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VARIATIONS IN CRITICAL FLICKER FREQUENCY WITH INTERSENSORY STIMULATION IN TWO MODALITIES

by

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CHAPTER ONE

INTRODUCTION

Psychological studies of intersensory relationships differ widely in their choice of factors that are considered important. In part this has been due to lack of a comprehensive theory that would generate testable hypotheses and accommodate findings. A more meaningful and integrated approach to the phenomena may result from developments in neurophysiology as well as psychology. Work on the reticular activating system, cybernetic concepts such as feedback mechanisms, and electrophysiological studies of animals' brains are some examples. However, investigations have remained within the category of psychological responses until recently.

The present study was formulated within the frame of reference of the mutually-recruitable-neuron or MRN theory, in which the important factor is considered to be the relative intensities of the sensory modes that are interacting. The mode to which a response is measured is called the primary mode, and any other concurrent stimulation is said to be in the secondary or accessory mode. This theory, as it has postulated central communication between sensory perceptions, is congenial with concepts in related disciplines. It is also able to offer explanations for seeming contradictions frequently reported in the literature.

Specification of the strengths of primary and accessory stimulations may account for contradictory explanations of inhibitory or facilitory effects reported. MRN theory predicts the sequence of increasing and decreasing magnitudes of response as a continuous function of increasing intensities of accessory stimulation. By controlling the strengths of primary and secondary stimuli, it has been possible to obtain empirical results approximating the predictions.

This is the report of an attempt to define further the elements composing the response curve obtained in heteromodal experiments. The aim of the study has been to extend the inhibitory conditions by introducing two accessory stimuli. Such a design also made it possible to test the generality of the theory as it applied to such combination of stimulation.

CHAPTER TWO

THE CONTEXT OF THE PROBLEM

Experiments on interrelations of sensory systems were classified in four categories by Ryan (1940). We are concerned only with those in which limits of perceptual function - thresholds, accuracy, or fineness of discrimination - in one mode have been modified as a result of concurrent stimulation in another. This review of empirical results will be limited further to include only those pertinent experimental studies dealing with vision, audition, and touch.

BACKGROUND OF EMPIRICAL RESULTS

Some studies have simply reported a careful experiment; others have included tentative explanations based on the results, such as Kravkov's irradiation theory (Kravkov, 1937); still others have derived testable hypotheses from theoretical positions such as Werner's genetic theory (Gorrell, 1953). It is difficult to compare the reports since common factors across these experiments are few. The experimental conditions are seldom the same, perhaps because there has as yet been little agreement as to which are relevant.

In the theory here considered, the emphasis has been on the relative intensities of the stimulation which is used. Such an approach allows for an explanation of results that otherwise appear contradictory. Consequently, the studies leading up to this investigation will be discussed with this concept in mind so that they will have a relevance to each other which is not otherwise apparent.

Davis (1953) investigated the effect of strong continuous accessory stimulation on visual sensitivity. The part of the study dealing with normal subjects showed the visual threshold rising in the beginning as a 1550 c.p.s. tone at 70 decibels above threshold was introduced. The raised threshold declined gradually as stimulation was continued. These results were predicted by a partial theory which had its inception at that time: the mutually recruitable neuron or MRN theory.

The central idea was that the tone and the visual stimulus both activated a pool of mutually recruitable neurons - MRNs - as well as the directly connected neurons in the cortex. The action of any sensory input might be to fire MRNs or to excite them partially, or subliminally. The sensory impulses arriving most frequently at the pool of neurons have the highest probability of firing the ones that were subliminally excited. Thus a weak (low frequency) accessory stimulation would raise elements to readiness for firing. Further, a strong accessory stimulation would give rise to impulses that would not only raise MRNs to readiness, but would fire even more of them than the primary system, since these accessory system impulses would arrive the more frequently. The theory postulates that when an impulse from a particular sensory system fires an MRN, the energy accrues to that system. The basis for sensitivity in a sensory modality is this energy from MRNs plus the energy from the activity of the specific sensory nerves. The changing effects of accessory stimulations of different degrees of intensity, on the primary system response, results from fluctuations in the sensitivity.

Gorrell (1953), tested visual sensitivity using critical flicker frequency as a measure, and two pitches of tone for secondary stimulation. He found that a 270 c.p.s. tone lowered CFF (inhibited it), and that a 2400 c.p.s. tone lowered it still more.

Trehub (1954) predicted that autonomic nervous system activity would serve as accessory stimulation and lead to modification of the primary responses which were made to a sensory stimulus. He used the absolute brightness threshold to test visual sensitivity and measured the intensity of autonomic activity by galvanic skin response. He was able to show that visual brightness thresholds first were facilitated and then inhibited as a function of increasing autonomic activity.

He postulated two components of the empirical curves seen in the heteromodal studies so far completed. One of these hypothetical components was a logarithmic curve corresponding to the rate of accrual of the MRNs to the primary system. A second component was an ogival function, corresponding to the rate of loss of MRNs to the primary system. Algebraic summation of these differently accelerated curves results in a curve closely duplicated by the data of the investigations of heteromodal effects: a diphasic function in which facilitation of response is followed by inhibition, as accessory stimulus intensities increase.

Wiesenfeld (1953) predicted and found the same diphasic response curve, using a graded series of intensities of 1550 c.p.s. tones to modify CFF.

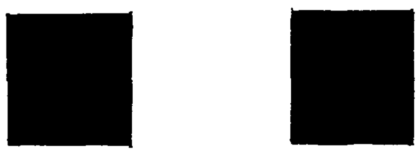
With this step in the construction of the theory supported by experimental evidence, Levine (1958) undertook to vary both the intensities of the primary and of the secondary stimuli. He predicted that it was the relative strengths of the two sensory inputs that generated the form of the diphasic curve, and was able to support this experimentally.

Shore (1955) examined the combined effect on visual sensitivity, of anxiety and induced effort. Visual sensitivity was measured by recognition of geometric targets in tachistoscopic presentation - a more complex response than has usually been dealt with. The number of correct target recognitions was compared for three groups having high, low, or medium scores on the Taylor Manifest Anxiety Scale, and tested at five levels of induced effort. Squeezing a hand dynamometer against five levels of resistive pressure constituted the measure of effort. Shore's results gave the diphasic curve with respect to effort but did not give definite information about the effects of anxiety.

Studies carried out in other contexts may now be considered from the perspective of this theory which clearly delineates the expectations of the small but consistent effects to be obtained when senses are simultaneously stimulated, and the intensities of the input are carefully controlled.

Urbantschitsch is credited with pioneering in the field, with very extensive work and observations that are still being investigated after eighty years (London, 1954). A major contributor is Kravkov. He has been productive of both data and theoretical explanations in experiments designed to examine various aspects of intersensory effects. Some of his results, when organized in terms of relative strength of primary and secondary stimuli, cease to appear contradictory. Differences resulting from wave length of the visual stimulus, and problems relating to the differences in response to white on black as opposed to black on white stimuli, are examples.

In general, Kravkov's position with reference to the opposite effects to be obtained when black stimuli are presented on a white ground, and when white stimuli are presented on a black ground, can be represented by the following illustration. Included in one paper (Kravkov, 1937, p. 807), is a sample of the black on white stimulus, which is reproduced here.



Kravkov's theory for what happens to visual acuity when this is viewed, is as follows: in the case of black objects on a white ground

> "an additional excitation of the brain center produces an increase in visual acuity. A heightening of the effect of the irradiation of the white surfaces is what underlies this phenomena."

On the other hand, black spaces between white objects may become obliterated as "white irradiation" increases. In other words, the neural activity generated by the brighter areas is always facilitated by the accessory stimulation.

An alternative explanation for the difference in response can be stated briefly. The sample of black on white is certainly a brighter stimulus than its opposite would be, in terms of total illumination. Predictions based on MRN theory would state that an auxiliary stimulus strong enough to inhibit response to a relatively weak (dim) primary stimulus could be paired with a stronger (brighter) primary stimulus, and that response to this relatively stronger one would be facilitated by the combination; e.g., to inhibit the response to the stronger black on white, it would be necessary to increase the intensity of the auxiliary input. Kravkov used a 2100 c.p.s. tone at 100 decibels, which might be sufficient to inhibit white on black but not black on white. The difference in response under these two particular conditions, then, is considered to be a difference only in their position on a continuum of facilitation followed by inhibition, and to be a function of the intensities of accessory stimulation relative to the intensity of the primary stimuli.

Hartmann (1933a) found that both black on white and white on black were facilitated by the concurrent auditory stimulation of unspecified intensities. These results were considered by him and by Kravkov to be contradictory to those just discussed. An explanation in terms of MRN theory would suggest that the auditory signal in Hartmann's experiment was not sufficiently intense, relative to even the white on black primary stimulus, to lead to inhibition of the response to it.

In further support for his position, Kravkov quotes Wilcox who found that discrimination under both conditions was facilitated initially, but that the white on black (dim condition, in the present terms)

> "...soon reaches a maximum facilitation corresponding to a comparitively low degree of illumination of the other eye; with a further increase of illumination, visual acuity suffers a rapid deterioration." (Kravkov, 1937, p. 810).

This is also consistent with MRN theory which predicts a difference in strong or weak primary stimuli as they are affected by increasing accessory input.

Other experiments by Kravkov include the "reversal of effect" obtained when the primary stimulus is a red or a green light, (Kravkov, 1939). With a 2100 c.p.s. tone at 100 decibels, Kravkov found CFF for a light source of any wave length shorter than 560 millimicrons was facilitated; CFF for any light source of longer wave lengths was inhibited. Green light of 540 millimicrons is shown to be the most effective wave length for the human eye, as determined by threshold responding. On the basis of MRN theory it is possible to predict that longer wave lengths could be inhibited by accessory stimulation of relatively low intensity as compared with shorter ones, which give rise to fast, frequent, nerve impulses.

Further support for such a prediction is suggested by another set of Kravkov's data from the same paper (1939). This data showed that a given wave length of green light was inhibited if it were presented at low intensity, and was facilitated by the same accessory input, if it were presented at a higher intensity.

Allen and Schwartz (1940-41) investigated these color effects using an array of stimuli in different sensory systems and "of adequate strength" to modify the response to flickering light at various wave lengths. The conclusion as to the effect of wave length was that "... it seems impossible to stimulate or influence in any manner a single color sensation alone ... while red is depressed, green is enhanced."

Maier, Bevan, and Behar (1961) explored the seeming contradiction in data on color phenomena in a "comprehensive evaluation of the effect of auditory input upon the CFF when several apparently important variables are treated parametrically and varied simultaneously." In a 3 x 3 x 3 design, monocular foveal CFF thresholds were determined by thirty six subjects for lights of different wave lengths, and concurrent tones in three frequencies and at three loudness levels. The study was made with 0, 40, and 80 decibel loudness measured in phons[1] at each frequency of tone.

The authors state that the different colored light sources were equated for brightness at the eye. Since the CFFs obtained are at different frequencies for each wave length, there is a question as to the equivalence of the stimulus strengths.[2]

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1. Phons, as a measure of loudness, refers to the number of decibels of intensity at which any tone must be presented to be equally loud as a 1000 c.p.s. tone at any desired intensity. Regarding the operational definition of intensities of sensory stimulation, it is seldom that specification of these psychological events is based on psychological dimensions - loudness and brightness, for example. Usually the physical properties of the stimulus are given, such as decibels and foot lamberts.

2. The Ferry-Porter law states that CFF increases as the light source becomes brighter. In these experiments, the green light was associated with the highest CFF, followed by blue, then orange.

It seems that investigators have not considered sufficiently the implications of controlled accessory stimulation and its relationship to specific primary stimulus intensities. In many papers which do not really specify relative strengths of primary and secondary stimuli, the results are not incompatible with the sort of explanation proposed here. Those by Serrat and Karwoski (1936), Newhall (1923), and Thorne (1934), are examples.

Jacobson's (1911) work varying weights and sound is relevant to this study. He was using 10 to 30 gram weights when he found that auditory clicks inhibited discrimination between weights. The weights as accessory stimulation also inhibited perception of the clicks, in another experiment, but this time the weight intensity was much greater - 300 grams.

BACKGROUND OF THEORY

A notion that has been familiar in psychology is the opinion that sensory stimulation *per se* affects the organism's functioning in every area; *i.e.*, nothing takes place in isolation in the central nervous system. Theorists are now in accord as to the necessity for a central nervous system locus for the processes underlying interrelations of the senses.

One of these processes, variously termed, has to do with a possible lowering of neural thresholds, resulting in the facilitation of a response. Kravkov discusses this as an "increase in excitability" (London, 1954). Allen states that he now thinks that it is central thresholds that are changed rather than receptor ones, since his heteromodal experiments have shown that so many kinds of sensory stimulations can cause changes in a designated primary sensitivity (Allen and Schwartz, 1940-41).

Another possible process to account for facilitation is what Kravkov (1934, p. 807) refers to as "increase in excitation" or "irradiation". In his words:

> "An additional excitation of the brain can be produced by a different indirect stimuli such as illumination of the other eye, a tone, an odor. In the latter cases, the excitation of the neurons directly involved is transmitted to the neurons of the optical nerve, thanks to their anatomical proximity, and thus a subliminal excitation is created in the visual center."

Hartmann talks about a subliminal fringe of neurons brought to threshold by means of indirect stimulation, and fired by and in the service of a designated primary mode. (Hartmann, 1933b) This is considered possible because of the anatomical proximity of the two systems at some point in the brain. There are as many choices of location for this activity as there are places where two systems can be shown to be contiguous.

Recently some very old questions have been answered. There is now clear evidence for interconnections between all senses, via subcortical routes. Electrophysiological studies have been able to demonstrate response to auditory clicks in the visual and somesthetic areas, for example. (Thompson and Strindberg, 1960) Some heteromodal experiments have been done with animals, both here and in Russia, that resulted in findings compatible with data from human subjects.

Gestalt theory has given rise to other explanations of these effects in the work of Thorne (1934), Hartmann (1933a, 1933b), and Jacobson (1911).

The essential concept they have in common is that of one sensory system as constituting the figure while the second one constitutes the ground. Auxiliary stimulation is sometimes seen as increasing or decreasing the figure-ground contrast. When a stimulus changes from ground to figure because of increasing intensity, its effect is said to change from facilitation to inhibition. In other words, whatever is stronger is focal. In general, empirical results have not been inconsistent with such holistic conceptions.

Werner's genetic theory explains how senses can appear to interact, though no direction for their effects can be predicted. (Werner, 1940). The theory emphasizes original equivalence of the senses in the neonate, with differentiation occurring gradually with age. A residual undifferentiated portion is said to remain, and the amount of sensory interaction is a reflection of the degree to which this residual is undifferentiated.

THE MUTUALLY RECRUITABLE NEURON THEORY

The MRN theory originally propounded by Davis, has in some respects been quite specific. Limiting considerations to variable strengths of sensory stimulation presented concurrently, the investigator is able to predict and obtain both facilitation and inhibition as a diphasic response continuum. Although a neuro-statistical model is offered, the theory remains on the psychological level by concerning itself with a series of relationships between the strengths of stimulations and the magnitude of a behavioral response.

Two neural elements are postulated: one which operates only within a specific sensory system, and a second more general one which can be fired by any sensory system and contributes its energy to the system firing it. The name "mutually recruitable neuron" was given to this general heteromodal element and hence to the theory.

In intersensory experiments, the sensitivity of the primary system is measured by a behavioral response. The sensitivity is due to excitation from two sources and will be referred to as baseline sensitivity. One of the sources is the excitation contributed by elements specific to the primary system and the other is excitation contributed by a set of general elements. The accessory system's effect on this baseline sensitivity, augmenting or decreasing it, is due to its impinging on the set of general elements, only. Specific neural elements are firing in the accessory system at the same time, but these are not part of the interaction, since they can contribute only to their own system.

The accessory system acts on those general elements which are not ready to fire, raising them to a level nearer their threshold for firing. Other elements that were near firing may be fired by the accessory system and will then be lost to the sensitivity of the primary system. If impulses from the primary system are stronger than those of the other system, *i.e.*, if they arrive more frequently at the MRN pool, they have a greater chance of capturing those heteromodal elements that are near threshold. When impulses from an accessory system raise more elements to threshold than they fire, the primary system is facilitated. However, at some stage in the increase in the intensity of the accessory input, its impulses begin to arrive more frequently than those of the primary system, and the balance shifts. As a result the magnitude of the measured response drops back to baseline level, and then may be depressed below it, if the disparity between primary and secondary signals is sufficient.

The diphasic response curve that is obtained has been analyzed into two theoretical components associated with two hypothetical processes: accrual of MRNs to the primary system and loss of MRNs to the primary system. Given a specific intensity of primary stimulation, response to it is augmented by the secondary system at a rate described by an arbitrarily assigned rule: it is a logarithmic function of the increasing accessory system stimulus intensity. This means that at low levels of secondary stimulation, increases in the intensity give rise to a rapid facilitation of response, whereas at higher levels, the successive increments have less and less effect. The rate of loss of MRNs to the primary system on the other hand, is described by another arbitrarily assigned rule: it is an ogival function of the increasing accessory system stimulus intensity. This has a growth rate initially slow but speeding up as intensities reach the higher levels, and capture more MRNs for their system then they help contribute to the primary system. The logarithmic and ogive curves are linearly additive. Their summation results in a curve closely ressembled by the empirical curves of intersensory experiments.

Consistent unexplained deviations from the theoretical response curve led Berkeley[1] to suspect a third component: a rhythmical function which shows up as a reversal in direction of the intersensory effect. Algebraic summation of a sinusoidal function with the ogival and logarithmic functions would result in a curve that corresponds closely to the empirical results of several heteromodal studies. Theoretically, further reversals would appear as the curve continues into the inhibitory area. It is precisely this evidence of a third component that is the goal of the present investigation.

SUMMARY

Investigations of sensory interactions, as they have dealt with the modification of a response by accessory stimulations, have been difficult to compare. Most reports emphasize defining experimental variables and accounting for results, rather than developing theories. One basis for comparison has been the predominance, in a report, of facilitory or inhibitory effects.

Theories have tended to be neurological, if only by implication, and to fit one class of data better than the other. Gestalt orientations have produced explanations that can accommodate both classes, but which are not specific as to which direction an effect will take.

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1. Austin W. Berkeley, personal communication.

MRN theory suggests relationships leading to predictions of both facilitation and inhibition as a continuous function of relative stimulus intensities between primary and auxiliary systems. An extension of the theory has been proposed by Berkeley: addition of a third component which would result in closer correspondence of the theoretical and empirical curves.

CHAPTER THREE

THE POSTULATE SYSTEM

In MRN theory, the assumed relationships among the sensory systems are expressed as intervening variables. These relationships are summarized in the postulates which follow.

Postulate I: There is a process P in a sensory system (designated as S_1) which increases the number of elements acting in that system only when stimulation (designated as I_2) in other sensory systems is present.

Postulate II: There is a process Q in a sensory system S_1 which decreases the number of elements acting in that system only when stimulation, I_2, in other systems is present.

Posulate III: There is a process R in a sensory system, S_1, which increases and decreases the number of elements acting in that system only when stimulation, I_2, in other systems is present.

Postulate IV: P is a positive logarithmic function of I_2.

Postulate V: Q is an ogival function of I_2.

Postulate VI: R is a sinusoidal function of I_2.

Postulate VII: The processes P, Q, R, take place in addition to the processes which increase the number of elements acting in S_1 when stimulation I_1 is present.

Postulate VIII: The intercept of P and Q is a positive function of I_1.

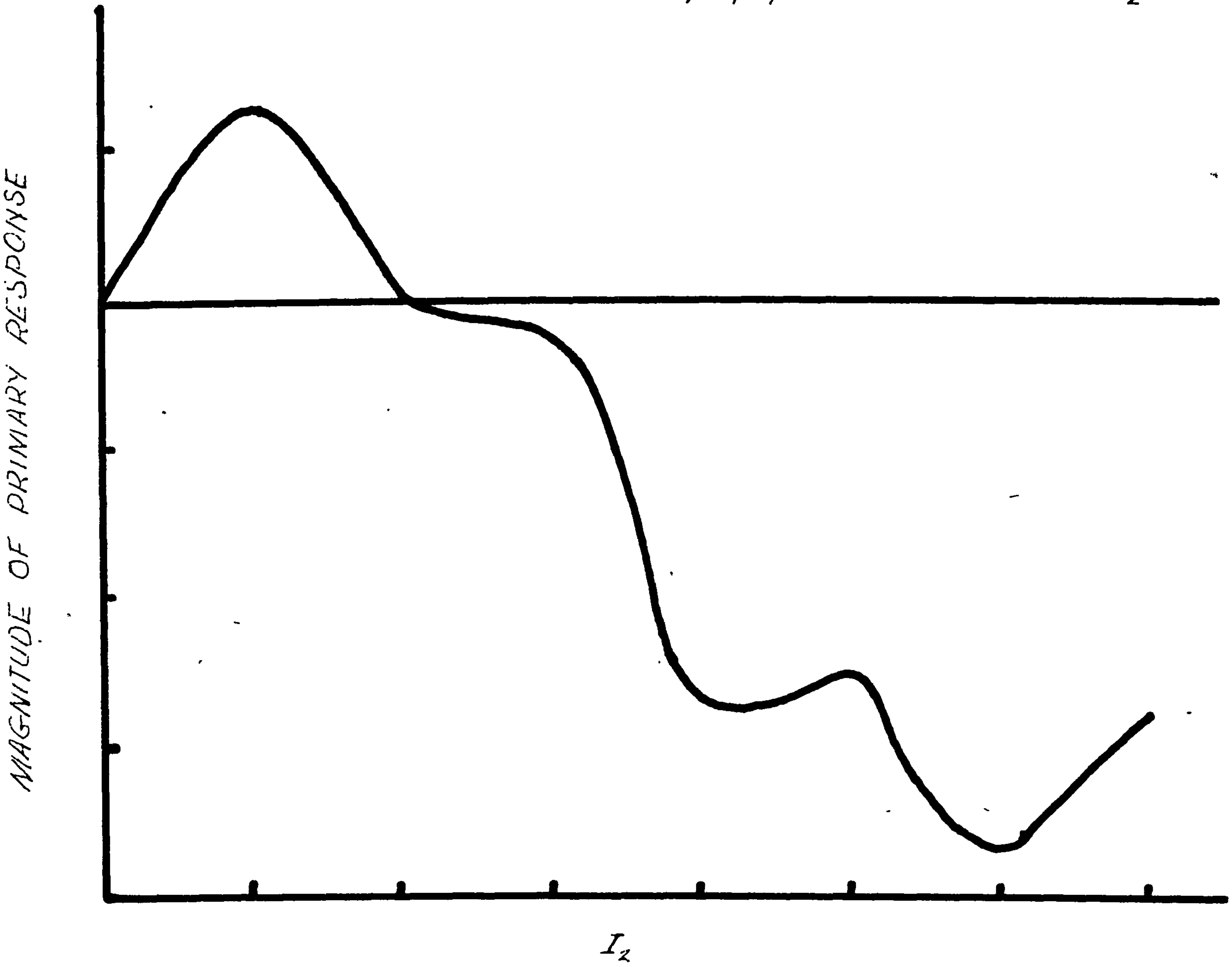
Postulate IX: The net change in the number of elements active in S_1 as a joint function of I_1 with I_2, is given at any point by the algebraic summation of P, Q, and R. (See Figure 1).

Postulate X: Sensitivity of a given sensory system is a positive function of the number of elements acting in that system.

Two predictions were made on the basis of deductions from these postulates:

1. Sensitivity in S_1 will be facilitated and inhibited as a function of increasing I_2.
2. More than one reversal in trend will be observed in the response curve.

FIGURE 1: RESULTANT OF $P_1 Q_1 R_1$ AS A FUNCTION OF I_2



CHAPTER FOUR

THE EXPERIMENT

Figure 1 shows reversals particularly in the inhibitory phase. Therefore, the present experiment was planned in such a way as to extend the inhibitory phase beyond that associated with the intensity of accessory stimulation usually employed. The highest intensity of stimulation used in previous studies could not be increased without discomfort to the subject. Since MRN theory has not been specific with respect to the ways that intensity of accessory stimulation may be achieved, a different approach was attempted. This study assessed the effect of presenting accessory stimulation in two different sensory modes at the same time.

Introduction of two concurrent sources of accessory stimulation could be considered to be equal to a single more intense accessory stimulus, within the context of the theory. If excitation from each of two accessory systems leads to capture of MRNs, at a high level of intensity, the total quantity of MRNs lost to the primary system would be sufficiently large to be associated with extended inhibition of the primary response. Then it follows that the expected additional cyclical variations in the response curve could be observed.

THE ACCESSORY STIMULI

The variable conditions for the experiment were matched as closely as possible with those of prior investigations in which data showed the distributions we wished to extend.

Accessory stimulation consisted of concurrent presentation of a weight and a tone. Because no attempt was made to establish stimulus equivalence between the tone and weight levels, the experiment was planned with three conditions: a control condition in which no accessory stimulation was present; a condition in which a range of tonal intensities (designated T_1 through T_7) was added to a constant weight and presented during responses to a visual stimulus; and one in which a range of weights (designated as W_1 through W_7) was added to a constant tone and presented during the responses.

Data from a pilot study were used to determine the range and the samples of stimulus intensities used. A 1550 c.p.s. tone was presented at the seven levels of intensity from 75 to 98 decibels used by Levine (1958). An audio-oscillator generated these tones and they were delivered to the subject through earphones.

Weights constituted the other accessory stimulation. Each weight was a multiple of 0.9 pounds: a canvas bag of B-B shot with a cord which could be attached by means of an S-hook to a canvas tape cuff on the subject's wrist. The designation W_1 refers to one of these units; W_2 refers to two together, and so on. Tables I and II summarize the experimental variables.

Results of a pilot study showed the effects of these weights and tones to be additive. They also suggested it would be possible to extend the total range of accessory stimulation by choosing W_3 as the constant weight and T_7 as the constant tone. T_7 was clearly inhibitory in effect, while W_3 was just after the intercept between baseline responding and the inhibitory part of the empirical curve.

TABLE I

INTENSITY OF TONES IN DECIBELS OVER 0.0002 DYNES/CM^2

Tone	Db
1	75
2	82
3	88
4	90
5	92
6	95
7	98

TABLE II

INTENSITY OF WEIGHTS IN POUNDS

Weights	Pounds
1	0.9
2	1.8
3	2.7
4	3.6
5	4.5
6	5.4
7	6.3

Trials were arranged as follows: presentations of T_7 plus a random choice of weights were arranged in alternate block with presentations of W_3 and a random selection of tones. Each block also contained a control trial in some position.

THE DEPENDENT VARIABLE: SENSITIVITY OF S_1

The measure of visual sensitivity was binocular determination of critical flicker frequency. The CFF was defined as the midpoint between the flash frequency at which a light just appears fused or steady, and the frequency at which it again appears to flicker as the frequency decreases.

The intermittent light source was a glow modulator tube (Sylvania Type R1131c) powered by an electronic pulse generator which yields a light dark ratio of 1:1 (equal periods on and off). The subject viewed the light source through a ground glass screen. The range of cycles per second that could be delivered was from 17 to 90. Changes in flash frequency were made by turning the shaft of the variable condenser of the pulse generator.

A blackened viewing box was fitted with a rubber edged head rest over a slit that was 60.9 cm. from the light source. The ground glass screen was circular and 2.5 cm. in diameter, resulting in a visual angle subtending two degrees, twenty one minutes. The experiments were carried out in a darkened room.

Changes in frequency were recorded. A hand switch controlled the direction of changes by controlling an instantaneously reversible motor whose geared shaft coupled with that of the condenser plates of the pulse generator.

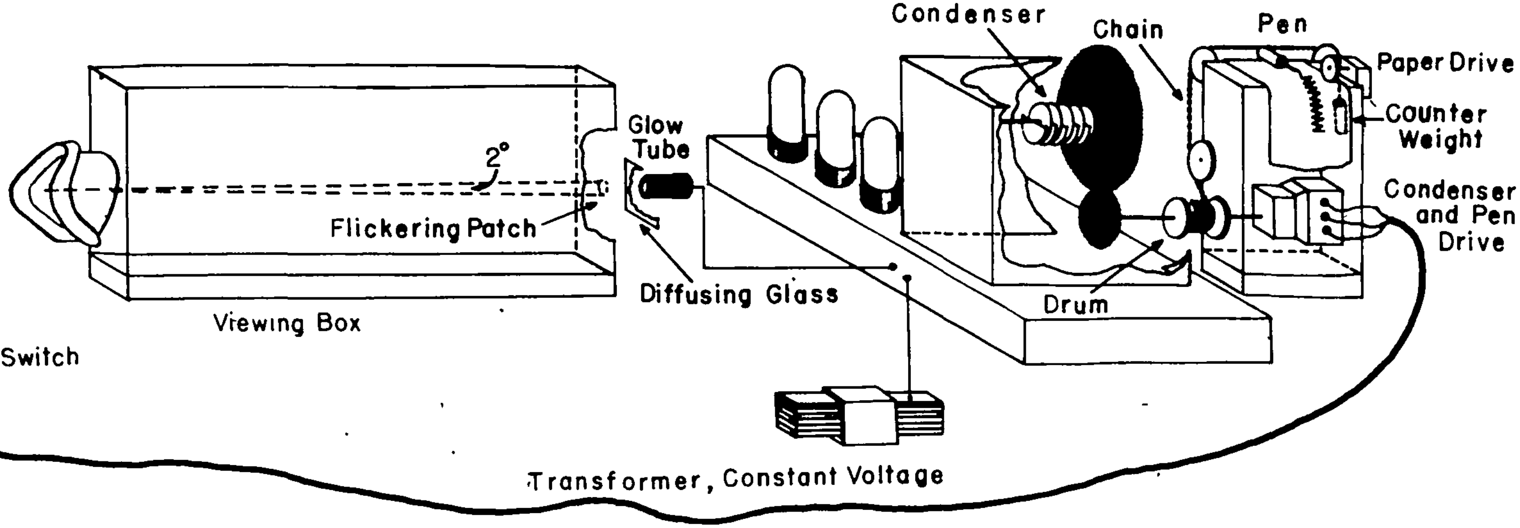
When the subject depressed the switch it caused the motor to turn the plates in one direction, increasing the flash frequency, and when he released it, the effect was reversed. A small drum on which a fine metal chain could wind and unwind was also on the drive shaft of the reversible motor. By means of pulleys, the chain crossed an eight inch metal tray and hung taut at the other side with a counter weight. A Northrup glass recording pen attached to the chain by a spring clip travelled back and forth as the subject activated the motor by his handswitch, making a continuous record on EEG paper which was fed through the tray by a small constant speed motor. See Figure 2.

A given flash frequency is then measurable as the distance in mm. of the recorded line from an arbitrary baseline. As the flash rate increased this distance increased. A reversal of the motor showed as a peak or a trough - the peak indicating perceived fusion and the trough, reappearance of flicker. A series of approximately 45 of these measurements was made in each 50 second trial. The mean value in mm. then translates into the CFF for that trial. A plot of the relationship between the millimeter measures and flash frequencies was employed to translate the means into cycles per second.

SUBJECTS

A population of responses from one subject was sampled for analysis in the experiment. Replication was carried out with a sample

FIGURE 2



Flicker Fusion Apparatus

of data from a second subject. Each subject was seen at the same time of day for fifteen days, but these times were not identical for both subjects. Otherwise, experimental conditions were as nearly identical as was possible.

The two subjects were professional men from the hospital, both of whom had experience in scientific work as subjects and as investigators. Both wore glasses and used them during the trials. Neither subject reported any auditory impairment.

PROCEDURE

Each subject had four days of practice sessions to become familiar with the procedure and the stimuli. Pilot work indicated that subjects became acclimated to the accessory stimuli in such a way as to decrease their inhibitory effects. Since investigation of these was our objective, practice was minimized. It is possible to recognize a trained subject's record by the size of the envelope (the distance between the peaks and troughs, or between flicker and fusion decisions) and by the regularity of the responding. Both subject's records indicated by their stability that they had mastered the routine.

During each of the fifteen sessions the following schedule was carried out. The subject was seated in front of the viewing box with his head resting on the head rest. The control switch was operated with the left hand and the right arm was rested on a padded stand for support when the weights were attached to the cuff on that wrist. After about fifteen minutes of dark adaptation the subject put on the earphones and practiced determinations for 50 seconds without accessory stimulation. After a 90 second rest, there were 45 minutes of trial in blocks of four, each following the same schedule:

i) 10 seconds of thresholds delivered while W, if any, was attached to the cuff.

ii) 10 seconds of thresholds delivered while T, if any, was initiated at threshold level and gradually maximized.

iii) 50 seconds of thresholds with concurrent stimulation by weight and tone at prescribed levels.

iv) rest (30 seconds between trials within block, and 90 seconds between blocks.)

When control trials were run or trials in which only a tone or a weight was to be presented, the same schedule was followed. However, the subject was told in advance when something was to be omitted, because they reported strong feelings of waiting for the accessory stimulations otherwise, which temporarily confounded the effect on the response.

ORGANIZATION OF DATA

To establish the CFF for any trial, each of approximately forty-five flicker and fusion points was measured in millimeters from an arbitrary baseline on the recording paper. The average flicker measurements plus the average fusion measurements divided by two gave a CFF expressed in mms. The CFF for an experimental trial was then compared to the CFF for the control trial which had occurred in the same block of four trials, and a difference score obtained still expressed in mms.

For the weight constant condition, there were eight levels of accessory stimulation from W_3, T_0 (i.e., W_3 and no tone) through W_3, T_7. There was one trial for each of these eight levels during a daily session. At the end of the fifteen sessions constituting the experiment, 120 of such difference scores were available as the basis for analysis of the data from the weight constant condition for a subject. The tone constant condition was presented during the same fifteen sessions and also produces 120 difference scores in exactly the same design.

The tone constant and the weight constant conditions were analyzed separately since there was no reason to believe that T_1 was equal to W_1 or, consequently, that any combinations of weights and tones were equivalent. Thus there were two analyses, one for each condition, for the single subject. Replication consisted of a sample identical in design, from a second subject.

The hypotheses as stated in terms of the operations just described are as follows:

1. The CFF means will vary as a function of the joint intensities of W and T.
2. The curve depicting the effect of the W and T on the CFF will show one or more reversals in direction of effect.

CHAPTER FIVE

RESULTS

The formal theory dealt with here predicts facilitation followed by inhibition of CFF associated with concurrent stimulation by a weight and a tone. In general, findings were consistent with these expectations. Statistical tests supported the prediction in both experimental conditions for the first subject. Inspection of the plotted data confirmed the expected direction of the modifications. The trend of performances of the second subject was also in the expected direction; however, the magnitude of changes was not large enough to provide statistical significance at an acceptable level.

A second prediction was that one or more reversals in the direction of the changes would be evident. This was confirmed for both the weight constant condition and the tone constant condition in the responses of both the subjects. These general results having been given, the supporting data will be considered in detail.

THE DATA

Intensity: For the first subject, the performance trend in the weight constant condition is shown graphically in Figure 3. Table I in Appendix D lists the mean difference scores which went into the curve. The null hypothesis of no difference between means associated with different intensities of accessory stimulation was tested by analysis of variance of the mean difference scores. Results of the statistical analysis of the performance shows an effect associated with Intensities which is significant at the .05 level. The summary of the analysis of the weight constant condition is presented in Table I in Appendix C.

FIGURE 3

SUBJECT I: MEAN DIFFERENCES IN CFF CONTROL AND CONSTANT WEIGHT CONDITIONS

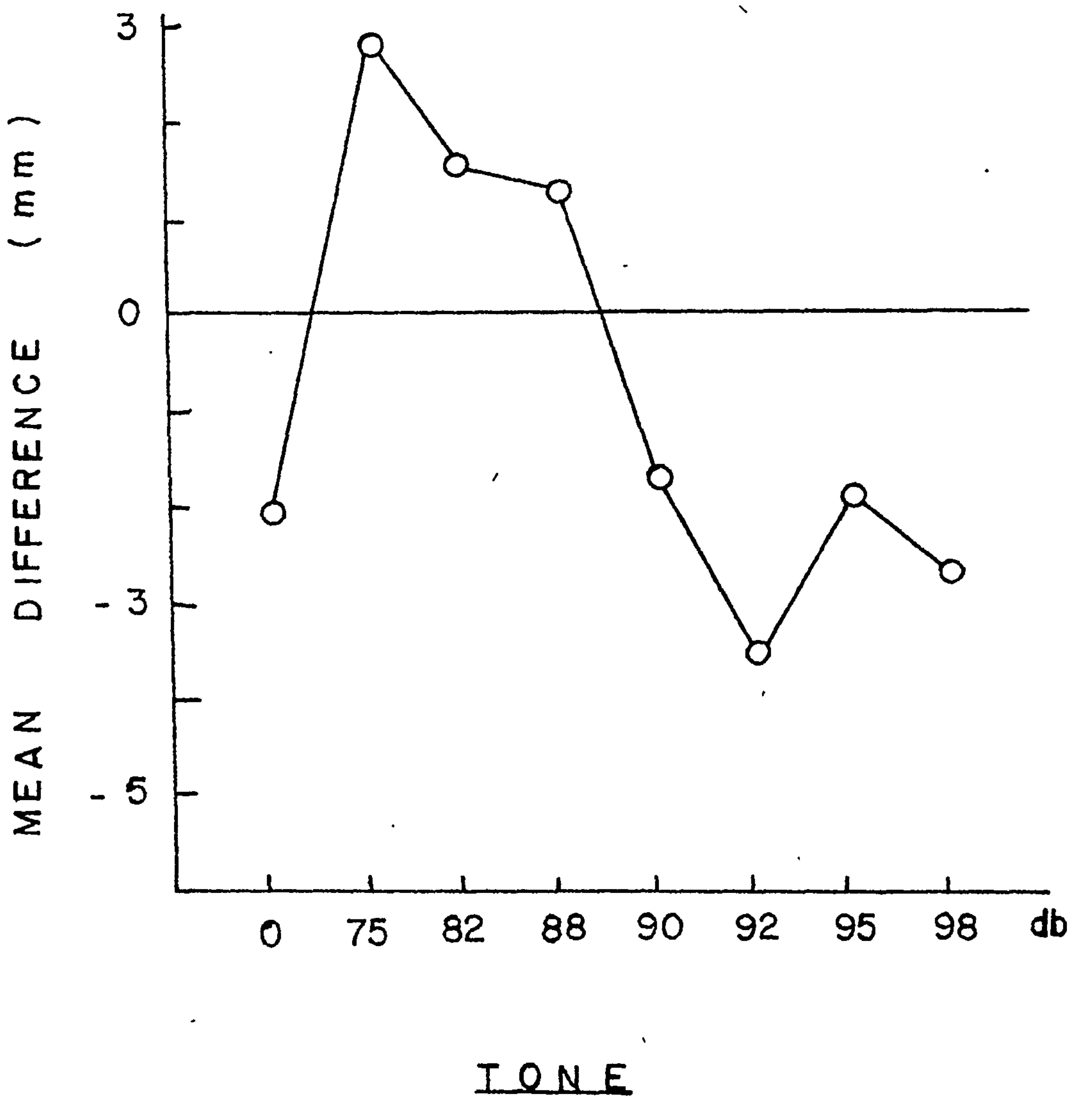


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Figure 4 shows the trend of the modifications of CFF under the other experimental condition, the tone constant condition, for the first subject. Table I in Appendix D lists the mean difference scores that are plotted there. Statistical analysis of the mean difference scores obtained under this condition also showed the effect of Intensities to be significant at the .05 level. Summary of the analysis is presented in Table I in Appendix C.

The performance of the second subject in the weight constant condition is shown in Figure 5. Table I in Appendix D lists the mean difference scores which are plotted there. Summaries of the analyses of variance for each condition are presented in Table II in Appendix C. The null hypothesis regarding the effect of increasing intensities cannot be rejected.

Figure 6 shows the performance of the second subject in the tone constant condition. The mean difference scores that went into it are listed in Table IV in Appendix D. Comparison of this curve with the corresponding one for the first subject (Figure 4) shows a strikingly similar response trend. The magnitude of the effect is, however, insufficient by comparison with random fluctuations to be statistically significant.

Reversals: The second hypothesis predicting reversals in trend is supported by inspection of the plotted data. For the first subject, these are in Figure 3 for the weight constant condition and Figure 4 for the tone constant condition. Remembering that these curves begin below baseline responding (*i.e.*, there are no levels of accessory stimulation that usually lead to facilitation of response, since even the constant weight or the constant tone alone is sufficiently intense to effect inhibition of CFF, as shown by pilot data) three clear reversals show in the curve for constant tone and two in the one for constant weight. The same picture is seen in Figures 5 and 6 for the second subject.

Magnitude of CFF modifications: Apart from statistical significance, these effects were of the order of one and one half cycles per second in the CFF responses of one subject and less in the other. The range from lowest to highest CFF was, however, from 27.0 to 38.5 c.p.s. for the first subject.

Summary: The prediction of a modification of CFF by different intensities of accessory stimulation was supported by the data from the first subject. The responses of the second subject, though showing a similar trend, were not of sufficient magnitude to result in statistical significance at the .05 level. The prediction of reversals in trend was supported in both subjects' performances, which also appeared very similar in their patterning of facilitation and inhibition.

In addition to their use in support of the predictions, the data lent themselves to some further analysis of temporal effects, which will be dealt with now.

TEMPORAL EFFECTS

The data from both subjects showed very large effects associated with session to session variations. In the data from the first subject, the trend of the mean daily performances did not appear to be systematic, but

FIGURE 4

SUBJECT I: MEAN DIFFERENCES IN CFF

CONTROL AND CONSTANT TONE CONDITIONS

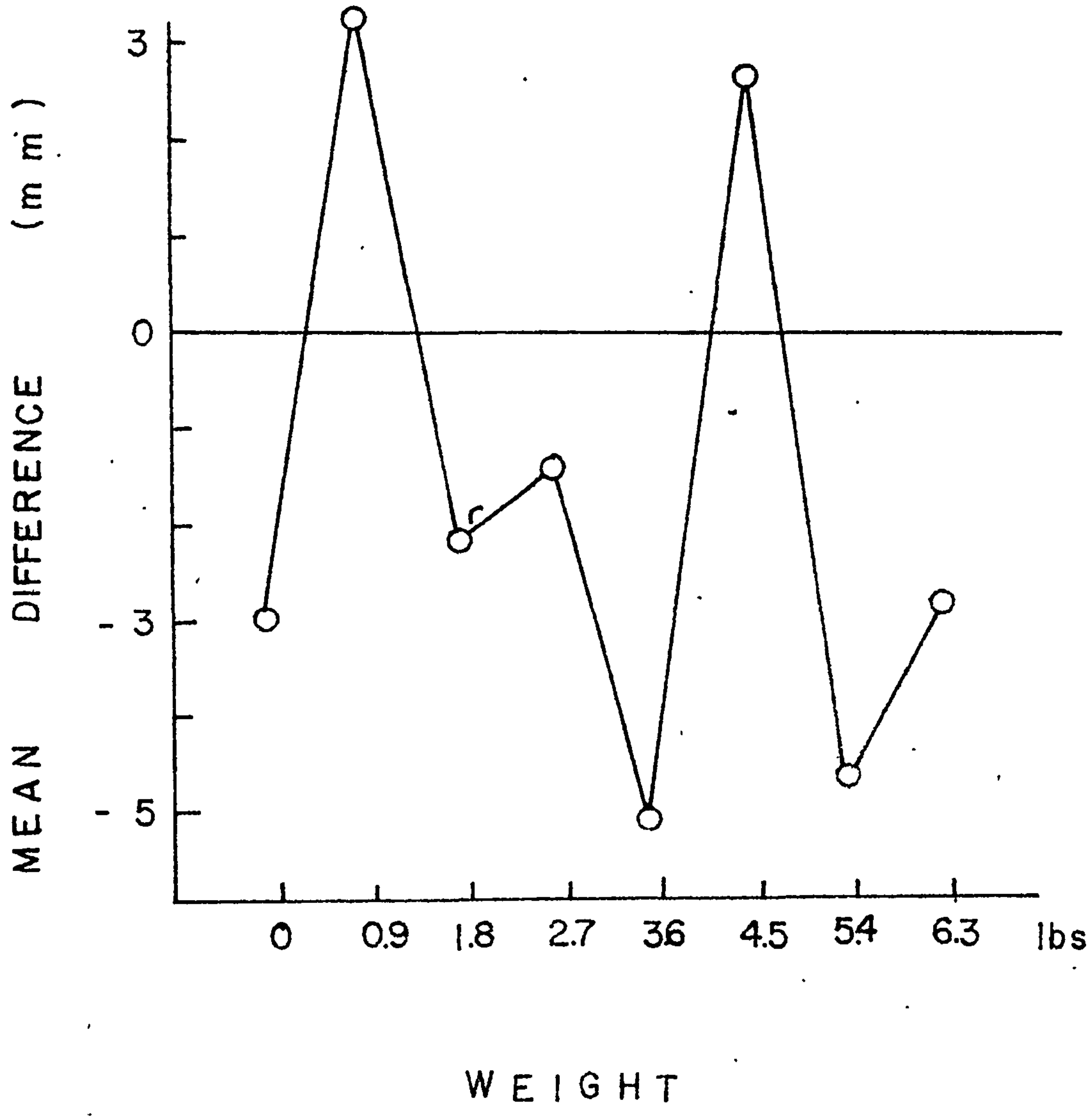


FIGURE 5

SUBJECT 2: MEAN DIFFERENCES IN CFF

CONTROL AND CONSTANT WEIGHT CONDITIONS.

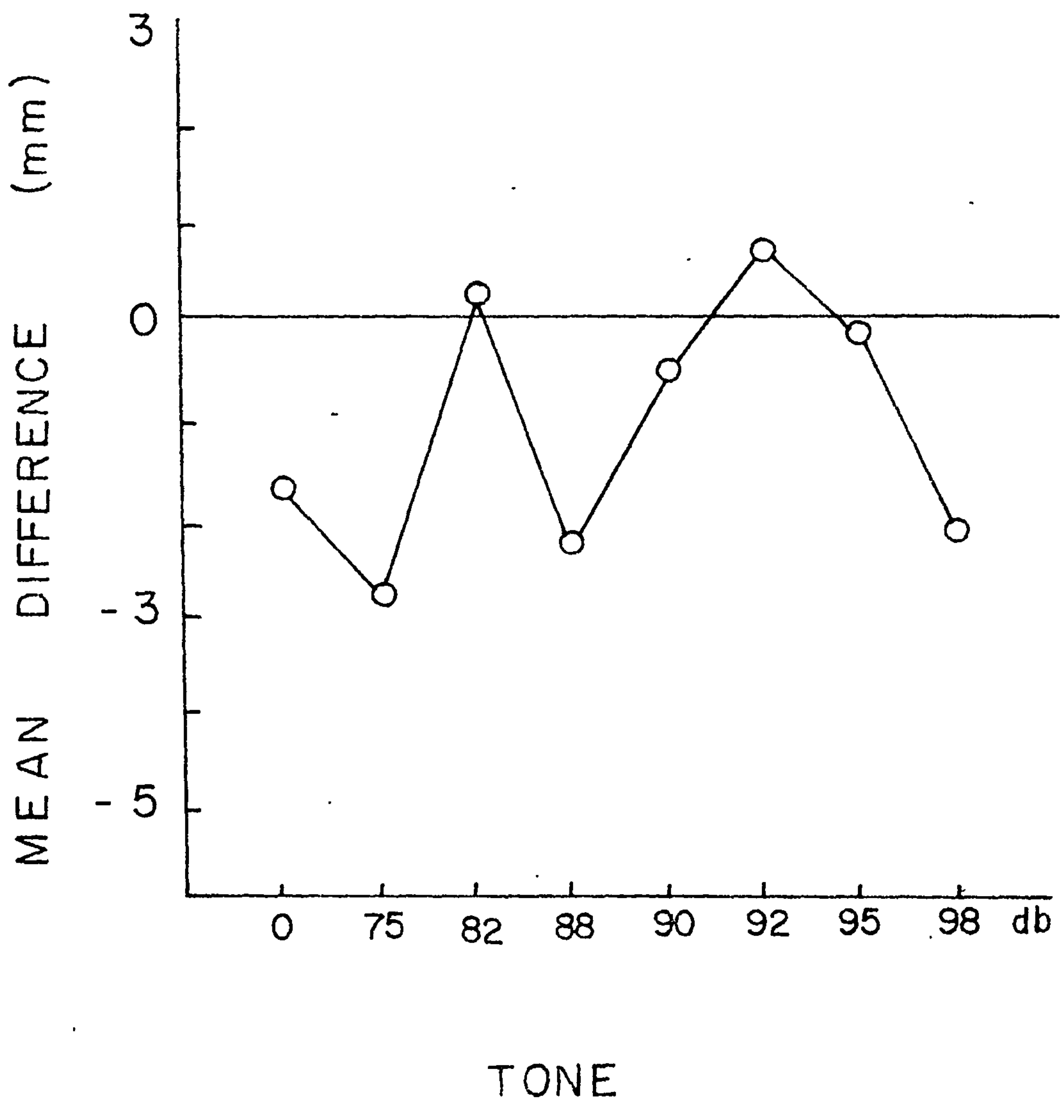
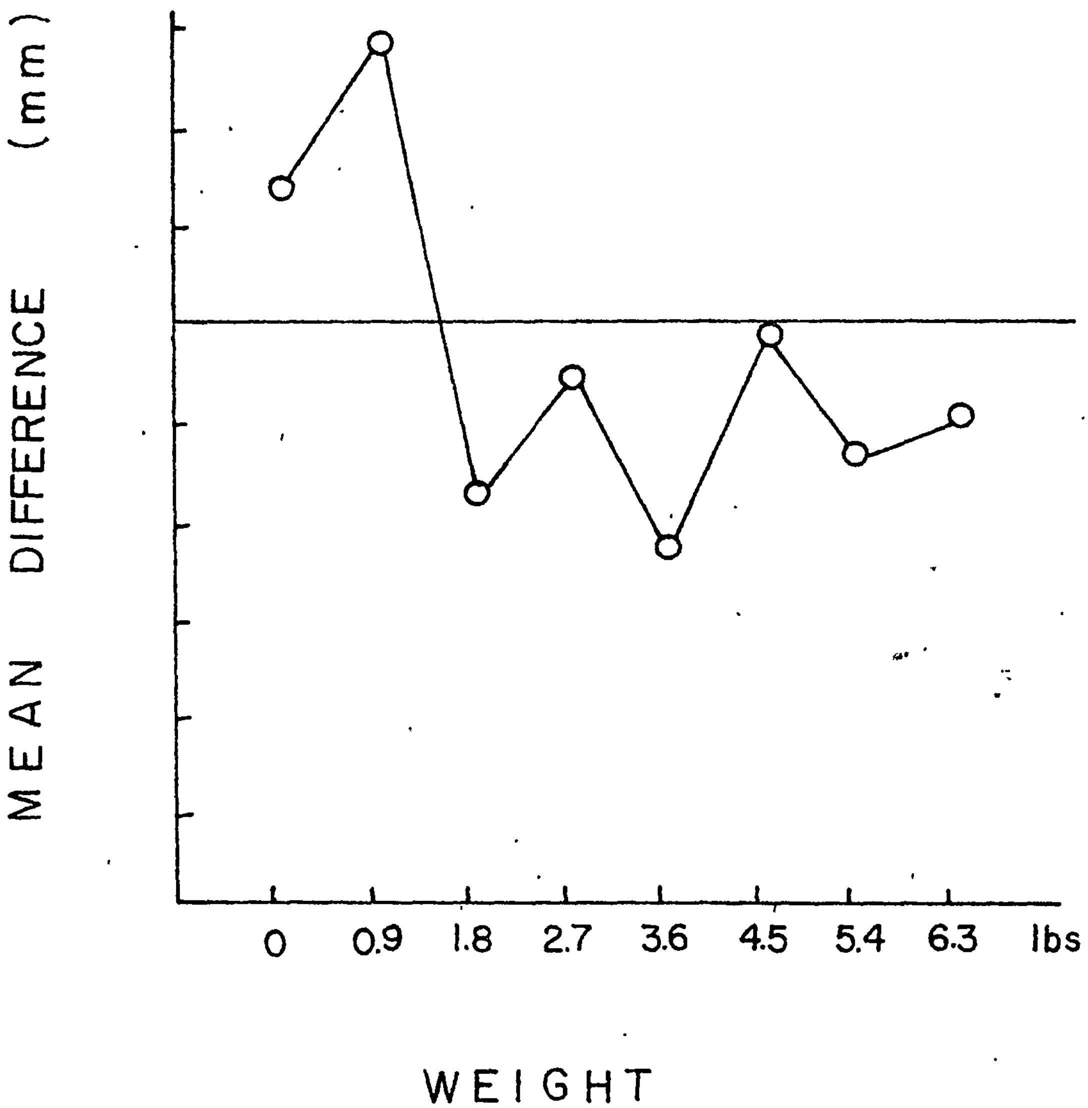


FIGURE 6

SUBJECT 2: MEAN DIFFERENCES IN CFF

CONTROL AND CONSTANT TONE CONDITIONS



rather to attain significant proportions due to large random daily fluctuations. The means for performance in each of the fifteen daily sessions are listed in Table II in Appendix D. The variation in CFF over daily sessions is also significant for both conditions in the analyses of the data from the second subject. Means for each session are listed in Table V in Appendix D. Fluctuations appear to be random, with the effect under both conditions of accessory stimulation varying in the same degree.

It was considered worthwhile to ascertain in what degree these temporal fluctuations might be effecting the experimental variables. A subsidiary analysis carried out for this purpose is summarized in Tables III, IV, and V in Appendix C. Sessions were grouped by successive weeks and also according to their occurrence at the beginning or the end of a week. Sessions on Mondays and Tuesdays were included in the category labelled Daygroup A; those on Wednesdays, Thursdays, or Fridays were Daygroup B. These two categories contained seven and eight days each, respectively.

For subject 1, in the analysis of the data from the weight constant condition, a significant interaction was apparent between the Daygroups and the successive weeks. The means are given in Table III in Appendix D and are plotted in Figures 7 and 8. The means were at first lower at the beginning of the week, and in later weeks were higher. The tone constant condition shows a slightly different pattern, with Daygroup a reflecting increasingly higher performances while Daygroup B means became increasingly lower. This interaction was also significant. This indicated that for the first subject the effect of auxiliary stimulation was more inhibitory at the end of each week and toward the end of the fifteen sessions.

The further analysis of temporal effects is summarized in Table V in Appendix C for subject 2 for the weight constant condition. Table VI in Appendix D shows the Daygroup means which indicate that Daygroup A was lower than Daygroup B during the second week, but higher thereafter, as for subject 1. (Daygroup B occurred during the first week.) The interaction was not significant in the case of the second subject.

In general, the temporal effects could be shown to have been inflating the residual but evidently not interacting with the intensities, since none of the interactions (I x W, I x D, I x W x D) was significant, in any of these subsidiary analyses. The F ratios for the Weeks, Daygroups, and their interactions showed that none of these variations was random when tested against the residual. However none of the components (Weeks, Daygroups, W x D) was significantly different from the unlabelled remainder of the temporal variations. This indicated that there is as much random variation remaining as it has been possible to label and quantify. Further analysis of temporal effects is not possible within the present design.

FIGURE 7

SUBJECT 1: MEAN PERFORMANCE

BY DAYGROUPS IN SUCCESSIVE WEEKS

WEIGHT CONSTANT

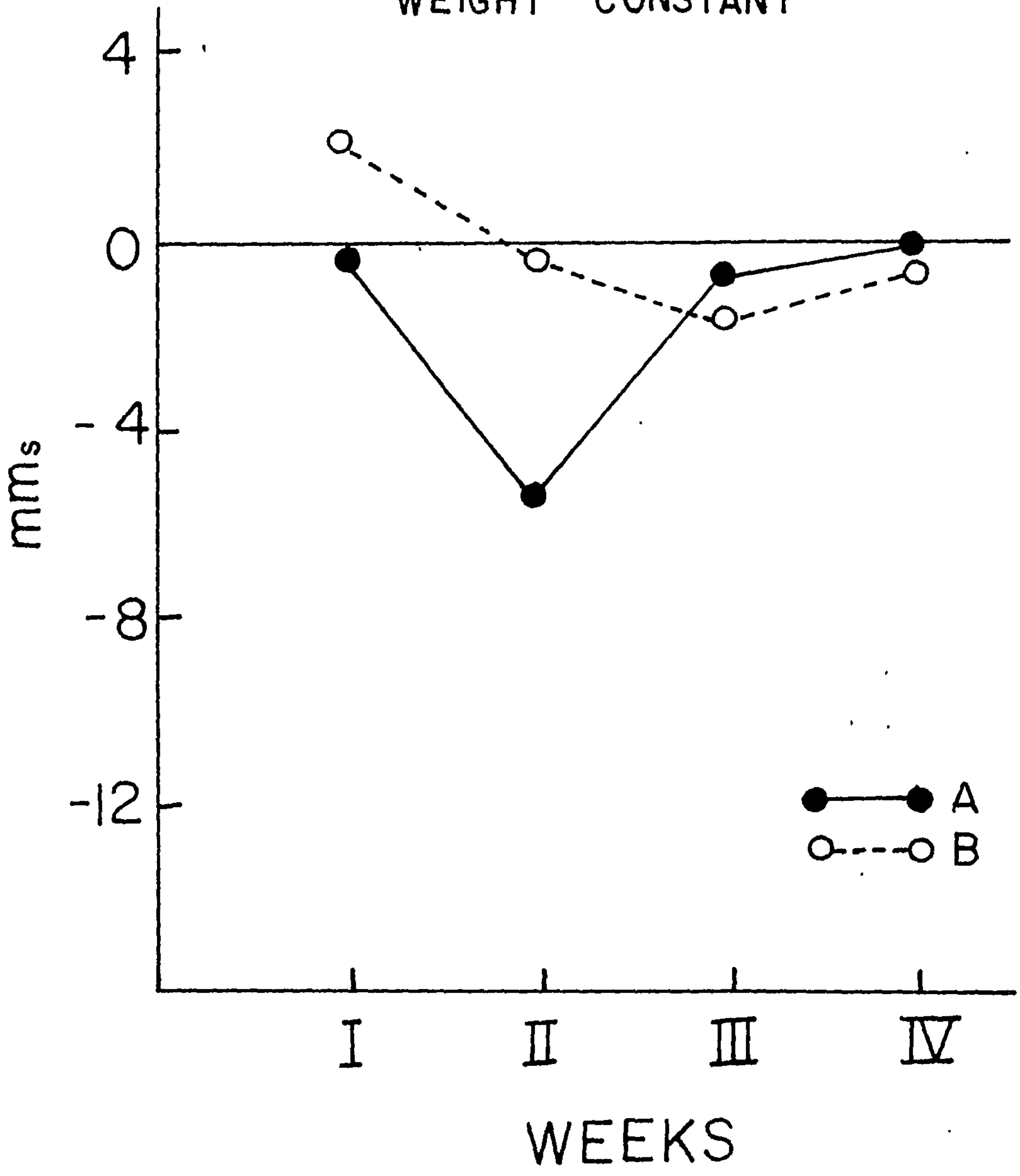


FIGURE 8

SUBJECT I: MEAN PERFORMANCE

BY DAYGROUPS IN SUCCESSIVE WEEKS

TONE CONSTANT

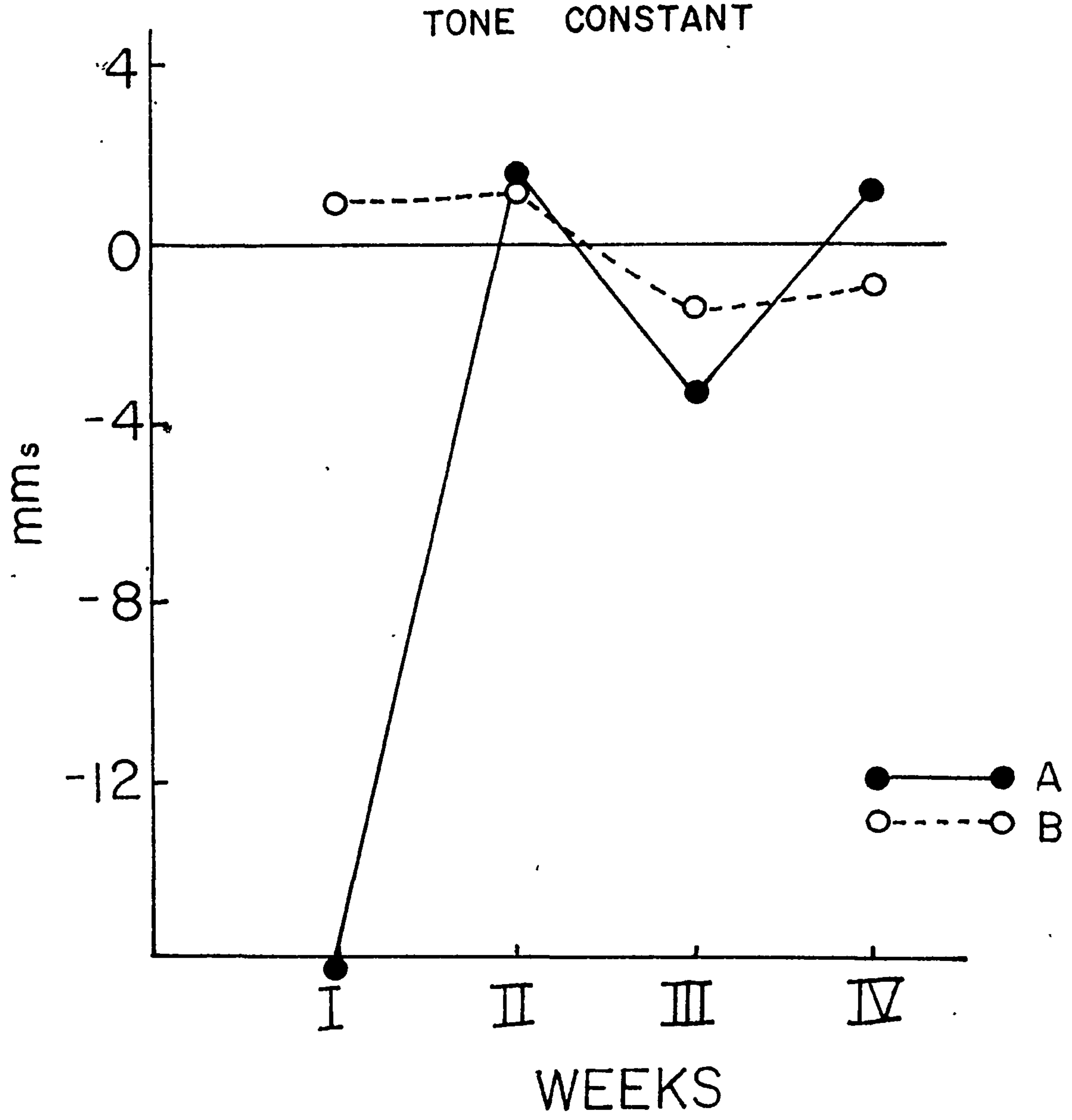
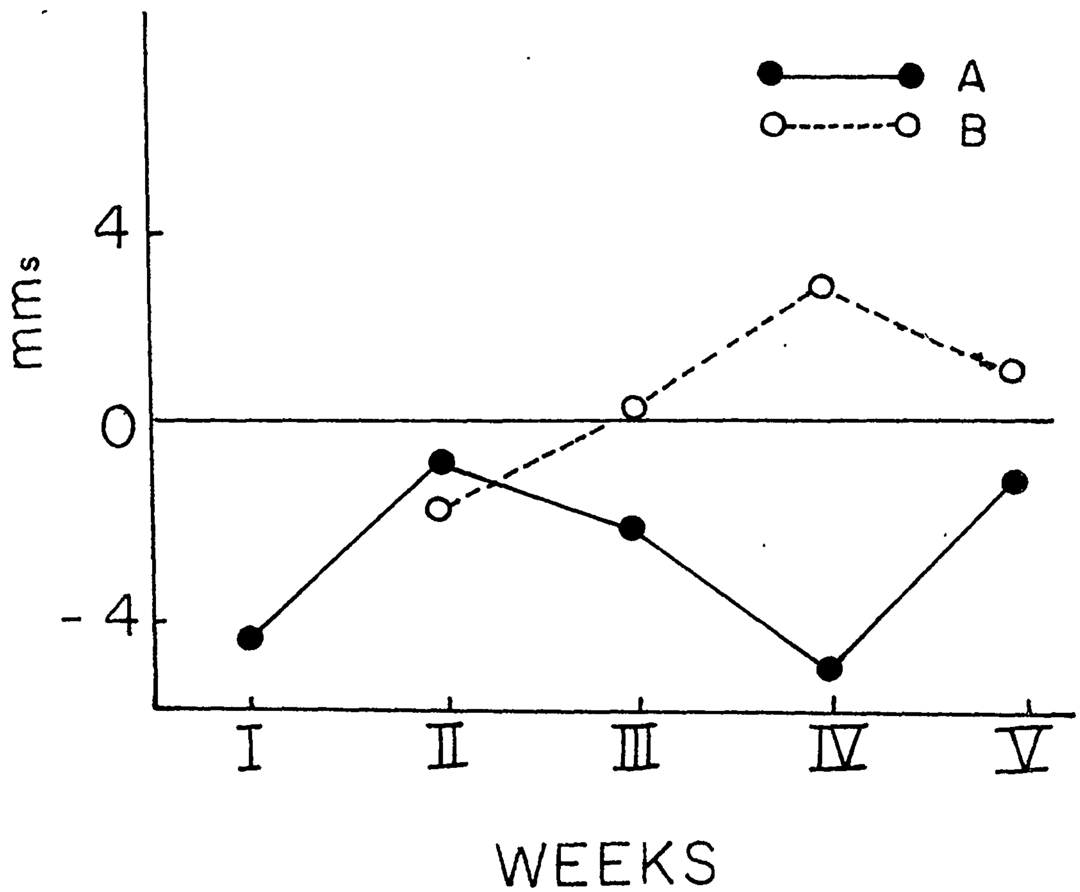


FIGURE 9

SUBJECT 2: MEAN PERFORMANCE BY DAYGROUPS IN SUCCESSIVE WEEKS

WEIGHT CONSTANT



CHAPTER SIX

DISCUSSION

The experimental results were, in general, as predicted for both subjects. This supports the predictive power of the formal MRN model.

In terms of the modification of a primary response by introduction of a second kind of sensory stimulation, the present results are consistent with findings reported in the literature on heteromodal experiments. Of the explanations which have been offered, MRN theory is most explicit in its use of the relationship between stimulus intensities to account for such results.

The data from this study are also consistent with the findings from other studies undertaken in support of that theory. Levine's and Wiesenfeld's data showing changes in visual response under conditions of accessory stimulation look like those of the present study, even to one reversal in trend. However, they do not extend as far into the inhibitory part of the response continuum.

THE INHIBITORY SECTION OF THE CONTINUUM

The problem of increasing inhibition was involved in seeking further evidence for a third component of the response curve. The theory has specified only that the shunting of excitation to a particular sensory system depends upon the relationship of intensities of the stimulations impinging on the MRN pool. The data from the present experiment support the implication that the source of the stimulations may be in two or more sensory systems. The expectation derived from Postulates II and X which state that there is a process in the primary sensory system that decreases the number of elements acting in that system only when stimulation in other sensory systems is present, and that the sensitivity of a sensory system is a positive function of the number of elements acting in that system. In terms of the model, it is the accessory systems' impingement on the MRN pool that is related to the behavior, although their activity along direct sensory pathways specific to their operation is also taking place.

In terms of the present experiment, this means that the effects of weight and tone could be combined, since their relationship to the CFF depends on the total number of MRNs to whose operation they contribute. The method used to increase inhibition beyond that which usually has been observed - combining a strong tone with varying weights, and a moderate weight with varying tones, as the accessory stimulation - thus allows for further generality for the theory. The possibility that other modalities will not so easily be combined is not ruled out.

REVERSALS IN TREND

The increase in inhibitory effect made it possible to observe the expected reversals. The prediction that one or more reversals in response trend would show up in the inhibitory part of the continuum was supported in every case. The functions are clearly not monotonic. Differences between the two subjects are in the magnitude of the effect and also in the location of the reversals along the scale of increasing strengths of accessory stimulation.

In the data from the first subject for the weight constant condition, T_1, T_2, and T_3 constitute a cyclical variation. In the case of the second subject, there is such a variation over T_4, T_5 and T_6. The peaks of both of these are actually in the facilitory area which indicates a distinct change in direction of effect since the response curves both begin well inside the inhibitory area. The two functions of the tone constant condition resemble each other even more closely. Although there is no assurance that any of these resemblences is more than fortuitous, they do suggest further support for the sinusoidal function.

OTHER ASPECTS OF THE DATA

Subjective differences in stimulus strength: Considering the congruity of the functions across weights for the two subjects, speculatively the peaks of performance may be displaced between the two curves by reason of different subjective experiences of the intensities of the stimuli, so that a W_3 peak for one subject may be the equivalent of a W_5 peak for the other. Spontaneous comment suggested that the tone was more insistent for the first subject and weight for the second.

A closer association between specific amounts of increase in the strength of accessory stimulation and the patterns of its effect on the response which is measured, should result from an experimental method in which input is equated across subjects. Primary system input also appeared to differ between the two subjects of the present study. It seems likely that the second subject perceived the flickering light as dimmer than did the first. His CFF of 19 c.p.s. was determined under the same conditions to which the other subject responded in the expected range of 30.0 to 32.5 c.p.s. Suggestions for equating the input will be made later.

Temporal effects: A large quantity of response variation for both subjects was that due to temporal effects. Pilot work made it obvious that an inhibitory condition is far from permanent. Subjects adapted to the stimulus intensities so that the amount of inhibition from any particular intensity of accessory stimulation decreased during each daily session, and although the inhibition was stronger again after an interval without testing, the overall trend was in the direction of decreasing effect. This is a major problem where increase in inhibition is necessary.

The present experiment comprised fifteen daily sessions of forty minutes of threshold determinations plus another twenty minutes of dark adaptation and preliminaries. A decrement in CFF can be shown to take place over the four trials of each block between long rests, over the five blocks of each session, and over the fifteen sessions. There is no clear information as to decrement over the individual trial. However, Davis has shown to what extent the sensitivity of the visual system is increased and decreased when a 75 decibel tone of 1550 c.p.s. is presented. Peak inhibition is ten to twelve seconds after the tone is at maximum strength. After this a slow decline in the effect continues for longer than the duration of a trial in the present experiment. Thus the mean CFF is representative of a tone's average effectiveness rather than the momentary effectiveness of a tone at the indicated intensity.

In addition to the patterns of decrement within and between daily sessions, two other sources of temporal variation were recognized in the data. There were differences between the means of sessions at the beginning and at the end of the week, and differences between the successive weeks. The placement of the sessions had a different effect in different weeks. The weekly means, however, tended to show a systematic decline in the inhibitory effect.

These patterns of decrement would make the whole response curve higher, but would not distort its shape, since conditions and levels of accessory stimulation were randomly distributed over the trials.

Analysis showed that there was no interaction between the temporal effects and the main effects. However the magnitude of the temporal effects compared to that of the main effects suggests that it would be worthwhile to have more information about the patterns of decrement in order to control them experimentally instead of relying on removing them statistically.

SUGGESTIONS FOR FURTHER RESEARCH

The results of the present study point out several directions for investigation. A logical sequel to demonstration of the occurrence of the reversals would be an attempt to predict and test stable variations in response associated with particular intensities of accessory stimulation. In addition, the problems of subjective differences in stimulus strength and of temporal effects, which appeared in the present work might be studied for the purpose of controlling them experimentally.

Scaling of accessory stimulations: Refinement of the scales of intensity in accessory sensory systems might make it possible for the experimenter to select samples of intensity that would lead to regular patterns of reversals within subjects across modalities and within modalities across subjects. If stable variations were obtained, they might be tested by selecting values of combined stimulations in a manner designed to cancel out or to enhance them. Information regarding these effects would be useful for further elaboration of the theory.

Need for information of this sort is also seen in the inability to account for the greater distinctness of reversals across weights than across tones, in terms of either sensory-specific differences or of differences due to the sampling of intensities used in the experiment. In other words, one possible source of difference is that a particular subject may discriminate more sharply between sensations of weight than sensations of sound. On the other hand, the levels of intensity of tone used may have been less clearly different or less widely separated than the levels of weight. To investigate these questions it would be necessary to establish norms for discrimination and to relate individual subjects to them.

Subjective differences in stimulus strength: It was also pointed out that it was not possible to be sure whether the effect of a given stimulation is equivalent between subjects whose experience of its strength is not equivalent. The strength of input is measured by a response - in the present study, the CFF. Primary system input or the baseline responding to it, _i.e._, CFF without concurrent accessory stimulation, should be equal between subjects in order to justify comparing modifications of it. The magnitude of the responses of the second subject of this study might have tended to approach that of the first subject if the intensity of the primary input had been increased until the baseline CFFs were equal.

Next, accessory stimulus intensity might be measured in subjective units, such as phons rather than decibels as the index of auditory intensity. A study designed to compare the modifications of response associated with a small range of stimuli that are physically identical, and those associated with an equal range of stimuli that are equated for subjective intensity, would also help settle this issue.

Temporal effects: Clarification of the complexity of temporal effects could be approached by investigating the relation of the size of the effects and varying lengths of intervals between experimental trials. The problem of adaptation to a range of stimuli of high intensity, which is one element of the temporal effects, might be handled by a design in which a group of subjects is trained, rested, and tested once, as opposed to designs for single subjects, with all the complications of temporal effects.

SUMMARY

Experimental results supported the predictions from the formal MRN model and allowed further generality for the theory in suggesting that excitations from more than one accessory system will act together to modify the primary response.

The data also pointed out some problems of intersensory experiments. Speculations regarding subjective differences in stimulus strength were made, and the relevancy of such a concept questioned. Implications of the temporal effects were discussed, together with the probable extent of their influence on the main effects.

Suggestions were made for further investigation of these problems and for a logical sequel to a study of the sinusoidal component: an attempt to scale accessory stimuli so that regular patterns of reversals could be tested.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

The present study tested experimentally hypotheses concerning relationships between magnitude of response to a sensory stimulation in one mode, (CFF), and a range of intensities of concurrent accessory stimuli in two other modes (weights and tones). Such heteromodal effects have been investigated under a variety of conditions. Reported results have included facilitation and inhibition of the response which is measured. Explanations have tended to be neurological, if only by implication, and to be able to account for one class of data (usually facilitation) better than the other.

A theory called the mutually recruitable neuron, or MRN, theory, originally propounded by Davis and developed by Trehub, Wiesenfield, and Levine, suggests that both magnitude and direction of effect are functions of the intensity of primary and accessory stimuli, relative to each other. Findings from their studies support such an explanation. Empirical results in the literature are generally consistent with these suggestions, as well.

MRN theory accounts for the data on the basis of two hypothetical processes: a loss of excitation to the primary system, and a gain in excitation by the primary system. Both loss and gain are measured by changes in the sensitivity of the system as reflected by the magnitude of response to it.

The two processes are associated with the quantity of general neural elements which contribute their excitation to the primary system. These hypothetical elements called MRNs are assumed to be activated by and contribute their energy to any sensory system whose impulses arrive at their location with sufficient frequency. This is in contrast to sensory specific neurons which are fired by and in the service of only one particular modality.

The rate of accrual of MRNs to a primary system is arbitrarily defined as a logarithmic function of the intensity of the accessory stimuli. The rate of loss is defined as an ogival function of the same intensities. Algebraic summation of these two functions results in a curve closely approximated by the data: a diphasic continuum of facilitation followed by inhibition. Consistent unexplained deviations suggested the possibility of a third, sinusoidal component which shows up as a reversal in the direction of the response trend plotted across increasing intensities, particularly in the inhibitory phase of the function.

In order to increase the inhibition of CFF and to avoid uncomfortably strong stimulation in a single modality, this study employed two sources of sensory stimuli: a range of weights with a range of tones. Two predictions were made:

1. The CFF will vary as a function of the joint intensities of weight and tone.
2. Reversals in direction of effect of weight and tone on CFF will occur.

A total of 240 mean CFFs were obtained from each of two subjects under one control and two experimental conditions. In one condition, a 1550 c.p.s. tone at 98 db, which was inhibitory by itself, was presented in combinations with a series of weights from about one to six pounds. In the other, an inhibitory weight of 2.7 pounds was held constant and accompanied by a series of 1550 c.p.s. tones of from 75 to 98 db in intensity. Absence of any accessory stimulation constituted the control condition. Statistical test of the null hypothesis was made by analysis of variance of the difference scores from the control values. The prediction of the appearance of the reversals was tested by inspection of the plotted data.

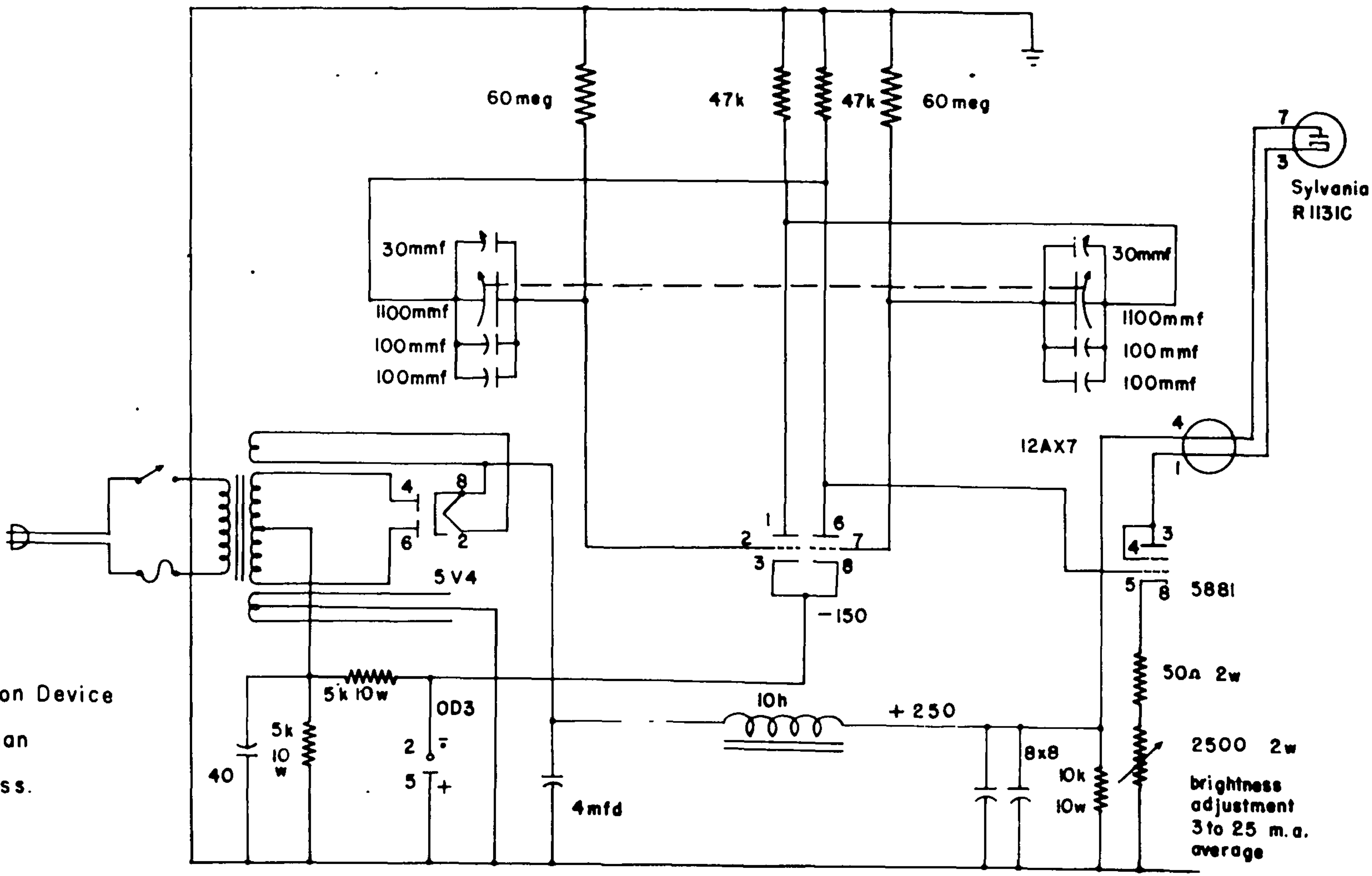
Modification of CFF as a function of increasing weight and tone was supported by responses of the first subject, with P = .05. Data from the second subject failed to show significant differences, but did show the same trend as seen in the first sample. The prediction of reversals was supported in both cases.

A very large effect associated with the daily sessions was evidently due to random fluctuations and could be shown not to be interacting with the experimental variables. These temporal effects and the possibility of important subjective differences in experience of the intensities were suggested as points of departure for further investigation. As a sequel to this study, scaling of accessory stimuli was suggested, so that regular patterns of reversals could be obtained.

The data from the present study support the ability of MRN theory to make predictions regarding modification of a response by concurrent accessory stimulation. It also gives evidence for a third component of the theoretical response curve of the model, and implies further generality for the theory in demonstrating the practicality of combining two sources of excitation as a means of effecting more inhibition.

APPENDIX A

CIRCUIT DIAGRAM



Flicker Fusion Device

John Degelman

Littleton, Mass.

APPENDIX B

RAW DATA

SUBJECT 1: DIFFERENCE SCORES

Level of Accessory Stimulation	Sessions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Mean
W_3, T_0	3.3	-6.9	-3.8	0.9	- 9.8	-5.5	-2.4	-10.5	-6.0	-3.7	-4.2	5.3	6.2	9.9	-4.3	-2.1
1	7.7	7.8	3.9	1.3	- 5.0	-3.0	14.4	2.8	14.6	-1.5	-3.3	8.2	-1.6	- 3.0	-1.2	2.8
2	-2.8	3.4	-5.5	2.2	-16.2	10.2	6.5	6.9	-7.2	-2.9	-0.5	-2.7	13.4	0.5	17.0	1.5
3	9.0	8.7	1.9	2.0	-13.4	-5.1	-3.2	4.6	-4.7	-8.0	-2.1	-1.0	3.0	12.5	14.3	1.2
4	-6.2	6.2	5.5	-4.3	-14.4	3.3	2.9	11.5	1.9	-0.4	-2.1	7.0	-4.0	-19.4	-14.2	-1.8
5	-5.3	5.4	0.2	1.8	-10.6	-2.0	-0.6	-17.1	-2.5	-1.0	-3.9	-4.8	0.3	14.3	-0.7	-3.7
6	-6.8	-2.8	3.7	-2.7	- 7.4	-7.3	3.4	- 3.5	5.0	2.6	5.1	-1.1	-5.0	-11.5	-1.1	-2.0
7	-3.0	0.6	6.0	4.7	-17.1	-8.0	2.9	- 4.4	-5.5	-4.5	0.1	-9.3	0.7	- 0.4	-6.1	-2.9
T_7, W_0	-10.2	11.3	0.2	-0.1	2.1	3.5	6.3	- 2.6	-22.3	-6.5	-0.3	-5.3	-4.1	- 7.1	-9.7	-3.0
1	4.3	0.6	13.3	1.2	2.4	-9.7	1.4	- 1.7	19.1	6.4	-4.0	1.6	-4.4	6.5	13.2	3.3
2	-25.4	-13.3	6.6	2.2	2.9	4.2	1.7	2.1	-16.4	-5.1	-7.6	4.1	3.2	7.8	0.6	-2.2
3	-21.5	-13.1	2.0	4.4	-3.5	-1.7	1.9	- 2.9	9.5	-1.9	-0.1	1.6	2.7	-5.6	7.6	-1.4
4	-33.7	-14.5	7.7	-0.3	0.8	-4.7	2.2	- 5.0	-21.5	1.8	1.4	-3.9	0.5	-6.0	-3.5	-5.3
5	- 6.5	11.6	11.3	1.7	4.3	-2.7	-1.8	- 2.4	12.5	-3.8	5.7	3.5	6.3	-11.7	-12.8	2.7
6	-33.2	-13.6	2.9	-4.5	0.7	6.5	5.6	5.0	-15.9	-7.6	5.7	2.2	7.5	-11.8	-8.5	-4.6
7	- 3.6	2.0	--	4.1	3.7	-0.3	7.2	- 1.1	-1.5	-4.5	-4.4	5.1	5.9	-11.5	-4.9	-2.7

SUBJECT 2: DIFFERENCE SCORES

Level of Accessory Stimulation	Sessions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Mean
W_3, T_0	-24.3	7.8	-3.2	-9.8	9.4	-5.3	-7.4	0.1	-7.3	4.0	7.9	3.7	0.1	4.3	-6.1	-1.7
1	-2.7	-10.0	-3.7	2.7	-5.5	-10.1	-11.3	-2.4	1.3	0.3	-9.2	-7.3	-2.5	1.2	-6.6	-2.9
2	-18.8	8.0	-1.2	-3.8	-4.1	6.1	-1.1	2.9	-2.7	12.4	3.4	-3.3	-5.1	1.9	8.9	0.2
3	2.2	-7.5	5.4	-15.2	-1.2	-6.7	-1.3	-2.7	-2.6	0.4	-9.5	9.5	-9.4	1.6	2.9	-2.3
4	0.4	4.1	-4.6	-6.1	-6.7	-4.2	-1.9	-0.7	-3.9	1.6	2.2	7.0	5.5	-6.1	6.3	-0.5
5	-13.8	4.2	4.6	-4.9	0.3	-1.0	14.2	3.1	-10.7	3.1	2.7	6.6	-1.7	4.6	1.4	0.8
6	-9.8	-0.4	4.3	6.3	1.1	2.8	-6.4	-3.2	-11.4	9.5	-5.9	6.3	4.4	8.7	-4.9	0.1
7	-3.1	-7.1	-11.8	-18.9	-8.3	2.0	-2.6	1.1	-4.3	4.6	16.6	3.9	-1.9	2.6	-5.4	-2.2
T_7, W_0	-15.7	2.8	-11.9	-2.2	3.6	-9.1	-4.3	14.4	9.7	0.2	13.0	0.0	0.3	15.8	4.5	1.4
1	2.5	5.1	-3.1	9.7	0.7	-2.5	-5.3	12.3	4.4	15.0	4.2	-2.6	-7.6	9.3	1.4	2.9
2	-9.2	-11.5	-8.1	-8.2	-3.0	3.3	-2.7	0.9	-6.5	-10.6	9.2	5.1	-0.4	6.1	8.2	-1.8
3	-1.2	-8.9	-15.1	3.0	-0.8	-0.1	11.4	-1.3	-12.1	-5.8	18.0	-9.0	1.7	9.4	3.5	-0.5
4	-5.6	-9.2	-7.2	-7.4	-0.3	-3.2	-0.2	1.3	-10.4	8.3	6.8	-13.9	-9.4	6.3	7.5	-2.4
5	-5.2	14.3	-4.5	-0.2	-4.7	-2.7	-3.3	4.6	2.5	-6.6	3.8	-1.1	4.8	10.5	-15.1	-0.2
6	-0.9	-6.6	-2.0	-7.2	-4.4	-3.7	1.7	5.3	-4.8	23.2	7.5	-6.5	-7.2	5.3	4.4	-1.4
7	-10.2	-1.9	-8.5	0.5	-2.5	-5.5	8.5	13.1	4.3	-15.5	8.6	-4.2	9.7	6.2	-17.8	-1.0

APPENDIX C

ANALYSIS OF VARIANCE SUMMARIES

TABLE I

SUMMARIES OF ANALYSES OF VARIANCE

SUBJECT 1

W_3 Across T

Source	Sum of Sq.	d.f.	Mean Square	F	F.95
Total	5716.34	119	--	--	--
*Intensities	584.24	7	83.46	2.18	2.10
*Days	1391.51	14	99.39	2.60	1.79
D x I	3740.59	98	38.16	--	--

T_7 Across W

Source	Sum of Sq.	d.f.	Mean Square	F	F.95
Total	9505.29	120	--	--	--
*Intensities	892.25	7	127.46	2.20	2.10
*Days	2954.12	14	211.00	3.65	1.79
D x I	5658.92	98	57.74	--	--

*Significant

TABLE II

SUMMARIES OF ANALYSES OF VARIANCE

SUBJECT 2

W_3 Across T

Source	Sum of Sq.	d.f.	Mean Square	F	F.95
Total	5446.99	120	--	--	--
Intensities	199.51	7	28.50	.73	2.10
*Days	1401.25	14	100.08	2.55	1.79
D x I	3846.23	98	39.25	--	--

T_7 Across W

Source	Sum of Sq.	d.f.	Mean Square	F	F.95
Total	7334.92	120	--	--	--
Intensities	312.43	7	44.63	.98	2.10
*Days	2564.40	14	183.17	4.03	1.79
D x I	4458	98	45.49	--	--

*Significant

TABLE III

SUMMARY OF ANALYSIS OF VARIANCE

SUBJECT 1

W_3 Across T

Source	Sum of Squares	d.f.	Mean Square	F	F.95
Total	5716.34	119	--	--	--
*Intensities	584.24	7	83.46	2.47	2.21
*Sessions	1391.51	14	99.39	2.9	1.90
*Weeks	220.30	3	73.43	2.17	2.80
*W x D	424.10	3	141.36	4.18	2.80
*Daygroups	142.48	1	142.48	4.22	4.04
*Remainder	604.63	7	86.38	2.55	2.34
Intensities with weeks & day-groups	3740.59	98	38.16	1.13	1.52
I x W	1218.32	21	58.01	1.71	1.78
I x D	344.82	7	49.26	1.45	2.20
I x W x D	523.13	21	24.91	--	1.78
Residual	1654.32	49	33.76	--	--

*Significant

TABLE IV

SUMMARY OF ANALYSIS OF VARIANCE

SUBJECT 1

T_7 Across W

Source	Sum of Squares	d.f.	Mean Square	F	F.95
Total	9505.29	119	--	--	--
*Intensities	892.25	7	127.46	2.30	2.21
*Sessions	2954.12	14	211.00	3.80	1.90
*Weeks	604.21	3	201.40	3.60	2.80
*Daygroups	263.80	1	263.80	4.76	4.04
*W x D	1340.52	3	446.82	7.10	2.80
Remainder	745.59	7	106.51	1.92	2.34
Intensities with week & day-groups	5658.92	98	--	1.11	1.52
I x W	1542.81	21	73.46	1.32	1.78
I x D	590.96	7	80.13	1.44	2.20
I x W x D	810.69	21	38.60	.69	1.78
Residual	2714.46	49	55.39	--	--

*Significant

TABLE V

SUMMARY OF ANALYSIS OF VARIANCE

SUBJECT 2

W_3 Across Tones

Source	Sum of Squares	d.f.	Mean Squares	F	F.95
Total	5446.99	119	--	--	--
Intensities	199.51	7	28.50	.80	2.21
*Sessions	1401.25	14	--	--	1.90
*Weeks	452.72	4	113.18	3.19	2.80
*Daygroups	379.62	1	379.62	10.72	4.04
W x D	6.70	4	1.67	--	2.80
*Remainder	562.00	5	112.40	3.17	2.34
Intensities with week & day-groups	3846.23	98	39.25	1.10	1.52
I x W	1072.09	28	38.28	1.08	1.78
I x D	258.02	7	36.86	1.04	2.20
I x W x D	677.74	21 ?	24.20	.68	1.78
Residual	1238.38	35	35.38	--	--

*Significant

APPENDIX D

TABLES OF MEANS

TABLE I

SUBJECT 1: MEAN CFF DIFFERENCE SCORES BETWEEN CONTROL AND EXPERIMENTAL CONDITIONS

Condition	Level	Mean D-Score in MM.*
W_3 Constant	T_0	-2.1
"	T_1	2.8
"	T_2	1.5
"	T_3	1.2
"	T_4	-1.8
"	T_5	-3.7
"	T_6	-2.0
"	T_7	-2.9
T_7 Constant	W_0	-3.0
"	W_1	3.3
"	W_2	-2.2
"	W_3	-1.4
"	W_4	-5.3
"	W_5	2.7
"	W_6	-4.6
"	W_7	-2.7

*The mean control CFF was at 130.7 mm. which corresponded to 31.5 c.p.s.

TABLE II

SUBJECT 1: MEAN PERFORMANCE IN EACH SESSION

Session	Mean D-Score W-Constant Condition	Mean D-Score T-Constant Condition
1	-0.5	-16.2
2	2.8	- 3.6
3	1.5	6.3
4	0.7	1.1
5	-11.7	1.7
6	-2.2	- 0.6
7	3.0	3.3
8	-1.2	- 1.1
9	-0.6	- 5.8
10	-2.4	- 2.6
11	-1.4	- 0.5
12	0.2	1.1
13	1.6	2.2
14	-3.2	- 5.0
15	0.5	- 0.3

TABLE III

SUBJECT 1: DAYGROUP MEANS IN SUCCESSIVE WEEKS

Week	Daygroup A	Daygroup B
	Weight Constant	
I	-0.5	2.0
II	-5.8	0.4
III	-0.9	-1.9
IV	0.2	-0.6
	Tone Constant	
I	-16.2	0.9
II	1.4	1.2
III	-3.5	-1.6
IV	1.1	-1.0

TABLE IV

SUBJECT 2: MEAN CFF DIFFERENCES BETWEEN CONTROL AND EXPERIMENTAL CONDITIONS

Condition	Level	Mean D-Score In MM.*
W_3 Constant	T_0	-1.7
"	T_1	-2.9
"	T_2	0.2
"	T_3	-2.3
"	T_4	-0.5
"	T_5	0.8
"	T_6	-0.1
"	T_7	-2.2
T_7 Constant	W_0	1.4
"	W_1	2.9
"	W_2	-1.8
"	W_3	-0.5
"	W_4	-2.4
"	W_5	-0.2
"	W_6	-1.4
"	W_7	-1.0

*Mean control CFF was at 73.7 mm. which corresponds to 22.5 c.p.s.

TABLE V

SUBJECT 2: MEAN PERFORMANCE IN EACH SESSION

Session	Mean D-Score W - Constant	Mean D-Score T - Constant
1	-8.7	-5.7
2	-0.1	-2.0
3	-1.3	-7.6
4	-6.2	-1.5
5	-1.7	-1.4
6	-2.2	-3.0
7	0.6	0.7
8	-0.2	6.3
9	-5.2	-1.6
10	4.5	1.0
11	1.0	8.9
12	3.3	-4.0
13	-1.3	-1.0
14	2.3	8.6
15	-0.4	-0.4

TABLE VI

SUBJECT 2: DAYGROUP MEANS IN SUCCESSIVE WEEKS

Week	Daygroup A	Daygroup B
	Weight Constant	
I	-4.4	--
II	-0.9	-1.9
III	-2.2	0.2
IV	-5.2	2.9
V	-1.3	1.0

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ABSTRACT

VARIATIONS IN CRITICAL FLICKER FREQUENCY WITH INTERSENSORY STIMULATION IN TWO MODALITIES

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The present study tested hypotheses concerning magnitude of response to sensory stimulation in one mode, (CFF) relative to intensities of concurrent stimuli in two other modes, (weights and tones). Such hetero-modal effects have been investigated under a variety of conditions. Reported results have included facilitation and inhibition of the response which is measured.

A theory called the mutually recruitable neuron or MRN theory, suggests that both magnitude and direction of effect are functions of the intensity of primary and accessory stimuli. Empirical results in the context of this theory and of others are consistent with these suggestions.

MRN theory accounts for the data on the basis of two hypothetical processes: loss of excitation to the primary system, and gain in excitation by that system. The theory posits general neural elements, MRNs, which are activated by and contribute their energy to any sensory system whose impulses arrive at their location with sufficient frequency. These are in contrast to sensory specific neurons which are fired by and in the service of

only one particular modality.

The rate of accrual of MRNs to a primary system is defined as a logarithmic function of the intensities of the accessory stimuli. The rate of loss is defined as an ogival function of the same intensities. Algebraic summation of these two functions results in a curve closely approximated by the data: a diphasic continuum of facilitation followed by inhibition. Consistent unexplained deviations suggested the possibility of a third, sinusoidal component which shows up as reversals in direction of response trend plotted across intensities, particularly in the inhibitory phase of the function.

In order to increase the inhibition of CFF and to avoid uncomfortably strong stimulation in a single modality, this study employed two sources of sensory stimulation: a range of weights and a range of tones. Two predictions were made:

1. The CFF varies as a function of the joint intensities of weight and tone.
2. Reversals in the direction of effect of weight and tone on CFF occur.

A total of 240 responses from each of two subjects were obtained under the following conditions: 1. a tone in combination with a series of weights; 2. a weight in combination with a series of tones; 3. absence of any accessory stimulation.

Modification of CFF as a function of increasing weight and tone was supported by responses of one subject with P = .05. Data from a second subject failed to show significant differences but did show the same trend as seen in the first sample. The prediction of reversals was supported in both cases.

Large temporal effects and the possibility of important subjective differences in experience of the intensities were suggested as points of departure for further investigation.

The data from the present study support the ability of MRN theory to make predictions regarding modification of a response by concurrent accessory stimulation. It also gives evidence for a third component of the theoretical response curve of the model, and implies further generality for the theory in demonstrating the practicality of combining two sources of excitation as a means of effecting more inhibition.

AUTOBIOGRAPHY

Born in Minnesota and educated mainly on the Eastern Seaboard, I completed work for the AB degree at Mount Holyoke in 1943. After marrying and beginning to raise a family I returned to school, to work for a Doctorate in Clinical Psychology at B. U. Practicums were at Boston State Hospital, Thom Clinic and Bedford V. A. Hospital.