is the signal duration (100 msec.), ISI is the inter-
            stimulus interval (400 msec.), I the target increment,
            and W the window for scoring. A response inside this
            window on the appropriate channel counts as a hit.
            B is a BOTH signal, X is a Disjoint signal (from
            Moray, 1970b).
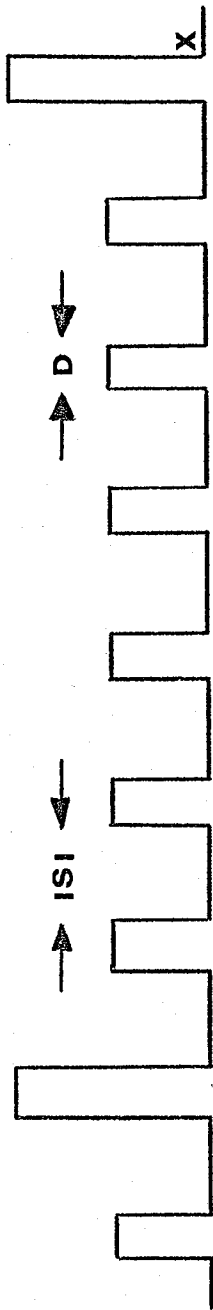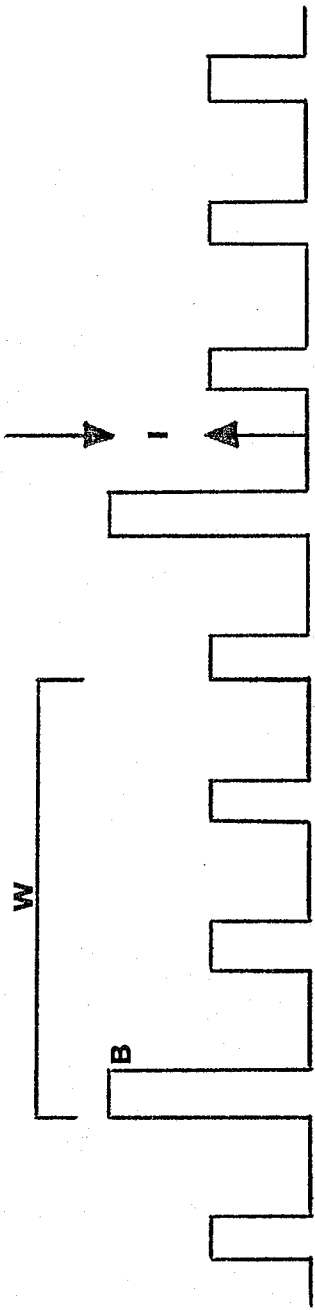
Contingent Event Analysis (CCEA). The language and conceptualizations are those of the Theory of Signal Detectability. CCEA is a method of investigating the responses of a subject to a particular stimulus with reference to an occurrence on a secondary channel (Appendix B).

Results and Discussion

There are three questions that can be asked relevant to the results of this study. One, could subjects differentiate signals stimulating different hemiretinae? Two, if signals could be differentiated using the hemiretinal fields, do the results demonstrate that the hemiretinae are an appropriate analogue to auditory input channels (i.e., do the hemiretinae give results that are similar to results obtained using the ears as separate input channels)? Three, is the apparatus employed in this experiment an appropriate apparatus for investigating the hemiretinae as stimulus input channels in vision?

If the results obtained from the hemiretinae are not similar to those from the ears, it may not mean that the apparatus is not appropriate. It may merely mean that the hemiretinae are not an appropriate analogue to the auditory input channels. However, if the experimental findings using the hemiretinal fields as input channels do show results similar to those obtained using the ears as separate input channels, these findings would support the contention that this apparatus is an appropriate apparatus for investigating the hemiretinae.

The most common finding in studies investigating selective attention in audition (Moray, Fitter, Ostry, Favreau, & Nagy, 1975; Moray & O'Brien, 1967; Sorkin, Pohlmann, & Gilliom, 1973; Treisman & Geffen, 1965) has been that selective attention affects discrimination sensitivity ($\underline{d}'$) systematically so as to favor selected messages over rejected messages, and favoring single or dedicated attention over time-shared attention. This appears also to be the case in this study. Figure 8 shows the overall

results of this experiment (note that the smaller the d' value,
the more difficult it was to discriminate between targets and
nontargets).

. . . .
Insert Figure 8 about here
. . . .

Single channel mode was run in an attempt to answer question
1 (i.e., can subjects differentiate signals stimulating different
hemiretinae?). The literature (see Chapter I) supports the notion
that the hemiretinae can differentially respond to stimulation.
In this case, the large d' values (perfect detection of targets
was set at an arbitrary value of 10.0) depicted in Figure 8 sug-
gest that neither subject had much difficulty in detecting the
targets. These data, then, merely support previous research and
do not demonstrate that this apparatus is any better than appar-
atus, previously used by other researchers investigating the
hemiretinae.

A better evaluation of the appropriateness of the apparatus
employed in this experiment may be obtained by a comparison of
the other conditions in the experiment with the similar conditions
in auditory research. Moray et al. (1975) have discovered an
elaborate fine structure fo auditory attention. When attention
is divided between two messages, the detection of a target in
one message falls only at those moments when a hit or a false
alarm is given to the second message. At those moments when a
correct rejection is made on the second message, performance is
indistinguishable from Single channel mode. Specific to the
order of results, their results show that Single channel mode
would be the easiest for subjects to discriminate between targets
and nontargets, Dedicated mode, and then Time-shared mode.

In this experiment, in Select mode there are two subcon-
ditions: (1) targets were presented to only one channel with
responses required of that channel alone (St1), and (2) targets

Figure 8. Mean $\underline{d}$' values for each subject for each presentation
mode. Subject 1 is labelled 1 and subject 2 is labelled
2 in each mode. S is Single channel mode, St1 is
Select 1 mode, St2, Select 2 mode, D1, Dedicated 1
mode, and TS, Time-shared mode.

Mean d̄'

7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0

7.770 6.306 5.547 3.781 6.088 4.474 4.886 3.745 3.842 3.375

1   2   1   2   1   2   1   2   1   2
  S   St1   St2   D1   TS
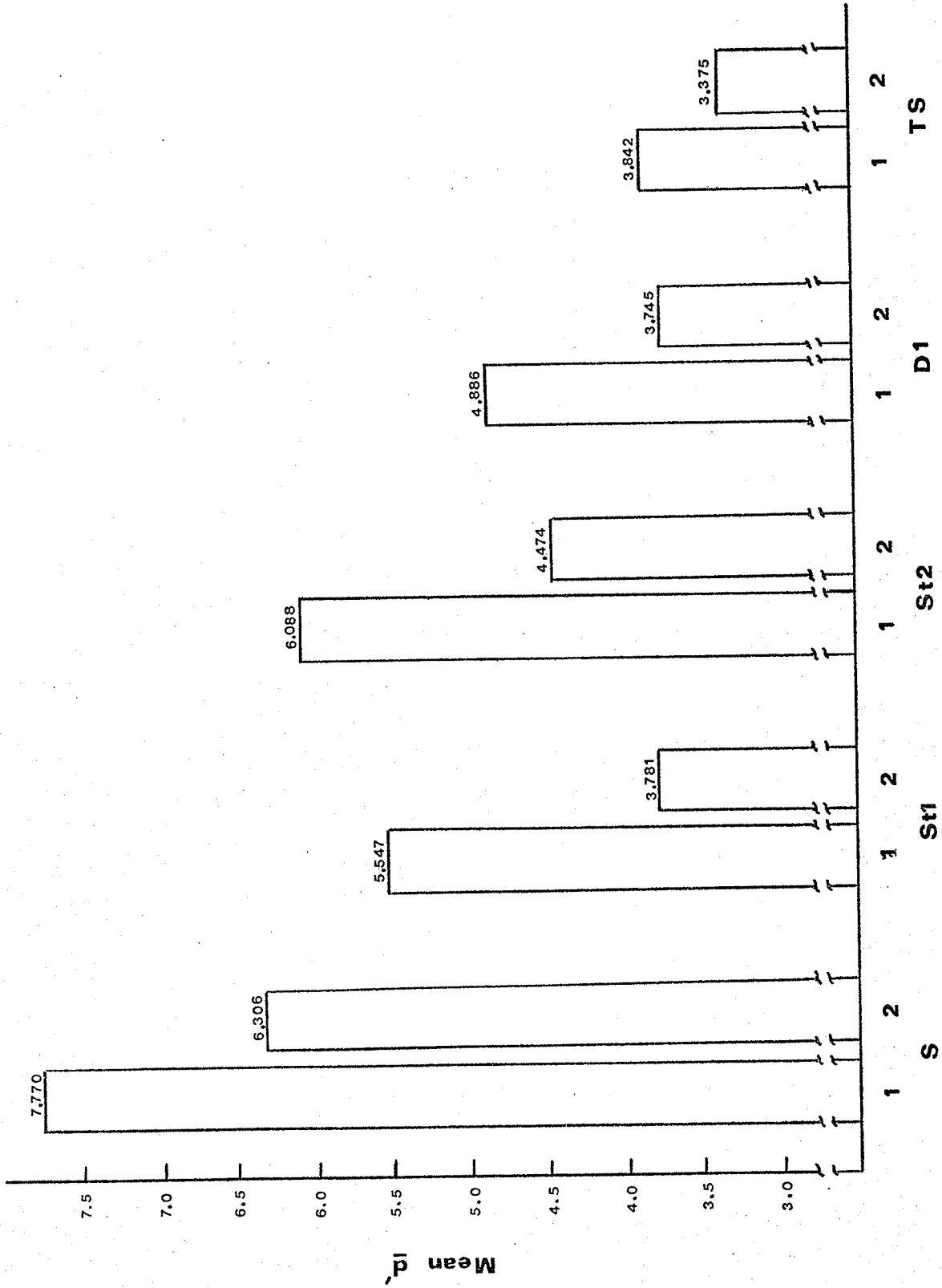
Mode of Presentation

were presented to both channels simultaneously, no nonsimultaneous
targets occurring, with responses required only to one channel,
of which the subject was informed before the session began (St2).
Each subject appears to have had less difficulty with St2 mode
than with St1 mode in discriminating targets (Figure 8). That is,
the results show that the St2 mode presentation seemed to be a
superior condition than the St1 mode presentation. Target de-
tection was better ($\underline{d}$' was higher) in the St2 mode than in the
St1 mode. This result was to be expected. Simultaneous targets
allow the subject to switch his attention between channels without
losing any information about the presence or absence of a target.
If targets are presented to only one channel and if subjects do
switch channels without instructions or necessity to do so, then
target information can be lost when the subject is attending to
the rejected channel and a target occurs on the accepted channel.
Subjects do sometimes attend to the rejected channel (Moray, 1970a;
Treisman, 1964).

In Dedicated mode there are again two subconditions: (1)
targets were presented nonsimultaneously to both channels with
no targets occurring simultaneously (D1), and (2) one-half of
the targets on both channels occurred nonsimultaneously with
targets on the other channel and the other one-half of the targets
on both channels occurred simultaneously (D2). In both subcon-
ditions, the subjects were informed as to which channel to attend.
Figure 8 shows the relationship of the D1 $\underline{d}$' values to the other
modes of presentation. It is apparent that each subject had
more difficulty (a lower $\underline{d}$' value) in discriminating between
targets and nontargets in this condition than in the two Select
modes and Single channel mode. D2 mode results will be discussed
later.

The data depicted in Figure 8 for the Time-shared mode
are from the marginal totals of the contingency event matrix

(discussed later). The data demonstrate an increase in discrimin-
ation difficulty between targets and nontargets relative to the
Single channel mode, the two Select modes and Dedicated 1 mode.

 Thus far, the order of difficulty for the different con-
ditions agrees with the order of results obtained by Moray et
al. (1975). However, Moray has also suggested a pattern of re-
sults obtainable when a response on one channel is paired with
a contingent event on the second channel. Detection of a target
on one channel is more difficult when a target (actual or imagined)
is perceived on the other channel.

 The Dedicated 2 mode data can be tabled as to whether a
target (T) or no target (NT) was present on the rejected channel
when a particular response (i.e., hit, miss, false alarm, or
correct rejection) was made on the accepted channel (Table 2).
In all cases, the situation in which there was a target on the
contralateral channel (X/T) had a lower d' value than the situ-
ation in which there was no target on the contralateral channel
(X/NT). Because d'/T is always lower than d'/NT, it is suggested
that discrimination of targets is more difficult for the sub-
jects when a target is present on the contralateral channel.

<p align="center">. . . . .
Insert Table 2 about here
. . . .</p>

 The Time-shared mode results can also be tabled as to
the response of the subjects to the contralateral channel (Table
3). It can be noted that, whenever a target was detected (and
responded to) on the contralateral channel, there was more dif-
ficulty in detecting a target on the ipsilateral channel than
if no target was detected on the contralateral channel. In

Subject 1				Subject 2		
	Channels				**Channels**	
	LT	RN			LT	RN
X/T	1.985	2.400		X/T	1.985	2.580
X/NT	7.600	4.570		X/NT	5.360	6.175
	LT	RT			LT	RT
X/T	6.175	6.750		X/T	2.745	5.842
X/NT	7.350	7.195		X/NT	3.525	7.820
	RN	LN			RN	LN
X/T	2.810	2.580		X/T	2.350	2.227
X/NT	3.780	3.025		X/NT	3.157	2.555
	RN	RT			RN	RT
X/T	2.112	6.750		X/T	2.112	2.925
X/NT	3.740	7.820		X/NT	3.297	2.247
	RT	LN			RT	LN
X/T	2.745	2.112		X/T	1.549	2.330
X/NT	4.200	7.820		X/NT	5.995	5.580
	LT	LN			LT	LN
X/T	2.580	2.170		X/T	2.017	2.925
X/NT	6.870	3.600		X/NT	2.705	3.815

Note. Maximum d' value = 10.0.

Table 2. D2 mode d' values. One-half of the targets occurred simultaneously on both channels.

addition, if the subject missed a target on the contralateral
channel, he had less difficulty in detecting an ipsilateral
target than if he had correctly judged that no contralateral
target was present. A comparison between mean d'/C (Table 4)
and the d' value for Single channel mode (Figure 8) shows little
difference. Comparing the combined mean of d'/H and d'/F against
d'/C (Table 4) shows that, again, the difference in detection of
targets is towards more difficulty if a target is present on the
ipsilateral channel. When performance was contingent on a contra-
lateral miss, d'/M, it can be observed that, generally, the de-
tection of the targets is better than in any other situation in
TS mode.

$$\bullet \bullet$$
Insert Tables 3 & 4 about here
$$\bullet \bullet$$

To recapitulate, whenever a target is responded to, whether
actually present or merely believed to be present, on the second
message, subjects appear to have more difficulty in detecting a
target on the first message. If, however, a correct rejection
is made on the second message, performance is indistinguishable
from Single channel mode. These results agree closely with the
results of Moray et al. (1975).

This study, in the opinion of the author, has shown that
the apparatus employed in this experiment is useful for dichoptic
viewing tasks. Subjects can differentiate between stimuli pre-
sented to different hemiretinae. In addition, presentation of
stimuli to different hemiretinae appears to produce results similar
to those obtained in dichotic presentations, especially to those
obtained in the studies by Moray (1970a), Moray et al. (1975),
and Sorkin, Pohlmann, and Gilliom (1973). This finding supports
the opinion that the hemiretinal fields are analogous to the
ears as separate input channels and enhances the suitability
of this apparatus. The apparatus ensures a precise placement of

Contralateral Contingencies

Subject 1

Channel		H	F	M	C
1	RN	1.849	5.000	10.000	10.000
2	RT	6.751	2.453	10.000	10.000
1	LN	1.594	1.629	10.000	10.000
2	RT	2.301	10.000	10.000	6.175
1	RN	2.651	10.000	5.675	6.695
2	LN	2.499	1.342	10.000	6.103
1	LT	6.150	10.000	10.000	10.000
2	RT	6.200	4.747	10.000	6.695
1	LT	1.586	10.000	10.000	10.000
2	RN	1.981	5.675	10.000	10.000
1	LT	2.986	10.000	10.000	10.000
2	LN	2.356	6.372	10.000	6.341

Contralateral Contingencies

Subject 2

Channel		H	F	M	C
1	RN	1.737	10.000	5.975	5.426
2	RT	2.549	5.426	10.000	5.706
1	LN	1.114	10.000	6.058	5.675
2	RT	2.123	10.000	5.842	5.202
1	RN	2.047	10.000	10.000	5.675
2	LN	1.878	10.000	10.000	5.306
1	LT	2.557	10.000	10.000	6.175
2	RT	5.568	5.675	10.000	10.000
1	LT	1.421	5.000	5.974	5.306
2	RN	2.104	10.000	3.377	5.598
1	LT	2.088	1.101	1.268	5.228
2	LN	2.278	.852	2.123	5.915

Note. Maximum d' value = 10.0.

Table 3. TS contingent event matrix. In TS mode whether a signal is on channel 1 or channel 2 is arbitrary. Responses are required to targets on both channels.

	Contralateral Contingencies			
	H	F	M	C
Subject 1				
	3.242	6.435	9.640	8.501
	4.839[a]			
Subject 2				
	2.289	7.338	6.718	5.935
	4.814[a]			

[a]The combined mean of the hits and false alarms.

Table 4. The mean $\underline{d}$'values from TS mode. For comparison,
the combined mean $\underline{d}$'value of hits and false alarms
is included.

visual stimuli. There is control, not only of the distance from
the eye that the stimuli are (thus regulating accommodation), but
also of the location on the retina that is stimulated (i.e., on
corresponding points controlling retinal disparity). It is sug-
gested that the regulation of this depth information (accommodation
and retinal disparity) restricts outside influences that may
affect the response made by a subject.

CHAPTER IV

Overview

There are a number of theories of selective attention.
All of these theories are based on findings from experiments
on audition, which involved the conceptualization that the ears
were separate input channels. The usefulness of this formulation
is supported in the literature of selective attention in audition
(e.g., Broadbent, 1958; Cherry, 1953; Moray, 1970a).

Although the supporters of the various models of selective
attention imply that the models are applicable to findings from
vision research in selective attention,   difficulties have
arisen when experimenters attempted to apply the models to
vision research data. If the assumption that the auditory models
are applicable to vision is valid, the difficulties must lie in
the appropriateness of the analogues between vision and audition.

A review of the literature suggests that the most appro-
priate analogy to auditory input channels is the hemiretinal.
But there is a lack of good apparatus suitable for examining
the hemiretinal fields as input channels. The major purpose
of this thesis is to conceive, design, and evaluate a new ap-
paratus for dichoptic viewing, especially with respect to an
appropriate analogue with auditory input channels.

Illustrative data obtained in a preliminary experiment,
employing the apparatus, demonstrates a close agreement with
results obtained in studies in auditory selective attention
utilizing a similar experimental methodology (Moray, 1970a,
1970b; Moray et al., 1975). For example, the order from easiest
to most difficult for target detection that Moray (1970a, 1970b)
and Moray et al. (1975) obtained for their conditions was Single
channel mode, Select mode, Dedicated mode, and Time-shared mode.
The obtained order in this study was the same (Single channel
mode, Select 2 mode, Select 1 mode, Dedicated 1 mode, and Time-

shared marginal mode). Furthermore, it was found that discrimination sensitivity was systematically affected by a contingent event on the contralateral channel, similar to the findings of auditory selective attention. That is, when attention was divided between two messages, the detection of a target by a subject was better (larger d' value) at those moments when a hit or a false alarm was not given to the contralateral channel.

These data are interpreted as providing support for the notion that the apparatus employed in the experiment is an appropriate means of evaluating the hemiretinae as separate input channels. The fact that the results of the experiment approximate those obtained in audition lend support to the contention that the hemiretinae are an appropriate analogue to the ears as input channels. However, more rigorous experimentation is necessary to substantiate this view.

Suggestions for Research

There are a number of directions one could go on the basis of this research. For instance, if the hemiretinal fields are substantiated as appropriate analogues to the ears as input channels, crossmodal and intersensory research could be initiated. This type of research would assist in the evaluation of the degree of dependence between sensory systems; that is, are different modalities completely independent of each other, completely dependent, or merely partially dependent? Each idea involves a different conceptualization of the mechanisms of perception.

A second suggestion is depth perception research. The concept of the horopter has been a valuable tool in the understanding of retinal disparity (Baird, 1970; Carr, 1935; Graham, 1965; Helmholtz, 1962). But the traditional horopter has not regulated accommodation effects. In addition, when accommodation has been investigated, the concept of the horopter has not been utilized. This means that disparity could have been confounding

the data. This apparatus regulates both factors (plus convergence because the eyes are fixated on the fixation point). Thus, one factor can be varied independently of the other.

A third proposal for research involves a discrepancy between theory and the real world that has been discovered by the use of the apparatus. Part of the concept of the horopter is that stimuli directed to corresponding points on the retinae should elicit a percept of a single image or object (Carr, 1935; Helmholtz, 1962). This was not the case in this study when stimuli were directed to the same hemisphere (e.g., the right nasal and left temporal hemiretinae were stimulated simultaneously), although the stimuli were supposedly directed to corresponding points. Subjects were able to detect targets in this situation. Experimentation on this point may result in a reformulation of the concept of the horopter.

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APPENDIX A

APPENDIX A

Experimental Methodology

One difficulty in analyzing data from selective attention
experiments is that typically the stimuli have semantic content
(e.g., Broadbent, 1958; Cherry, 1953; Moray, 1970; Taylor &
Moray, 1960; Treisman, 1960; Treisman & Geffen, 1967). When
analyzing such data, it is difficult to tell whether the obtained
effects are a result of a peripheral analysis (e.g., at a switch,
preprocessor, attentuator, or capacity allocator) or higher level
semantic analysis in the cortex. Nevertheless, this research
has led to plausible qualitative generalizations. However, little
quantitative theory has emerged (Moray, 1970b). Furthermore, it
is difficult to know whether the visual system reads the language
the same as the auditory system hears it. Since it is not known
how similar the two modalities process language, the best way to
begin might be a quantitative study of selective attention at a
non-semantic level.

Recent experiments in auditory selective attention have
used tone bursts as signals (Moray, 1970; Moray, Fitter, Ostry,
Favreau, & Nagy, 1975; Sorkin, Pohlmann, & Gilliom, 1973).
Typically tone bursts of different frequencies are delivered to
separate ears. The task of the subject is to discriminate be-
tween nontargets and targets. The targets were the same as the
nontargets with the exception of a slight change in one char-
acteristic (e.g., a change in intensity, duration, or even frequency).

In Moray's experiments (1970a, 1970b) there were four
conditions of presentation: single mode, in which only one ear
was used, the other being silent throughout; select mode, in
which both ears received tone bursts, but the listeners were
to ignore one ear completely and respond only to the other;
XOR mode, in which both ears received tone bursts to which the

the listeners were to respond, but targets never occurred simul-
taneously; and IOR mode, in which targets could occur either on
the left ear, on the right ear, neither, or simultaneously on
both. In addition, Moray included a control condition using
IOR presentation mode. In this condition the listeners were
to ignore the single targets and were to respond only to the
simultaneous pairs (a logical AND presentation).

A strange fact is that, although the various models developed
to account for selective attention data purport to explain simul-
taneous targets (Broadbent, 1958; Kahneman, 1973; Treisman, 1960),
they have not investigated the logical AND mode of presentation.
"Most of the experiments have been either Select Mode...or, more
rarely, XOR [Mode] (Treisman and Geffen, 1967, for example)"
(Moray, 1970a, p.185). Moray's (1970a, 1970b) results demonstrate
that the detection of AND presentations depends upon the differences
between targets and nontargets. For example, targets with a large
increment in intensity were more detectable than targets with a
smaller increment in intensity. The AND signals were better
detected as the difference between targets and nontargets increased.
The general order of results from best detection level to poorest
was select, single, XOR, IOR, and the control condition (i.e.,
the logical AND).

Chattaway

A P P E N D I X B

APPENDIX B

Contralateral Contingent Event Analysis

Contralateral Contingent Event Analysis (CCEA) as adapted
by Moray, Fitter, Ostry, Favreau, and Nagy (1975), is a method
of using the Theory of Signal Detectability for quantitatively
analyzing experiments where a human's information processing
ability is divided with a view to discovering whether or not
messages can be processed independently.

If a stream of events are presented to a perceiver, some
of which are targets to which he should respond "yes", and others
nontargets to which he should respond "no", the stimulus-response
stream then consists of four classes of events: Hits (H), Misses
(M), False alarms (F), and Correct rejections (C). When the
frequencies of occurrence of these classes of events are converted
to probability values, one can calculate the values for $\underline{d}'$ and β
associated with those events.

Considering a Time-shared situation in which two messages
are presented and the perceiver is required to respond to both
messages, detecting targets in each, one could make the a priori
assumption that if the messages are independently processed one
could proceed as for a single channel case (Moray & O'Brien,
1967; Treisman & Geffen, 1967). However, this a priori assumption
of independent processing is unlikely to be warranted (Moray et al.,
1975). Each kind of stimulus-response pair for channel 1 can be
paired with four kinds of events on channel 2 and vice versa:
H1/H2 (the number of hits occurring on channel 1 at moments when
a hit is also made on channel 2), H1/F2 (the number of hits
occurring on channel 1 at moments when a false alarm is made on
channel 2), H1/M2 (the number of hits occurring on channel 1 at
moments when a miss is made on channel 2), and H1/C2 (the number
of hits occurring on channel 1 at moments when a correct rejection

is made on channel 2). Tables B.1, B.2, and B.3 summarize the

events that comprise the set of experiments required to inves-

tigate exhaustively the phenomena for Single channel mode, Dedicated

mode, and Time-shared mode.

. . . .
Insert Tables B.1, B.2, and B.3 about here
. . . .

Single channel (S) mode is the condition in which only

one message is presented to the perceiver. Dedicated (D) mode

is the condition in which two messages are presented but only

one is to be processed, the other being rejected. Time-shared

(TS) mode is the condition in which two messages are presented

and both must be processed. The matrices for S and D modes are

self evident from the point of view of how to calculate the

relevant statistics. In S mode (Table B.1) hit probability is

given by the contents of cell 1 divided by the contents of cell

1 and cell 3 (1/[1+3]) and false alarm probability is given by

2/(2+4). In D mode (Table B.2), there are two hit probabilities,

dependent upon whether there was or was not a target on the re-

jected message at the moment that the data were collected. These

are given by 2/(2+6) and 4/(4+8) and false alarm probabilities

are given by 1/(1+5) and 3/(3+7). In the case of TS mode (Table

B.3) there are four conditions under which a hit can be made in

a channel. For example, if the cells were numbered as in the

table, one would have:

     1. $\underline{d}$' channel 1/H2....p(H)=1/(1+9), p(F)=5/(5+13)

     2. $\underline{d}$' channel 1/F2....p(H)=2/(2+10), p(F)=6/(6+14)

     3. $\underline{d}$' channel 2/H1....p(H)=1/(1+3), p(F)=2/(2+4)

     4. $\underline{d}$' channel 2/F1....p(H)=5/(5+7), p(F)=6/(6+8).

The extension of such calculations for the remaining cases is

evident and will not be made explicit here.

This method allows a fairly fine grain analysis due to

the ability of TSD measures to distinguish sensitivity from

Table B.1. Single channel mode input/output matrix. T means
that the input was a target and NT that the input
was no target (from Moray et al., 1975).

Input

	T	NT
Yes	1	2
No	3	4

Output

Table B.2. Dedicated mode contingency matrix. NT/NT means that

there were no targets presented at that time an either

channel, T/NT that the accepted channel had a target

but there was no target on the rejected channel, NT/T

that the accepted channel had no target at the same

time that the rejected channel had a target, and T/T

that both channels had targets simultaneously (from

Moray et al., 1975).

Input

	NT/NT	T/NT	NT/T	T/T
Output Yes	1	2	3	4
No	5	6	7	8

Table B.3.   CCEA matrix for time-shared mode.   This is not an
             input/output matrix but a contingent event matrix.
             H is hits, F, false alarms, M, misses, and C, correct
             rejections (from Moray et al., 1975).

Channel 2

	H	F	M	C
H	1	2	3	4
F	5	6	7	8
M	9	10	11	12
C	13	14	15	16

Channel 1

response bias. Because of this the sequences on the two channels
need not be statistically independent if one wished to determine
whether the two messages are processed independently (Moray et
al., 1975).

A P P E N D I X   C

APPENDIX C

     The following are data tables for sensitivity ($\underline{d}'$) values
for discrimination between targets and nontargets. The maximum
value allowed was 10.0, set arbitrarily. This value represents
perfect discrimination of the targets. The lower the $\underline{d}'$ value,
the more difficult it was for the subjects to discriminate be-
tween targets and nontargets. For a description of how these
values were obtained from the responses of the subjects, refer
to Appendix B.

Subject	Channel			
	RN	LT	RT	LN
1	6.896	7.250	8.878	8.054
2	6.751	5.399	6.425	6.647

Table C.1. Single channel mode $\underline{d}'$ values.

Nontarget	Target Channel			
Channel	RN	RT	LN	LT
Subject 1				
RN	---	4.209	10.000	3.365
RT	3.570	---	7.652	2.400
LN	3.245	4.524	---	2.727
LT	7.218	7.652	10.000	---
Subject 2				
RN	---	6.750	3.237	3.177
RT	3.135	---	2.855	5.257
LN	3.827	3.237	---	3.462
LT	2.520	3.755	4.163	---

Note.   Maximum $\underline{d}'$ value is 10.000.

Table C.2.   Select 1 mode input/output matrix.   RN is the right nasal hemiretina, RT, the right temporal, LN, the left nasal, and LT, the left temporal hemiretina.

Nontarget	Target Channel			
Channel	RN	RT	LN	LT
Subject 1				
RN	---	7.470	6.555	6.834
RT	4.628	---	7.155	7.652
LN	6.285	4.118	---	4.706
LT	7.218	4.025	6.405	---
Subject 2				
RN	---	4.932	3.873	4.053
RT	3.732	---	3.732	6.405
LN	6.555	3.080	---	3.873
LT	5.708	4.163	3.568	---

Table C.3. Select 2 mode input/output matrix.

Nontarget	Target Channel			
Channel	RN	RT	LN	LT
Subject 1				
RN	---	4.615	3.630	7.635
RT	3.825	---	4.615	7.310
LN	3.740	3.415	---	6.955
LT	4.615	4.240	4.040	---
Subject 2				
RN	---	3.215	2.850	3.015
RT	5.470	---	1.210	3.565
LN	3.200	5.470	---	2.745
LT	3.100	7.865	3.230	---

Table C.4.   Dedicated 1 mode input/output matrix.

Channel 1	Channel 2			
	RN	RT	LN	LT
Subject 1				
RN	---	4.225	3.450	3.140
RT	3.040	---	3.850	7.100
LN	3.420	3.300	---	3.610
LT	3.630	3.970	3.370	---
Subject 2				
RN	---	3.395	2.515	2.780
RT	3.060	---	2.990	3.370
LN	3.220	3.380	---	2.580
LT	6.120	4.140	2.925	---

Table C.5.   Input/output matrix for the Time-shared mode marginal totals.

A P P E N D I X   D

APPENDIX D

The following are data tables for response bias values
for discrimination between targets and nontargets. These values
represent the decision criterion of the subjects for a particular
condition. These values were obtained in the same manner as were
those in Appendix C (i.e., see Appendix B).

Subject	Channel			
	RN	LT	RT	LN
1	.133	5.873	.286	26.889
2	4.628	32.737	25.093	20.619

Table D.1. Single channel mode. RN is right nasal
hemiretina, LT, left temporal, RT, right temporal,
and LN, left nasal hemiretina.

Nontarget	Target Channel			
Channel	RN	RT	LN	LT
Subject 1				
RN	----	1.237	1.000	35.810
RT	28.102	----	.000	5.793
LN	15.643	2.562	----	15.476
LT	.000	.000	1.000	----
Subject 2				
RN	----	2.2×10^4	58.889	16.452
RT	60.842	----	32.979	9.7×10^4
LN	16.881	58.956	----	53.026
LT	21.097	9.252	27.542	----

Table D.2.   Select 1 mode input/output matrix.

Nontarget	Target Channel			
Channel	RN	RT	LN	LT
Subject 1				
RN	----	.000	$3.0x10^4$	.000
RT	13.600	----	.000	.000
LN	$4.4x10^4$	3.570	----	4.084
LT	.000	6.306	$3.7x10^4$	----
Subject 2				
RN	----	7.628	38.332	37.532
RT	18.789	----	18.789	$3.7x10^4$
LN	$2.9x10^4$	61.602	----	38.332
LT	$7.8x10^4$	27.542	22.120	----

Table D.3.   Select 2 mode input/output matrix.

Nontarget	Target Channel			
Channel	RN	RT	LN	LT
Subject 1				
RN	----	13.103	19.619	.000
RT	1.862	----	13.103	.000
LN	1.567	6.163	----	.000
LT	13.103	4.801	30.380	----
Subject 2				
RN	----	27.203	20.804	59.817
RT	9.0×10^4	----	7.8×10^4	8.720
LN	17.252	8.9×10^4	----	21.487
LT	13.517	.001	12.221	----

Table D.4. Dedicated 1 mode input/output matrix.

Channel 1	Channel 2			
	RN	RT	LN	LT
Subject 1				
RN	----	4.625	9.257	7.699
RT	2.012	----	1.967	.000
LN	1.670	3.281	----	1.220
LT	4.350	2.542	7.508	----
Subject 2				
RN	----	14.006	9.558	15.250
RT	18.022	----	8.739	7.682
LN	7.130	50.433	----	17.017
LT	8.261	25.256	7.582	----

Table D.5. Input/output matrix for the time-shared marginal totals.

Subject 1				Subject 2		
	Channels				**Channels**	
	RN	RT			RN	RT
X/T	.477	8.6×10^3		X/T	2.096	2.318
X/NT	1.566	.001		X/NT	47.559	1.888
	RT	LN			RT	LN
X/T	.355	.466		X/T	.901	2.538
X/NT	4.359	.001		X/NT	2.4×10^4	2.2×10^4
	LT	LN			LT	LN
X/T	.144	.822		X/T	1.404	.432
X/NT	.000	4.142		X/NT	19.505	32.427
	LT	RN			LT	RN
X/T	2.268	.611		X/T	2.268	1.345
X/NT	.001	11.507		X/NT	3.7×10^4	2.0×10^4
	LT	RT			LT	RT
X/T	.000	.000		X/T	2.818	2.8×10^4
X/NT	.000	.000		X/NT	7.937	.001
	RN	LN			RN	LN
X/T	1.000	1.345		X/T	1.000	4.133
X/NT	1.699	4.787		X/NT	15.739	10.415

Table D.6. Dedicated 2 mode response bias values calculated using CCEA (see Appendix B).

Channel	Contralateral Contingencies			
	H	F	M	C
Subject 1				
1 RN	.490	4.0×10^4	1.000	1.000
2 RT	.000	1.000	1.000	1.000
1 LN	.591	1.256	1.000	1.000
2 RT	1.058	1.000	1.000	1.000
1 RN	.961	1.000	.000	9.5×10^3
2 LN	1.359	1.388	1.000	2.2×10^4
1 LT	.000	1.000	1.000	1.000
2 RT	.000	.000	1.000	9.5×10^3
1 LT	1.908	1.000	1.000	1.000
2 RN	.800	3.2×10^4	1.000	1.000
1 LT	.635	1.000	1.000	1.000
2 LN	.681	.000	1.000	1.6×10^4
Subject 2				
1 RN	1.863	1.000	.000	3.6×10^4
2 RT	2.043	3.6×10^4	1.000	3.1×10^4
1 LN	.795	1.000	2.3×10^4	3.2×10^4
2 RT	3.127	1.000	2.8×10^4	3.9×10^4
1 RN	.771	1.000	1.000	3.2×10^4
2 LN	3.451	1.000	1.000	3.8×10^4
1 LT	3.343	1.000	1.000	2.0×10^4
2 RT	3.4×10^4	.000	1.000	1.000
1 LT	1.497	4.0×10^4	2.5×10^4	3.8×10^4
2 RN	2.439	1.000	1.095	3.3×10^4
1 LT	1.642	1.146	1.301	3.9×10^4
2 LN	.921	1.000	1.595	2.6×10^4

Table D.7.   Time-shared contingent event matrix.