6240

AROUSAL AND PERSEVERATION:

A THEORETICAL MODEL

by
Stephen Kaplan

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in the
University of Michigan
1962

Doctoral Committee:

Professor Edward L. Walker, Chairman
Professor Gerald S. Blum
Assistant Professor John H. Holland
Associate Professor Donald E. P. Smith

ACKNOWLEDGEMENTS

I could wish for no finer collaborator and co-adventurer in all matters, psychological and otherwise, than my wife, Rachel. Her advice and assistance have been essential in the development of this theory and the research program related to it. To her this dissertation and its author are immeasurably indebted.

The stimulating theoretical context out of which this work arose is due to my teacher, Dr. Edward L. Walker. I am grateful both for the freedom he provided to follow my own directions, and for his example as a psychologist's psychologist. His sophistication in psychological matters, his skill in locating relevant psychological issues in unexpected places, and his talent for devising simple and elegant solutions to complex experimental problems are all qualities worth striving for.

Automata theory has supplied the theorist with a tool that takes him out of the arm chair and provides him with as tough-minded, demanding, and intellectually respectable task as he could ask for. Dr. John H. Holland introduced me to this area and extended my understanding of it through years of patient coaching and stimulating discussion. His enthusiasm for my attempts at disciplined theory building has been a greatly appreciated source of reinforcement.

Dr. Donald E. P. Smith has joined me in many long and stimulating discussions concerning a wide range of theoretical topics. He has also contributed to my outlook by the example he has provided. He has followed the directions implied by his theory with courage and

dedication, no matter where it leads or what demands it makes.

Dr. Gerald S. Blum's ability to combine theory and sound experimental methods in his research program gained my respect from the time he introduced me to the Department and its many facets some five years ago. Through discussions with him I have regained the hope that the convergence of various psychological theories may still someday occur.

Two of my colleagues, Dr. Auke Tellegen and Mr. Paul Cornwell, have been particularly helpful through their comments on an earlier version of the manuscript. The micro seminar we held together has been both stimulating and enjoyable. Their interest in the enterprise has meant a great deal to me. Another colleague, and an outstanding student of mine, Mr. Lewis J. Kleinsmith, has played a central role in the research program that provides a background for this dissertation. His effectiveness in research is unmatched, and his failure to be inhibited by the knowledge that certain things cannot be done has been refreshing and profitable. I am also indebted to several of my other students who have discussed theoretical issues with me and who have been unrelenting in their demand for clarity.

Dr. Donald O. Hebb's writings have had a great influence on my thinking and are crucial to this dissertation. His encouragement is also warmly appreciated. I am also grateful to Dr. Peter M. Milner. His stimulating reactions to some of my theoretical ideas have served as an important and valuable incentive.

This research was supported in part by PHS Grant M4239 from the National Institutes of Health, Public Health Service, to Dr. E. L. Walker.

PREFACE

This dissertation places a heavy emphasis on theory. Thus some comments concerning the nature of theory may be in order.

The construction of theory has been a neglected topic in psychology. Courses are not offered in this area, and texts have little to say about how it should be done. Yet theory continues to persist. Theory building would perhaps be a more highly regarded activity if there were clear cut procedures for going about it and suitable criteria for evaluating the results. While these remain largely unsolved problems, the recently developed field of automata theory offers some promising tools. A simple but tremendously demanding contribution of automata theory is the suggestion that a statement is rigorous when it is specified sufficiently clearly to be understood by a computer. Another suggestion of this approach is that wherever possible each step follows from previously established statements, which ultimately lead back to the primitives of the system.

Theory has been, and must be, an intuitive enterprise. It involves a creative process, a new or different way of looking at familiar material. It is thus an art, at least to a large degree. The balance provided by the demands of automata theory is therefore most welcome. Art can be fuzzy; theory should not be. Although fulfilling these rigorous demands seems beyond the grasp of current psychological theory, the presence of such standards must have a salutory effect. Even approximating these requirements places a model in a much more readily disprovable position than is the case for most contemporary theory. Ambiguity is perhaps so comfortable for the very reason that it softens the awkward encounters with the empirical world.

Simplification is the hallmark of theory. In other words, a theory is like an amplifier, filtering out all but a small part of the available information (Walker, 1958a). Thus theory involves the rejection of certain alternatives in favor of other alternatives. All theories are over-simplifications in the sense that they do not use all the available information. Whether in the process a theory clarifies or distorts depends upon the appropriateness of the decision to accept a given alternative in favor of other possibilities.

The way these decisions are made is a complex issue. Here intuition plays a large part, and the basis for the decision is often difficult or impossible to verbalize. In other cases the decision seems reasonable in the light of its effect on other aspects of the theory. The demand of specifying concepts as clearly as possible complicates the situation; the number of decisions to be made is greatly increased. Given this multitude of decisions, some will undoubtedly be wrong or not fruitful. One can only strive for formulations explicit enough to make these errors discoverable.

Evaluation of these decisions is not easy. Since a theory consists of an interrelated set of such decisions the problem of evaluating a single decision is closely related to the problem of evaluating the theory in general. In fact, as Cronbach and Meehl (1955) have pointed out, these issues are usually inseparable, since any single concept only has an effect in conjunction with other concepts in the theoretical network.

The mode of theory evaluation that first comes to mind is, of course, empirical test. Since, however, any single finding has only a minor effect upon the status of a theory, numerous different studies must be undertaken. Another mode of theory evaluation is how many fruitful studies it leads to, the heuristic criterion. A theory should have within it many more possibilities and implications than its author can see at the time of its birth and infancy. Thus the kind and number of experiments suggested by a theory provide important criteria for evaluation of a theory, but both are long range procedures.

There are other criteria that can be assessed somewhat more readily. A theory should have wide scope. It should hang together. It should be rich in its possibilities, suggesting new ways of looking at familiar phenomena, and reasons for looking at overlooked ones. It should involve few central concepts relative to the number of implications it leads to. And by studying it with suitable care, others besides its author should be led to insights, predictions, and experiments.

In evaluating a theory on the basis of these criteria it is important to remember that theories are not static. They grow and change. This growth is not merely a drift to adjust to the ever shifting sands of empirical results. It occurs for many reasons. A theory changes as erroneous decisions are identified and corrected. It grows as manipulation of its various concepts leads to a clearer understanding of their relationships. It matures as the concepts are sharpened and checked through contact with the outside world. It grows also as it comes to encompass a broader and broader empirical domain. Thus in a young theory it is perhaps not its current status, but its potential that is of paramount importance. It must be solidly founded and show capacity for growth. A theory worth its name is not built to rise of fall on the basis of a single experiment, but to guide and be guided by a whole program of research.

TABLE OF CONTENTS

Chapter

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

It is traditional in psychology for a theory to start with aspirations far grander than the minute realm it finally claims for its own. This theory is no exception. It sets out to deal with a broad spectrum of behavior; one hardly less broad than that Grey Walter (1953) set for his model.

> But if the performance of a model is to be demonstrably a fair imitation of cerebral activity, the conditions of stimulation and behavior must equally be comparable with those of the brain. Not in looks, but in action, the model must resemble an animal. Therefore it must have these or some measure of these attributes: exploration, curiosity, free-will in the sense of unpredictability, goal-seeking, self-regulation, avoidance of dilemmas, foresight, memory, learning, forgetting, association of ideas, form recognition, and the elements of social accommodation. Such is life.
>
> (Pp. 120-121)

Further, following Cronbach (1957), it should deal simultaneously with general laws and individual differences. In other words, these two domains must interact rather than follow their traditionally parallel course.

At its present stage of embryonic development, it seems safe to say that the theory presented here accomplishes none of these things. The fond hope that it may some day achieve these goals is based on the following reasons. First, it is a structural theory. That is, it attempts to reach behavior through inferring a few basic underlying mechanisms rather than by cataloging behaviors. Second, the structure it posits is a physiological one. A theory whose postulates are at the behavioral level is in danger of producing no more theorems than it has postulates. A further advantage of a physiological model is that the postulates themselves are subject to empirical findings.

Finally, it makes an attempt at rigor. It may be useful here to distinguish between rigor and precision. It is highly unlikely that the model will be able to make exact or precise predictions in the foreseeable future. The intention is, however, that the predictions made by the model can be arrived at unambiguously, and that others using the same model can arrive at the same predictions. In its present state, the model is neither completely deductive nor purely intuitive. Rather, predictions from the model lie somewhere in between, on the continuum between the ambiguous and the rigorous. An attempt will be made to show that conclusions are reasonable in the light of the assumptions of the theory, and that in many cases the conclusions may even be expected from these assumptions. It is the intent of this paper to develop a theory explicit enough to be programmed on a computer. Such aspiration makes it no more likely that the theory will be correct, but it will hopefully lead to the earlier detection of errors.

The approach employed here emphasizes a number of hypothetical neural mechanisms that can be related to the once outmoded concept of perseverative activity. This topic, however, is once again beginning to receive attention in the psychological literature. The concept has even received a certain degree of physiological support (Burns, 1954). Much of the recent concern has centered around perseverative consolidation, the increment in memory observable following a period of rest. Glickman (1961) has written an excellent review of the empirical work in this area. Since this review, further studies using electroconvulsive shock (Feldman & Neet, 1960; Thomson et al, 1961; Madsen & McGaugh, 1961) and drugs (Breen & McGaugh, 1961; McGaugh et al, 1961; Paré, 1961) have provided additional support for this concept.

Less attention has been devoted to another aspect of perseveration: the concurrent effects of trace activity. An important beginning in this area has been made by Walker (1958) and his students working on the concept of action decrement, the relative unavailability of an activity during consolidation. The focus of this paper will be in this area of concurrent effects. Particular emphasis will be placed upon the nature of trace activity as a function of stimulus input and arousal parameters.

In psychological scope this model is primarily cognitive, or perceptual-cognitive. The sensory system is short-circuited; a "stimulus input" is treated as a pattern of excitation impinging on the system. The motivational system is similarly short-circuited; arousal is treated as a nonspecific form of input. The potential role of the limbic system, for example, is not considered. Thus the locus of the model, at this stage of its development, is not the entire conceptual nervous system, but primarily the cortex.

The theoretical model of trace activity developed here spans several levels. The neuron level provides the molecular base for the remainder of the model. This level concerns the various physiological processes that are thought to influence the behavior of individual units in the nervous system. Models at this level have been examined with considerable care by Rochester et al (1956), Milner (1957), and Kaplan (1960), and will not receive detailed discussion here.

At this level factors influencing whether or not a neuron will be fired must be specified. In broad outline these include such considerations as the input from other units, the recency of such input, and the state of the neuron in question (refractoriness and fatigue). It is assumed that the post synaptic potential (Eccles, 1957) is responsible for the temporal and spatial summation in the system.

Another factor of considerable importance at the neuron level is the set of rules determining the strength of connection as a function of use and disuse. There are apparently two distinct learning rules appropriate at this level. On the one hand there is post tetanic potentiation (PTP), a transient increment in connection strength (Eccles, 1953). It depends upon rapidly recurring, or tetanizing, stimulation. It has been hypothesized that it results from an over-replacement of transmitter substance in the end buttons of neurons following depletion due to the high level of firing. Since the evidence seems clear that this is a temporary effect, and since there is considerable evidence for relatively permanent memory in animals, another learning rule is postulated. This one posits a more lasting and more slowly acquired increment in connection strength as a function of repeated firing.

Another neuron level property, inhibition, is of particular importance for the remainder of the model. Early efforts at simulating neural nets, such as Hebb's (1949), ran into difficulty when the entire population of units under investigation became active. It was as if the entire brain became one grand phase sequence. Thus it became clear that an inhibition concept was a necessary addition to Hebb's rather austere model (Rochester et al, 1956; Milner, 1957). This was, of course, counter to the physiological Zeitgeist since the electrical theory of synaptic transmission then in vogue was at a loss to deal with inhibition, and preferred to believe that it did not exist. Within a few years, however, Eccles (1957) converted to inhibition and chemical transmission, and heresy became orthodoxy once again.

The model to be presented here depends not only on the existence of inhibition, but on a certain pattern of excitatory and inhibitory units as well. It is assumed that the inhibitory units do not generally inhibit the excitatory units controlling them, but other excitatory units. Milner (1957) makes this a postulate. Evidence for such an arrangement exists in the eye of the limulus (Ratliff et al, 1958), but it has not as yet been shown in the human brain.

Building upon these properties of the neuron level is the network level whose principles are of central importance in this theoretical model. The relationship of these principles to unit properties will be the subject of Chapter II.

The leap from the network level to the behavioral level is provided in Chapter III. To permit prediction to behavior, a bookkeeping system must be developed which enables one to follow the fluctuations in the hypothetical network activity in response to changes in arousal level and stimulation. This is accomplished with the help of a flow diagram, in an effort to make a rigorous statement through the use of some techniques of automata theory.

Chapter IV concerns an example of the kind of research suggested by this model.

CHAPTER II

THE NETWORK LEVEL

The characteristics of the network level should follow from the neuron level. The central concept at the network level is the perseverative trace. With a model essentially similar to the neuron level model briefly outlined in Chapter I, Rochester et al (1956) used computer simulation to explore the behavior patterns of groups of hypothetical neurons. They found that through repeated stimulation, diffuse networks capable of self-sustained activity were formed. This result serves both to define the perseverative trace, and to indicate that the concept is a reasonable outcome of neuron level properties. As used here, the term "trace" will refer to this interconnected network, no matter what its current mode of activity or state.

Four major classes of network characteristics are discussed in this chapter. The *properties* of the perseverative trace and its environment begin the discussion. These properties give rise to certain *effects* of perseveration. Both concurrent effects, such as short term memory, and long term effects, such as perseverative consolidation, are considered. These effects of perseveration, in turn, give rise to still *higher order implications*, culminating in an analysis of curiosity as an inherent property of the nervous system. The chapter concludes with a discussion of the ways in which perseveration is *modulated*. Of particular importance for later chapters is the discussion of the effects of one modulator, arousal, on perseveration.

Properties of the perseverative trace

Many of the properties of the perseverative trace are simply molar analogs of the properties at the neuron level. This follows readily since a trace is simply a network of individual units. Thus the fatigue that builds up through activity in each unit of a trace influences the overall behavior of the trace. "Average fatigue level of a trace," then, summarizes the unit property of fatigue at the trace level. Likewise the "average refractoriness of a trace" and the "average connection strength of a trace" summarize unit properties across all units in a trace.

Other properties of the trace are strictly group properties, and have no direct analog at the unit level. The size of a trace at any moment in time is the number of units participating in it. The speed is defined as the mean rate of firing per neuron per unit time. The pattern of inhibition and excitation is also a group property. Given the assumptions concerning inhibition at the neuron level, any trace can be seen as a set of excitatory units which excite inhibitory units which in turn inhibit other excitatory units. To use a spatial analogy, a neural circuit can be conceived of as being surrounded by a diffuse shell of inhibition. Space, in this analogy, represents a meaning dimension; in other words, it concerns the degree of interconnection rather than cerebral geography. It is not impossible, however, that the geography in certain instances, such as the projection areas, might correspond in some degree to a similarity dimension.

Properties of the environment

The neural environment of the trace is a key factor in the way the trace operates. An important aspect of the neural environment is the extent of activity in the system. The set of all units in the cortex that are active at any moment in time will be called neural space. The neural space has no specific locus, but involves different neurons at different times. Milner (1957) has advanced the interesting hypothesis that the size of neural space is relatively constant over time. Since a certain proportion of units in the system are inhibitory, any activity produces inhibition, and hence forced inactivity in other units. So at any given time only a certain proportion of all units in the system can be active. Any increase in activity will tend to increase inhibition, making further increase in activity more difficult. Likewise a decrease in activity weakens inhibition, encouraging more activity. Through this negative feedback system, the area of activity, or neural space, will tend to remain fairly constant. In this sense one can speak of the homeostatic neural space. As Milner (1957) has pointed out,

> Many factors have been neglected in this analysis; some ... difficulties (such as the fact that when the level of neural activity rises, the increase in inhibition will be offset to an indeterminate extent by increased temporal and spatial summation) cannot be dealt with until better quantitative data are at hand. In the meantime we can only postulate that the parameters involved have values within the limits necessary to allow the network to behave in the manner described.
>
> (P. 245)

Effects of the trace: concurrent

To the casual observer, the interval following a trial (or experience) might seem rather quiet, and even dull. It is the central hypothesis of this paper, however, that upon closer observation a variety of interesting and important phenomena are present during the life of the active trace. In determining which of these phenomena will occur at a given time, the size and speed of the trace play central roles.

Any stimulus input impinging on the units of an active trace may be blocked by that trace. Since a majority of the excitatory units of the active trace are likely to be either firing or refractory, and since the shell of inhibition limits firing in other excitatory units, the input pattern may be unable to establish a corresponding trace. Blocking is, consequently, a function of similarity or overlap between the ongoing and the potential trace. It is also more likely the greater the speed of the ongoing trace, since with higher speed more units will be active or refractory, and there will be stronger inhibition of surrounding units.

If a stimulus input does establish a corresponding trace, it may in turn interfere with an ongoing trace. This too is a positive function of the overlap, but an inverse function of the speeds of the traces. That is, interference is more likely the greater the speed of the potential trace and the smaller the speed of the current trace.

In a theory of this kind, behavior and thought are the result of trace activity. At the same time it must be possible for a trace to be active and not be affecting behavior directly. Three states of trace activity will be distinguished in terms of the degree to which behavior is directly affected. A trace that is currently directing behavior (or thought) will be said to be "in increment." If an active trace is not in increment, it will be in one of two other states, depending upon how readily it can be recalled. If it can be recalled readily, it is serving as short term memory. If it is relatively difficult to recall, it is said to be "in decrement."[1]

Increment

On the theoretical level, increment can be distinguished from the other states of the trace under discussion by the proportion of active units, or the size, of the trace. In order to direct behavior (or thought) the trace must have a certain minimum of its units active. If, on the other hand, only some smaller subset of units is active, the trace will be in one of the two non-incremental states.

It would seem that consciousness is in some respects quite similar to increment. While it is clearly possible for a trace to influence thought without being conscious, it seems unlikely that a trace could be conscious without influencing thought. Perhaps just as some minimum proportion of units of a trace must be active in increment, an active trace occupying a plurality of neural space will be conscious. This is reasonable if it is assumed that only a single thought tends to be conscious at any given moment, since only one trace can occupy a plurality of neural space at any one time. Although the scope of attention is limited in this way to only one thought at a time, this places no limitation upon the number of other activities that can occur simultaneously, as long as they are below the threshold of consciousness. By this analysis, the size of the trace is central to consciousness, as it is to increment.

Short term memory and decrement

In these two states the active trace is not directly affecting

---

[1] "Decrement" as developed by Walker (1958) and "decrement" as used here involve somewhat different mechanisms, but refer to the same phenomenon.

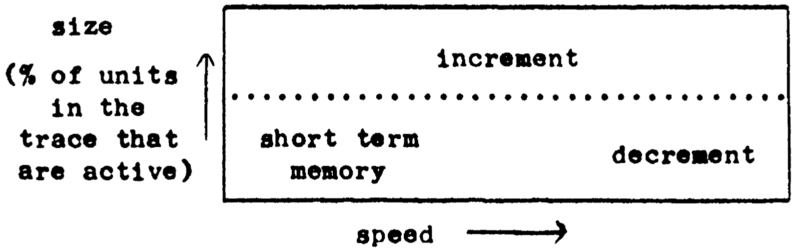
behavior. They can be distinguished at the behavioral level by asking the subject to recall the information stored in the trace. Facile recall indicates short term memory. When the subject finds it difficult or impossible to recall the information despite his intention to do so, the trace is in decrement. In practice this means that a base level of recall must be established in order to determine the degree to which recall is hindered.

In terms of the theory, the non-incremental trace does not appear in behavior because of its small size. Too small a proportion of the units of the trace are active. The ability to recall, however, depends upon stimulating the units in the active trace as well as additional units to produce a trace of increased size, or increment. The possibility of utilizing the active trace in this way, however, is limited by the speed of the trace. At relatively slow speeds this is readily accomplishable and thus material in short term memory can be recalled.

When the trace is reverberating at great speed, however, the activity and refractoriness it generates make it relatively immune to outside influences. (This parallels the blocking of input discussed previously. In this situation, however, the "input" represents the intention of the individual to recall. Thus the input comes from some other circuit in the system rather than from the perceptual world.) This is the case of decrement.

The greater the unavailability of the active trace, the higher the probability of activating other units instead, so that the resulting trace differs in certain respects from the original one. It follows that the larger the size of the ongoing trace, the greater the displacement will be. This is only true up to a point, since increasing size ultimately leads to increment.

Thus the theoretical distinction between decrement and short term memory is based on speed. The two non-incremental states are not sharply distinct, but represent ends of a continuum. At the slow speed end is short term memory, the state in which the trace is relatively readily influenced by the intention to recall. Decrement, at the high speed end of the continuum, is the state of the trace in which intention will tend to have little or no effect on the active trace. Increment is differentiated from the non-incremental states by the proportion of active units. The relationship of these states of the trace is summarized below.



It should be evident that the analysis of concurrent effects of trace activity presented here requires that size and speed be in some degree independent. This independence depends upon the homeostatic neural space concept, in that inhibition sharply limits increase of trace size after the trace is established. There is no comparable limitation on the speed of trace activity. Furthermore, a decrease in trace size may lead to an increase in trace speed (all other things being equal) since the units lost through time will tend to be the less active members of the trace.

Effects of the trace: long term

The long term effects of perseveration have received increasing attention in recent years. Consolidation, inferred from the improvement in performance occurring over a period of time during which no overt practice occurs, follows from the nature of trace activity and the rule for increase of connection strength. Trace activity involves repeated firing of a restricted set of units, and repeated firing increases connection strength.

Over a number of trials interference may occur repeatedly and fractionation thus becomes an important aspect of trace activity. In the Organization of Behavior, Hebb (1949) introduces fractionation in his discussion of the way in which a cell assembly loses units initially associated with it. The addition of inhibition to the legitimate repertoire of the conceptual nervous system makes fractionation even more likely to be a common occurrence. By the learning rules of the class of neural models under consideration, the probability that a sequence of units will fire increases with repetition and decreases with disuse (at least within certain limits). Take for example any sequence of units ABC within a given circuit. If a pattern of excitation is imposed such that A tends to be excited while B is simultaneously inhibited, there will be a decrease in the number of AB pairings. Presumably this pattern of excitation will elicit some other sequence, say AX. Thus the number of AB pairings is decreased relative to the AX pairings, and the latter sequence will gain in probability. Eventually the AX sequence may becomes more likely, thus replacing AB in the circuit. The original circuit has beome fractionated.

Higher order implications

In the same way that the properties of the neuron level suggest a number of interesting properties of networks, network properties lead to some principles at a still higher level. Two such principles will be discussed here, both involving an extended time period.

The change in neural activity that occurs over a series of trials is quite complicated. Initially the units excited by the stimulus input belong to other circuits as well, and thus additional units are excited, resulting in relatively widespread activity. As the organism samples his environment, he perceives various sets of stimuli, and corresponding sets of units are successively activated. Since the organism is mobile, and the environment is often independently changing, a different stimulus set is sampled from trial to trial, resulting in variations in the neural units that are excited on any given trial. It is assumed, however, that there is a certain degree of continuity in the organism's environment, so that the stimulus population is not entirely different at each time step. Each successive sampling, then, excites some units common to previous samples. In this way partially overlapping traces are established. As described previously, both fractionation and interference occur as trials continue. Gradually the subset of units common to most sample sets gains strength of interconnection at the expense of noncommon units and thus the effect of a stimulus becomes less widespread and more reliable. This process, whereby the same stimulus pattern ultimately has its effect on fewer units and thus has a much smaller effect on ongoing neural activity than it did initially, will be called condensation.[1]

---

[1] The term "condensation" is borrowed from graph theory. A condensation of a directed graph (digraph) is a sort of summary. It is itself a digraph whose points represent closely connected sets of points in the original digraph. As Dr. E. L. Walker has pointed out, the graph theory meaning of the term has interesting implications. The strongly connected sub-parts of a circuit will undoubtedly perseverate longer and thus become part of the "summary circuit." The fact that condensation arises out of units common to many experiences implies that these units will become strongly connected.

As the set of units activated by the stimulus pattern is progressively reduced, a task that initially enjoyed vast cognitive involvement ultimately can be performed with little or no effort and attention. Note, however, that the condensed trace continues to exert an important influence on behavior.

One of the most important implications of condensation is that experience with a given stimulus pattern should lead to a decrease in time spent with the pattern. As a trace condenses, fewer and fewer units are involved. At the same time, due to the homeostatic nature of neural space, the previous level of neural activity will tend to be maintained through a lowering of inhibition which reduces thresholds throughout the system. This will increase the organism's sensitivity to further neural activity, whether instigated by ongoing traces or external stimulation. In general, the organism will tend to spend less time with familiar stimuli since they produce little cortical involvement. He will spend more time with novel stimuli since they produce widespread involvement. Thus novel stimuli will tend to maintain the level of neural activity. It may be said that curiosity, or sensitivity to and time spent in contact with novel stimuli, follows from the nature of the system.

Modulation

We have seen how a number of different states of trace activity arise from differences in the size and speed of the trace. Variables influencing the size and speed of the trace are thus of particular importance in this system. One such modulator of trace activity is the level and balance of transmitter substance and transmitter hydrolizer. Acetylcholine (ACh) is thought to mediate transmission across the synapse, and may be the transmitter substance in the cortex. Cholinesterase (ChE) which hydrolizes or destroys ACh, also produces its effect at the synapse. Which particular substances mediate synaptic transmission is of course not crucial to the theory. ACh and ChE are, however, the best candidates based on current physiological evidence (Crossland, 1960). Whatever substances are involved, influence in neural transmission makes them of considerable interest for this theory. Further discussion of these modulators will be relegated to a future paper.

Arousal is the other essential modulator in this system. As used here, arousal is equated with the nonspecific facilitation of neural activity, presumably under reticular and hormonal control. Such nonspecific facilitation provides diffuse stimulation of cerebral units, in effect lowering thresholds throughout the system. This causes firing to occur more readily. Thus an increase in arousal produces an increase in the activity level, or speed, of a trace.

Arousal may also increase the size of an active trace, but to a far lesser degree since, being nonspecific, it also facilitates activity in other traces. The result, following the neural space argument, is an overall increase in inhibition, limiting the possibility of size increase.

Arousal plays a unique and important role in modulating the effect of stimulus input. Any input produces a distribution of excitation in the corresponding projection area. Thus a stimulus will produce a range of effects upon different neural units, ranging from very strong to very weak excitation. Which of these units is actually fired depends upon both the strength of excitation it receives from the stimulus, and the degree of nonspecific activity present. Thus given a constant level of stimulation, the higher the level of of arousal, the more units will be fired, or, in other words, the larger will be the trace produced by the stimulus. Thus it is at the time that the stimulus initiates a trace that arousal has its major effect upon trace size.

The momentary increase in arousal that follows stimulation has a quite different effect upon the trace. In general a trace decreases in size through time since units are lost through fatigue. Thus the momentary increase in arousal following stimulation will increase the speed of the trace while it still has most of its original units. Through post tetanic potentiation, this will result in a considerable temporary increase in connection strength which in turn prolongs the activity level of the trace. A momentary arousal increase at some later time will have the same effect, but upon a smaller set of units of that trace. High overall arousal, on the other hand, while supporting the trace in a similar way will also have a contrary effect. As noted above, high arousal level will tend to facilitate stimulus input in general, so that the trace is in constant danger of interference from subsequent stimulation. These two effects of arousal may balance each other.

The differential effect of arousal depending upon whether a trace is being initiated or is already under way has interesting practical implications. From the previous discussion it follows that the momentary increase in arousal following the presentation of a stimulus will have a very different effect from the organism's resting or base line arousal level. Two measures of arousal that have shown great promise in recent years have these temporal properties. Basal resistance level (BRL) is a rather gross skin resistance measure that reflects the organism's general level of arousal and changes relatively slowly in time (Levy et al, 1958). Galvanic skin response (GSR), a momentary drop in skin resistance, is a brief, transient phenomenon which often occurs in reaction to a particular stimulus. We have seen that any brief stimulus will receive facilitation from the resting arousal level at that time (measured by BRL) but it may no longer be present when the GSR occurs. Thus, as indicated previously, BRL will be the most important influence on the size of the trace, while the speed of the trace may be strongly influenced by GSR.

SUMMARY

The perseverative trace is the central concept at the network level. Its properties are fatigue, refractoriness, connection strength, size, and speed. The trace also has a characteristic pattern of inhibition which leads to the homeostatic neural space, the immediate environment of the trace.

Besides blocking stimulus input and interfering with other traces, the active trace can have three additional states. These are increment, when the trace is influencing behavior (or thought), short term memory, when the trace is not influencing behavior but is available, and decrement, when the trace is neither directly influencing behavior nor available. In terms of the model, differences in the size and speed of the trace are responsible for the differences in state.

Over a series of trials trace activity leads to perseverative consolidation. Through repeated interference a series of trials also leads to fractionation. In this way condensation, the development of a smaller, more efficient trace, occurs. Since the homeostatic neural space requires new stimulation to maintain the activity level as traces condense, organisms seek novelty.

Arousal, one of the modulators of the system, has differential effects upon the size and speed of the trace depending upon timing. A momentary increase in arousal following stimulation (GSR) will have its major effect on the speed of the trace. The overall arousal level (measured by BRL) plays an important role in determining the size at the moment the trace is set up by stimulus input.

CHAPTER III

BOOKKEEPING AT THE NETWORK LEVEL

An orderly accounting of the ways in which the perseverative trace changes as a function of time, stimulation, and arousal requires a bookkeeping system. A flow diagram of the kind used as a preliminary step in writing a computer program seems well suited for such accounting. A statement must be explicit and relatively devoid of ambiguities to be interpretable for the limited cognitive capacity of the computer. The clarity and detail necessary for a flow diagram are requirements as helpful as they are distressing for the theorist. It is interesting that computer technology has in this way provided the theorist with an operational definition of rigor.

In certain respects, however, the diagram discussed in this chapter is intentionally inappropriate to any general-purpose computer now in existance. The present day computer behaves in serial fashion. Yet, as von Neumann (1958) has pointed out in his excellent book, The Computer and the Brain, the brain is a highly parallel mechanism. Thus the diagram represents several processes as occurring simultaneously. Although for the purposes of programming a general-purpose computer these processes could be serialized, the parallel form is a more appropriate model of the physiological processes it represents.

The steps of the diagram concern some relatively molar outcomes of the mechanisms developed in Chapter II. Not all of the previously discussed outcomes are included here; rather the flow diagram emphasizes those aspects of activity in a single trace that are influenced by arousal and stimulus input, and that are important in determining the concurrent effects of trace activity. This limitation in the scope of the diagram is intended to aid in relating the very general theoretical considerations introduced previously to the necessarily specific empirical concerns in the next chapter.

The flow diagram is also limited in the slice of time and space it comprehends. It represents trace activity at a single instant in time. Over the course of many iterations it can of course follow a trace through as long a time as is desired. The spatial restriction is less flexible, however. The focus is on a single perseverative trace and the immediately surrounding neural space; if stimulus input should terminate the ongoing trace, the focus immediately shifts to the new trace and its surrounding space.

Thus the flow diagram represents but one of many possible bookkeeping systems representing the molar activities of the model.

Notation

The variables dealt with in the diagram are coordinate with the network level concepts spelled out in Chapter II. These variables are identified in Table 1. The trace, T_t, is the element at this level. Four properties of the trace are considered, the size or number of active units (n_t), the speed or intensity of activity (i_t), the connection strength (c_t), and fatigue (f_t). Refractoriness does not receive explicit mention in the diagram. Indirectly it is included in the speed concept, since the two variables are highly correlated.

There are two kinds of input which influence the trace. An arousal change (ΔA_t) may produce a change in the speed of the trace ($\Delta_A i_t$), and to a limited degree, in the size of the trace ($\Delta_A n_t$). An arousal change also of course influences the arousal level (A_t) of the system.

The second type of input, a new stimulus (S_t), is more complicated to deal with. There are three properties associated with a new stimulus. Two of these properties are similar to those of the trace. Since the stimulus input is not a trace, however, these properties are defined somewhat differently. The stimulus input has size (X_t) in the sense of the number of units it impinges upon. It has intensity (Y_t) in the sense of the average level of stimulation (in pulses per second) the units it stimulates receive. The third property of the stimulus input is the proportion of overlap (Z_t) between the units of the ongoing trace and the units it impinges upon. This property defines the similarity of the stimulus and the trace.

The properties of the new stimulus permit the computation of the size (n_{S_t}) and speed (i_{S_t}) of the hypothetical trace (T_{S_t}) that would be set up by the new stimulus if no competing trace were present. This collection of stimulus-related properties is necessary to determine if the stimulus is blocked, or if the trace is interfered with by the stimulus. In the latter case the amount of interference ($\Delta_S n_t$) is computed.

A majority of the factors discussed above produce changes in the size and speed of the ongoing trace. There is the change in size produced by stimulus interference ($\Delta_S n_t$), that produced by arousal change ($\Delta_A n_t$), and that produced by the joint effect of connection strength ($\Delta_{c/f} n_t$). These together produce the total change in size ($\Sigma\Delta n_t$).

Speed is influenced by arousal ($\Delta_A i_t$), connection strength and fatigue ($\Delta_{c/f} i_t$), and the decrease in size that occurred in the previous time step ($\Delta_n i_t$). These are the components of the total change in speed ($\Sigma\Delta i_t$).

To simplify the diagram, a threshold for blocking (b) and a threshold for the termination of the ongoing trace (k) have been added.

The remainder of this chapter concerns the exposition of the flow diagram (Fig. 1). The discussion that follows immediately concerns the flow diagram's coordinate system and serves as an overview. Figure 2 provides a parallel flow diagram in words rather than symbols and a more detailed commentary is provided in a step-by-step guide to the diagram.

Coordinate system

The flow diagram is embedded in a somewhat informal coordinate system. Although the primary function of the coordinate system is to provide a convenient system for identifying any particular step under discussion, it also serves to emphasize common elements in the horizontal and vertical strata of the diagram. There are three principal vertical divisions of the model (Fig. 1). The middle two columns, C-D, concern the changes in the ongoing trace as a function of its previous activity. The summing of the changes in the trace produced by other factors appears here also. On the left, columns A-B deal with the new stimulus input. The key issues here are (1) whether the stimulus input is blocked by the ongoing trace, (2) if not, to what degree the new stimulus interferes with the ongoing trace, and (3) whether the interference, if any, is sufficient to terminate the activity of the ongoing trace. If so, the properties of the new trace elicited by the stimulus input are computed. This trace then replaces the previously ongoing trace as the focus of the model. On the right,

TABLE 1

FLOW DIAGRAM NOTATION

T_t	Current trace
T_{S_t}	Trace that might potentially be set up by S_t

Inputs

S_t	New stimulus (0 or 1)
X_t	Size of S_t
Y_t	Intensity of S_t
Z_t	Proportion of overlap or similarity with T_t
ΔA_t	Arousal change

Properties of T_t

n_t	size (number of units)
i_t	speed (intensity)
c_t	connection strength
f_t	fatigue

Properties of T_{S_t}

n_{S_t}	size
i_{S_t}	intensity

System property

A_t	arousal level

Joint properties of T_t & T_{S_t}

r_t	overlap (similarity)
q_t	ratio of speeds

Constants

b	"blocking threshold"
k	minimum size

Changes in properties of T_t

$\Delta_s n_t$	change in n_t produced by S_t
$\Delta_A n_t$	change in n_t produced by ΔA_t
$\Delta_{c/f} n_t$	change in n_t produced by c_t & f_t
$\Sigma\Delta n_t$	total changes in n_t
$\Delta_A i_t$	change in i_t produced by ΔA_t
$\Delta_{c/f} i_t$	change in i_t produced by c_t & f_t
$\Delta_n i_t$	change in i_t produced by previous drop in size
$\Sigma\Delta i_t$	Total change in i_t

Functions

$A_i(x)$	Effect of ΔA_t on speed function
$A_n(x)$	Effect of ΔA_t on size function
$B(x)$	Blocking function
$C_i(x)$	Effect of c_t on speed function
$C_n(x)$	Effect of c_t on size function
$E(x)$	Effect of A_t on n_{S_t} function
$F_i(x)$	Effect of f_t on speed function
$F_n(x)$	Effect of f_t on size function
$G(x)$	Effect of A_t on i_{S_t} function
$I_c(x)$	Effect of speed on c_t function
$I_f(x)$	Effect of speed on f_t function
$R(x)$	Interference (retroaction) function
$V(x)$	Effect of previous change in size on speed function

(See Appendix I for an indication of the shape these functions might take.)

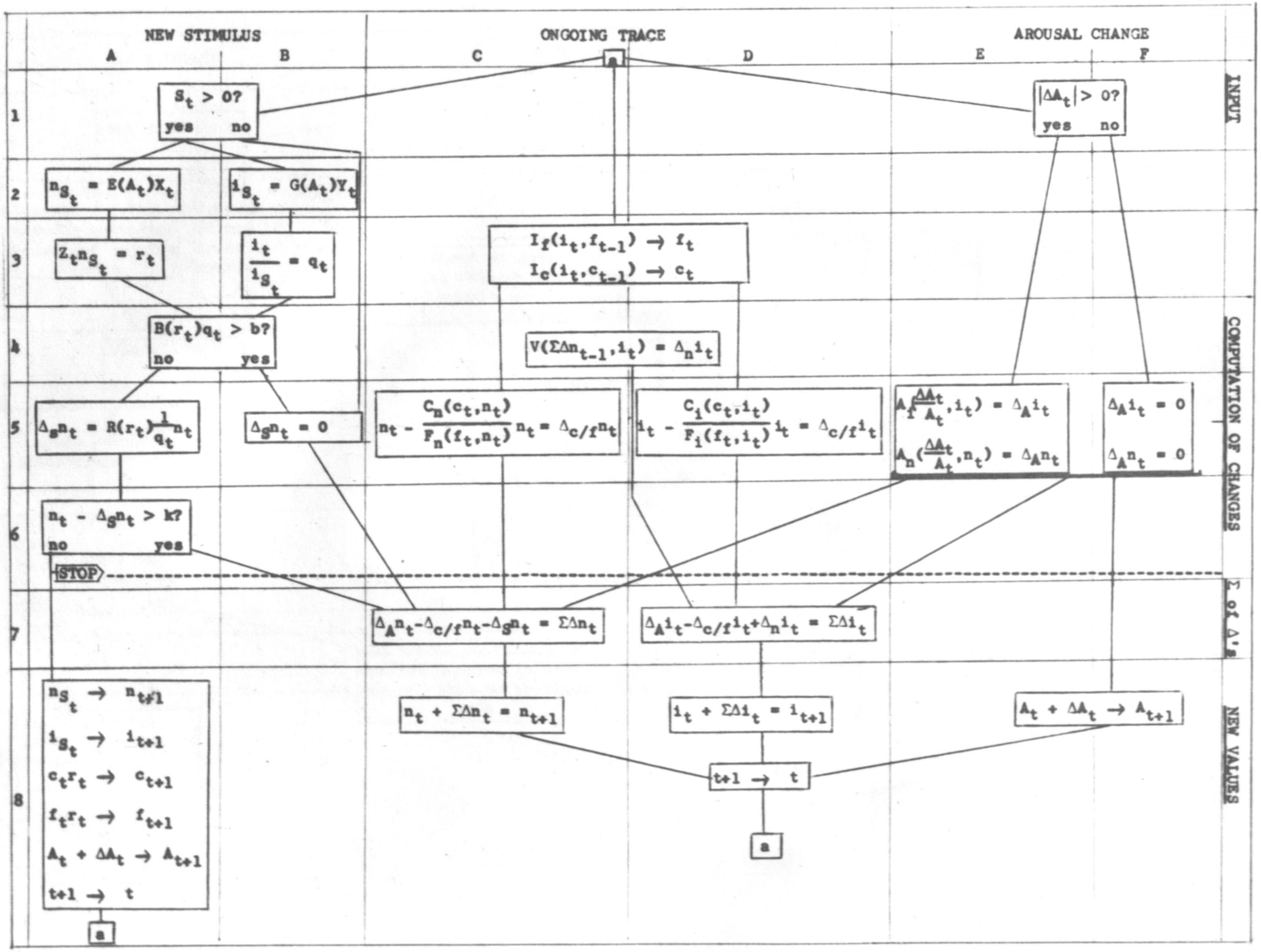


Fig. 1 - Flow diagram of model at network level

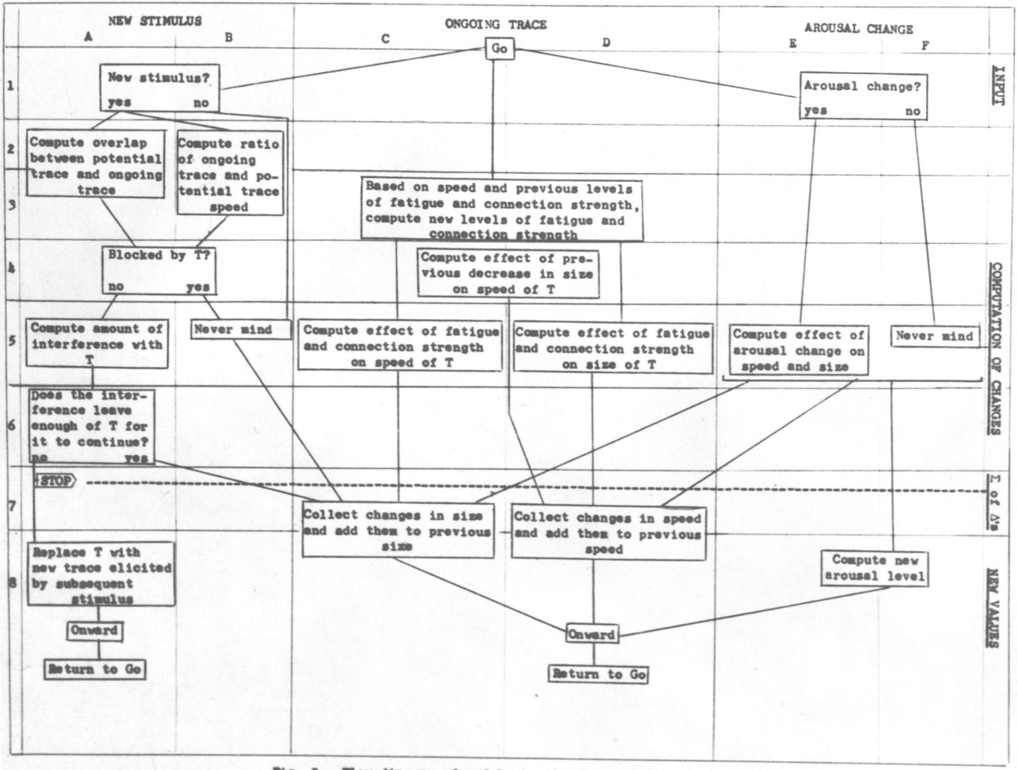


Fig. 2 - Flow diagram of model at network level (non-symbolic)

columns E-F, is the evaluation of the effect of an arousal change, if any, upon the ongoing trace.

The horizontal divisions of the flow diagram's coordinate system concern the ordering of events within the time step. Any new stimulus or arousal change begins at Row 1. Rows 2-4 are preparatory to the computation of changes in size and speed of the trace, which occurs in Row 5. The issue of whether the ongoing trace is to be overcome by the stimulus input is decided in Row 6. If the trace is overcome, activity is terminated in all columns except A. In Row 7 the various changes in size and speed are summed, and in Row 8 they are used to compute the new values of the key parameters.

Stepwise guide to the flow diagram

Section AB 1-5 of the diagram concerns the effect of the trace upon new stimulation. If there is none (that is, if the stimulus is not blocked), this section deals with the degree of interference produced by the stimulation.

Stimulus input (AB 1) presumably fluctuates over time. Thus there will generally be some new stimulus at each new time step, albeit small and weak on many occasions.

The size (A 2) and speed (B 2) of the trace that would be set up by the stimulus input is computed. In order to evaluate the properties of each such hypothetical trace, there must be some standard comparison condition. This standard is the trace that would be set up given no competing trace, and given the level of arousal obtaining in the system at time t.

The ratio of trace intensities (B 3) is necessary to determine whether the new input will be blocked. As concluded in the previous chapter, blocking is also a function of the overlap between the two traces (A 3). If these factors are sufficiently strong the blocking threshold will be reached (AB 4). In other words, the stimulus will be unable to influence a sufficient number of units to have any effect upon ongoing neural activity.

If the stimulus input is not blocked, it has an effect upon the ongoing trace (A 5). This effect again depends upon the overlap of the two traces and the ratio of intensities. In this case, however, the ratio is the reciprocal of the ratio involved in determining whether blocking has occurred. This is because blocking is more likely the greater the relative strength of the ongoing trace, while interference is more likely the less the strength of the ongoing trace.

Section A 6-8 determines whether the ongoing trace has survived the interference produced by the stimulus input, and if not, establishes the properties of a new trace based upon the stimulus input. It is impossible for a trace to continue if interference results in the loss of too many units. A small number of units can neither control sufficient inhibition to limit extraneous activity, nor sustain its own activity for any length of time, since the probability of a unit in the miniature trace passing on excitation to some other still active unit is greatly decreased. Thus any small number of units not incorporated in the new trace is quickly terminated by inhibition from the new trace. Since this diagram operates on a relatively long time step, any activity remaining from the deposed trace will terminate before the beginning of the following time step.

Thus if the remaining number of units in the trace is not greater than a certain minimum,[1] the activity of the ongoing trace ceases, and a new trace based upon the stimulus input becomes the focus of the theory. In this case the computation of values for the now deposed trace are no longer relevant and are terminated (A 6). Values must then be determined for the new trace (A 8). The new trace acquires the previously computed values of the potential trace in the case of size and speed. Fatigue and connection strength are a different matter, however, since any units that remain from the previous trace will retain the fatigue and connection strength levels of the previous trace. In other words, the state of the neurons that made up the deposed trace is relevant to the degree that these units participate in the new trace. Thus to the extent of overlap, the connection strength and fatigue of the deposed trace are carried on.

Section CD 1-5 of the diagram deals with the activities of the ongoing trace as a function of what transpired during the previous time step. The effects of fatigue and connection strength upon the size and speed of the trace are computed in this section of the diagram.

Fatigue increases as a direct function of speed and an inverse function of the previous level of fatigue (CD 3). That is, the higher the speed of the trace, the more fatigue is produced, but the greater the fatigue produced previously, the smaller the increment in fatigue

---

[1] This stipulation of a threshold provides an interesting illustration of a theoretical choice point. Although, as I have argued above, it seems likely that a remnant of a trace would quickly terminate, this is certainly not the only logical possibility. The flow diagram could be modified to permit the remnant of the ongoing trace to continue as long as any of its units remained active, to "die a natural death," as it were. While it seems reasonable to assume that this modification would not have sufficient effect to be worth further complicating the model, it does represent a decision point -- one perhaps suggested, but clearly not demanded, by the principles of the network level.

at this time step. An increase in connection strength, likewise is a direct function of speed and an inverse function of the previous level of connection strength.

Fatigue and connection strength have compensatory effects upon the size of the trace (C 5). Fatigue causes a reduction in the size of the trace through the dropping out of units, while connection strength tends to delay the loss of units. Following the post tetanic potentiation model discussed previously, connection strength increases rapidly as a function of speed. Fatigue increases more slowly as a function of activity, but reaches an asymptote much later. The analysis for the speed of the trace as a function of fatigue and connection strength (D 5) follows the same pattern as for size.

The loss of units at the previous time step will increase the speed of the ongoing trace (CD 4). A unit that drops out must have received fewer inputs from other members of the trace than one that remains active. Thus units drop out in the order of their membership strength, with the less central units going first. In this way the dropping out of units is a factor favoring higher mean activity level of the remaining units.

Section EF 1-8 deals with the effect of a change in arousal on trace activity. The effect of arousal (E 5, F 5) upon the speed of the trace depends upon the degree of change in arousal at time t and the current speed of the trace; likewise the effect upon size depends upon the degree of change and the current size. Any arousal change, of course, also influences the level of arousal in the system (EF 8).

Section CD 7-8 brings together the influences on speed and size developed at various points in the diagram. As we have seen above, of the changes influencing the size of the trace (C 7), the arousal change is positive, while the effects of stimulation and the ratio of connection strength to fatigue will in general have a negative effect. The factors affecting the speed of trace activity (D 7) generally are positive tending to produce an increase in speed through time.

Finally the changes are added to the previous levels of size and speed, setting the values for the next time step (CD 8).

CHAPTER IV

FIGURE DRAWING AS A FUNCTION OF AROUSAL AND INTERPOLATED INTERVAL

The theoretical model described in the previous chapter makes a number of statements about the ways in which arousal modulates trace activity and thus affects behavior. In the present chapter, a study will be presented as an illustration of the kind of research suggested by the model. The empirical area selected to explore some of these statements is provided by measurement of change in figure drawing as a function of time, with arousal recorded concurrently.

Memory for geometric figures is by no means a new area of research. Although the technique has not previously been used in conjunction with arousal assessment, it may be pertinent to review briefly the area from the point of view of the methodological problems that need be considered.

According to Woodworth's (1939) review of the early literature, the first study in which a subject was asked to reproduce a figure from memory after an interval of time was carried out by Philippe in 1897. Research on this problem was greatly stimulated by Wulf (1922) who emphasized the tendency of remembered figures to achieve a "good Gestalt" over a period of time. Wulf felt he had found good evidence for the Gestalt dynamic-trace hypothesis. His conclusion was not, however, accepted without argument. In the research that followed, more and more attention was paid to the methodological issues central to any research on changes in memory for geometric figures.

Hanawalt (1937) showed that having the subject draw the same figures repeatedly introduced a progressive error different from the change occurring over time when no intervening drawing had taken place. He also demonstrated that a subject often can recognize the correct figure even when his drawing would indicate poor retention.

The importance of simplicity in experiments of this kind was emphasized by Hebb and Foord (1945), who presented only two figures to their subjects. They sided with Hanawalt in arguing that multiple drawings by the same subject introduce a confounding factor since the relevant trace or some alternative trace must be excited each time. Thus they tested for retention only onee for each subject, and used the method of recognition.

Walker and Veroff (1956) used the reproduction method of measuring retention and saved it from disrepute by demonstrating that the productive error, that is, the successive error produced by drawing alone, is essentially random and small compared to the change that occurs over a period of time. It is important to note, however, that this applies to a single drawing and not to a series of successive drawings. Presumably in the latter case, Hanawalt's finding that progressive errors occur would still hold.

Since in several respects the reproduction method has distinct advantages over recognition, Walker and Veroff's demonstration that a single drawing is not a major source of distortion is of considerable importance. The method of recognition has often been shown to be less difficult than the method of recall (reproduction, in this case). Recognition would, therefore, be a less sensitive measure of memory error. A further advantage of the reproduction measure follows from the different operations employed. Presenting the subject with a blank sheet of paper upon which to draw a figure does not re-excite the trace in the same way as presenting him with series of similar figures from which to choose.

Woodworth and Schlosberg (1954) argue that much of the variance attributed to memory change may in fact be due to a distortion in the original perception. An effect of this kind can be controlled by having the subject draw the figure immediately after it is presented as well as some time later. In this way, the later drawing can be compared to the initial one rather than to the stimulus figure (Hebb & Foord, 1945).

It is these procedural matters rather than more substantive issues that are of relevance here. While taking these methodological pitfalls into account, the design of the present study was necessarily different from its predecessors since it was based on a different model. The purpose of this study is to explore the effects of different arousal patterns upon concurrent trace activity. Figure size was chosen as an index of trace activity on the suspicion that the well documented tendencies of memory for figures to vary in time might be due, in part, to concurrent activity influenced by arousal.

Thus, rather than being interested in "good Gestalten" or in the particular properties of particular figures, the emphasis in the present research is upon the dynamics of trace activity as a function of time and arousal. The salient features of the design reflect this purpose:

1. The figures were simple, neither resembling particular objects nor having any intentional strains toward some missing symmetry or other aspect of good form.

2. The time intervals sampled were relatively short for this kind of research. They were chosen on the basis of data from a previous

investigation (Kleinsmith & Kaplan, 1962), involving retention of paired associates of differing arousal values rather than geometric figures, which provided the best indication of the time course of trace activity in humans presently available.

3. In order to assess the influence of various arousal patterns, skin resistance was monitored during the presentation and initial drawing of the figures. The method used permitted assessment of the two components of arousal mentioned in Chapter II. Both the momentary fluctuations in response to a stimulus, galvanic skin response (GSR), and the underlying arousal level, basal resistance level (BRL), were obtained.

Arousal predictions

In terms of the model, a momentary arousal increase (measured by GSR) has its major effect upon the speed of trace activity. In terms of the concurrent effects involved, this increased speed should lead to deeper decrement of the trace and therefore a relatively large change in the size of the drawings. On a longer range basis this should lead to better learning; that is, a memory trace more representative, or a more accurate reproduction, of the original drawing.

In the case of arousal level (using BRL as the index), by contrast, it has been argued that the effect is upon the size of the trace, and to a lesser extent upon speed. The prediction in this case is unfortunately not as clear cut, since there is no direct link between size and behavior as there is with speed. A prediction here can be made only with the addition of a number of hypotheses, thus weakening its direct bearing on the theory.

The additional hypotheses are used to relate certain aspects of trace size to the perceived size of a figure. When a subject views a figure, a distribution of excitation is produced in the visual system. Arousal level will determine the proportion of this distribution that is fired, and that thus becomes part of the ensuing trace. It then follows that high arousal level leads to a higher proportion of visual system units in the trace. If such a proportion is assumed to be a factor in the remembered size of the stimulus, then a higher arousal level will lead to memory of larger figures. Since remembering a geometric figure is rarely confused with seeing one, it will be assumed that a large proportion of the visual projection area units in the trace will drop out fairly rapidly after termination of stimulation. Thus a momentary increase in arousal following stimulation might also influence the proportion of visual units in the trace by preventing some of these units from dropping out before they had become a stable part of the trace. By this argument arousal level would tend to lead to memory for larger figures, with GSR having a similar but weaker effect.

METHOD

Subjects - Sixty University of Michigan undergraduates obtained from the introductory courses in psychology served as subjects.

Apparatus - Skin resistance was recorded with a modified Varian G-11A (Varian Associates, Palo Alto, Calif.) which permitted simultaneous recording of GSR and BRL. The electrodes were of the zinc variety described by Lykken (1959) and were attached to the first and third fingers of the subject's non-writing hand.

Procedure - Four figures, presented in random order, were used. These were a square (10 mm per side), a circle (50 mm diameter), a pair of parallel lines (40 mm long, 5 mm apart), and an obtuse angle (135°, 30 mm each side). Each figure was drawn in black india ink on white oak tag, 3 x 5 inches.

The subject was told that he would be presented with four figures, one at a time, and that after he saw each one he should "draw it as accurately as he could" in the 3 x 5 inch booklet before him. A stimulus card was then presented for 5 seconds and as it was taken away, the subject drew the figure. This procedure was repeated four times and the subject drew each figure on a different page in the booklet.

Skin resistance was recorded throughout this period and an event mark on the record, produced as each card was presented, indicated the subject's arousal reaction to each stimulus.

Design - The subjects were divided into five groups, differing in the time period between the initial drawing of the figures and the recall session. The time intervals used were: 2 minutes (immediately after finishing the initial drawing), 10 minutes, 40 minutes, one day, and one week. The first four groups were also tested at one week. At each recall period, the subject was given a new booklet with four 3 x 5 inch sheets of paper stapled together and was instructed to draw the four figures (in any order) as accurately as possible. A few subjects forgot one of the figures, the angle in all cases, and were reminded.

It should be noted that the initial presentation of the stimuli and all but the week recall session were individually administered. The week session was conducted in small groups and all subjects were instructed at the same time to draw the four figures in their booklets. Arousal records were obtained only for the initial drawing.

Data analysis - I. Figure drawing: One measurement was used to characterize each figure. Square: the longer distance between sides taken midway across the square. Circle: diameter at the widest point. Parallel lines: the length of the longer of the two lines. These three measures were obtained to the nearest millimeter. Angle: size of the angle in degrees. A few subjects drew the angle as an acute triangle (at the week recall interval). These responses were omitted from the analyses.

II. Skin resistance: Any drop in the subject's skin resistance which occurred during the presentation of the figure (5 seconds) was considered an arousal deflection (GSR). These were converted to per cent deflection, thus making scores comparable across subjects. The deflections were divided into two categories by assigning the two highest changes for each subject as High, and the two lowest, Low. This was done to assure equal representation of the subjects in the high and the low GSR categories. Where all four deflections were zero or one per cent, all four were classified Low. If the two middle values were tied, the ties were not broken, but both were assigned to the same classification, High if greater than 7% (median for the group), and Low if 7% or lower.

Basal resistance level was scored by recording the resistance level immediately before the presentation of each figure. All readings above the median for each figure were then classified as Low arousal level and those below the median were considered as representing High arousal level. Since with only one exception all four BRL scores for each subject fell in the same category, subjects were classified as High or Low arousal level across all figures.

RESULTS

Figure size

The mean size of each figure at each time period sampled is presented in Fig. 3. The first points represent the initial drawing for all 60 subjects, while each subsequent point represents an N of 12. (The raw data on which this and the two subsequent figures are based may be found in Appendix II.) No reliable trends in size of drawing across the four figures can be seen in Fig. 3.

The mean size of each figure at each time period is presented in terms of high and low GSR in Fig. 4. Although GSR was scored so that wherever possible each subject had two high and two low GSR's, no restrictions were placed upon the distribution of high and low GSR by figure. This for any given figure the N's for the two groups at each time interval vary (see Appendix III).

As can be seen in Fig. 4, each geometric figure presents a unique pattern. It is interesting to note, however, that the patterns for high and low GSR are generally quite different.

The effect of arousal level (BRL) on figure size can be seen in Fig. 5. Since the split into high and low arousal level was made on the basis of the total sample, the N's for these groups at each time condition vary (see Appendix III).

According to the previous argument, a major effect of arousal level is through the facilitation of stimulus input, leading to a higher proportion of visual units in the resulting trace. The possibility that this aspect of initial trace size is reflected in the remembered size of the figure receives support from the week test interval data (Table 2). For each figure, the subjects in the high

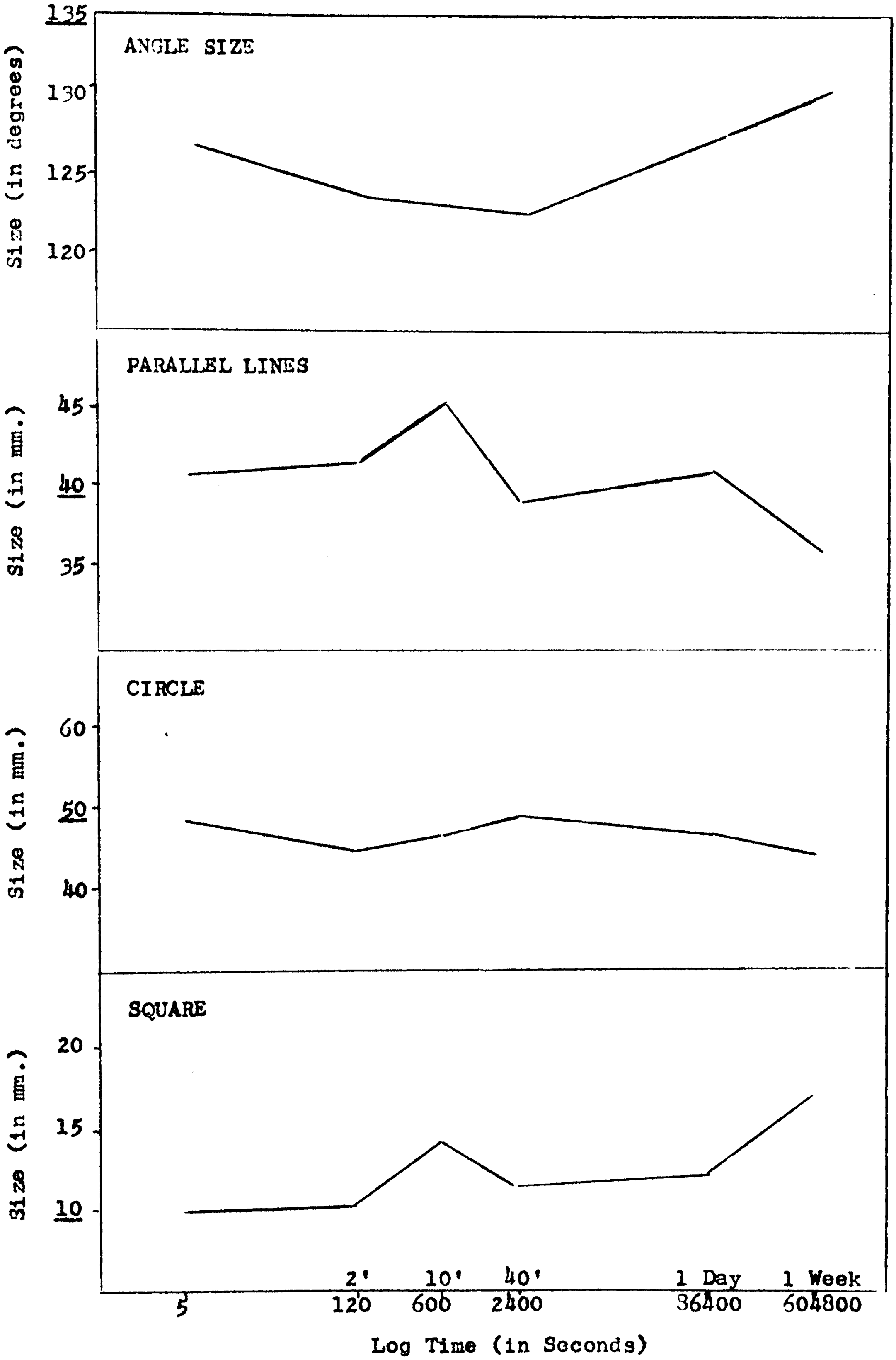


Fig. 3 - Mean size by condition. (Underlined values on ordinate indicate correct size.)

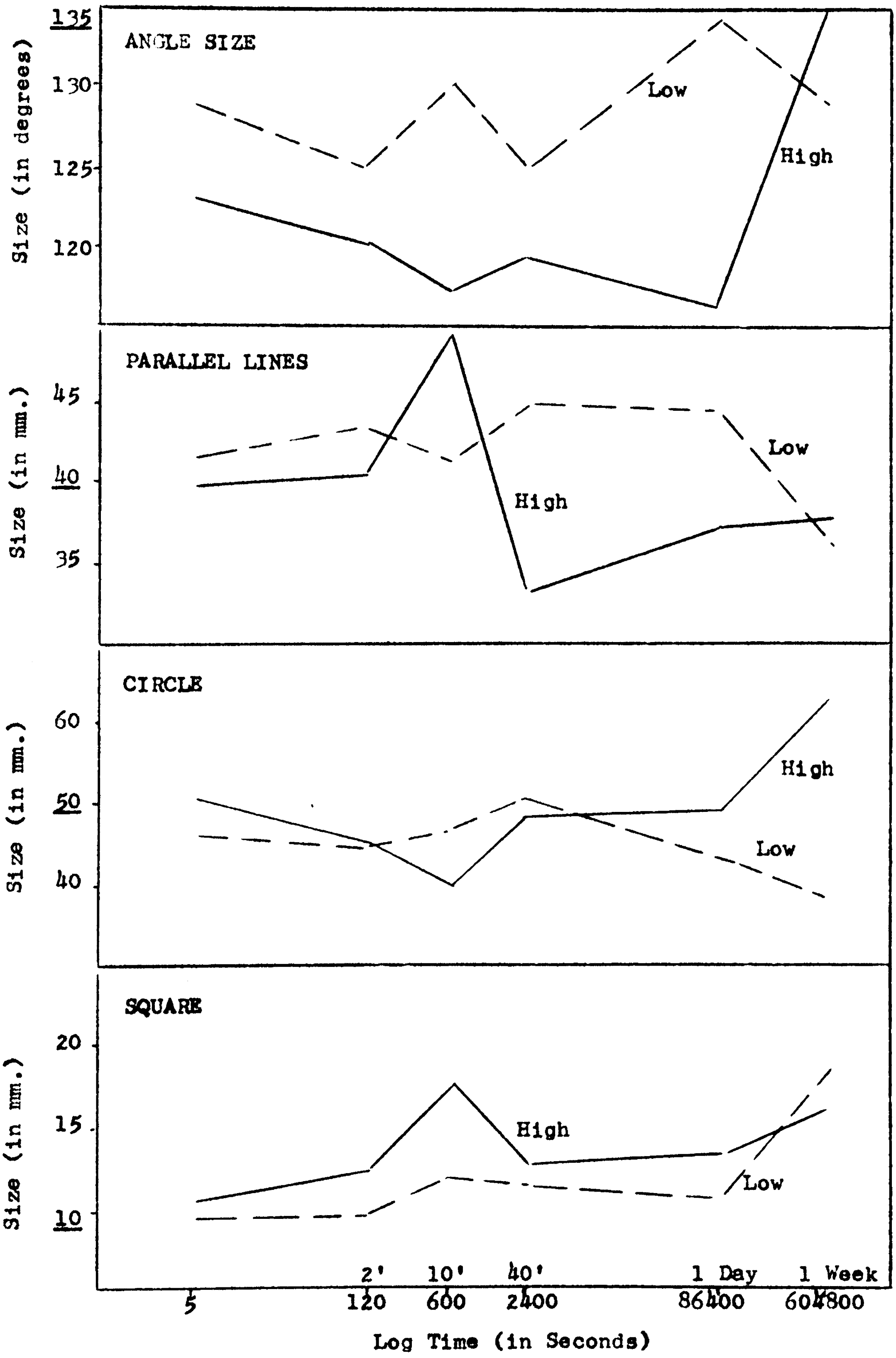


Fig. 4 - Mean figure size by condition, showing high and low GSR. (Underlined values on ordinate indicate correct size.)

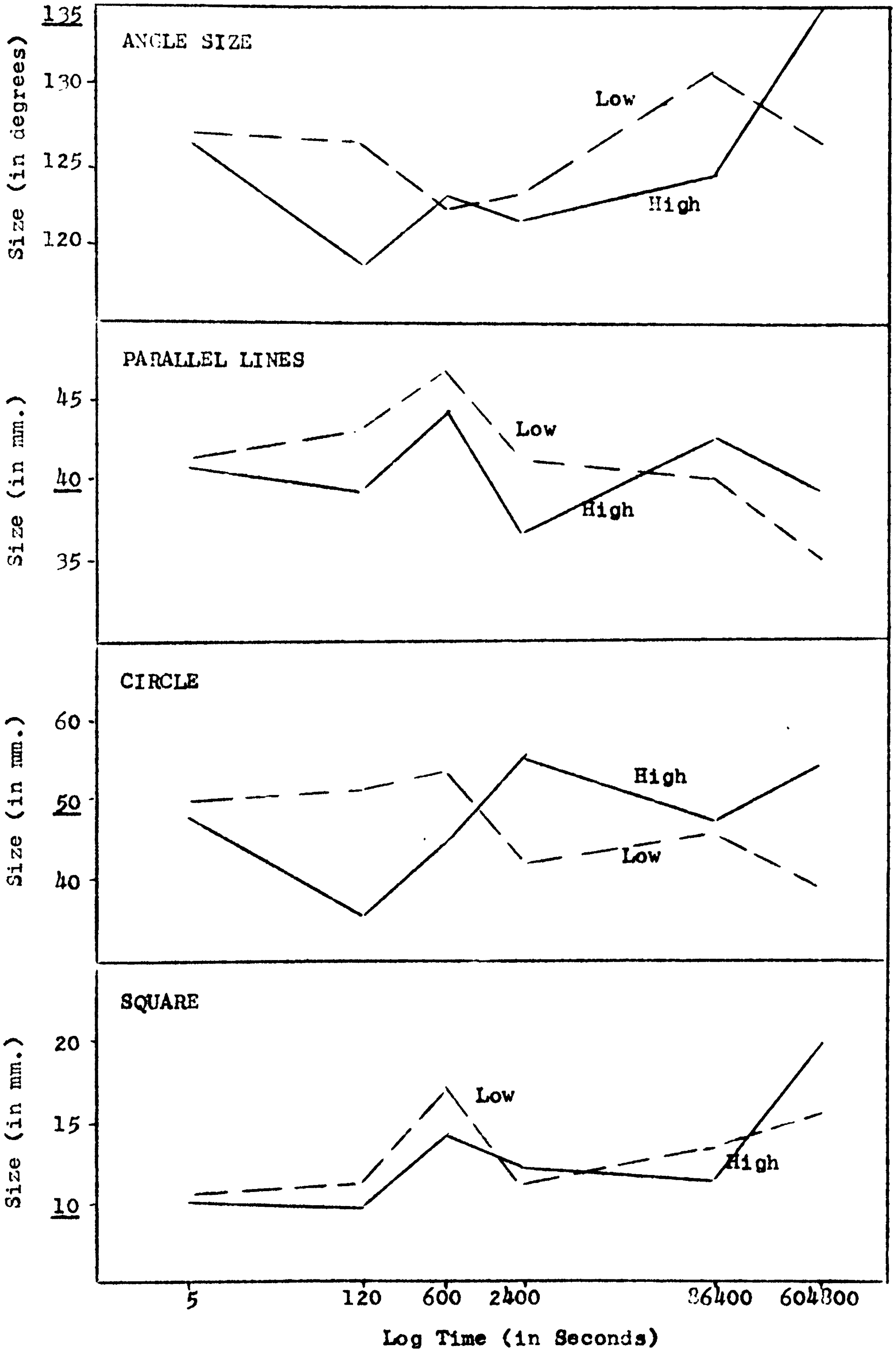


Fig. 5 - Mean figure size by condition, show high and low arousal level. (Underlined values on ordinate indicate correct size.)

arousal level (low BRL) group drew larger at a week than did the low arousal level subjects.

TABLE 2

MEAN FIGURE SIZE FOR HIGH AND LOW AROUSAL LEVEL
AT ONE WEEK RECALL INTERVAL

	Square		Circle		Lines		Angle	
	Mean	N	Mean	N	Mean	N	Mean	N
Low arousal level	15.8	8	39.5	8	35.8	8	126.8	5
High arousal level	20.0	4	54.5	4	39.3	4	135.8	4

In order to combine figures, all measurements were converted to standard score units and a mean value was obtained for each subject. A rank sums test (Mann-Whitney) comparing high and low arousal level yields significance at p = .01 (one-tail).

The momentary arousal increase following stimulus presentation (GSR) was also expected to have some effect upon figure size. In this case the effect is on the speed of the trace. With higher GSR the speed would be greater, leading to stronger interconnections, and preserving the size of the trace by retarding the loss of visual units that would otherwise drop out rapidly following stimulus termination. This GSR effect on size can be seen in Fig. 4 at the one week interval. In three out of the four figures the high GSR drawings are larger than the low GSR drawings at this point.

Since BRL is hypothesized to have the major effect upon size, with GSR having a somewhat weaker effect, the four combinations of BRL-GSR patterns can be ordered in terms of the predicted size of the drawing. It would be expected that subjects with both high arousal level and high GSR for a particular figure would draw the largest; high arousal level and low GSR would come in second; low arousal level and high GSR would be third, and instances of low arousal level and low GSR would result in the smallest drawing, in the long-term condition. Although the N's for such an extensive breakdown are small indeed (ranging from 1 to 6 subjects per cell), the results tend to support this prediction. Table 3 presents the rank of each of the four categories for each figure. It also indicates the mean rank for each BRL-GSR combination across figures, showing the expected trend.

TABLE 3

RANKS FOR SIZE OF DRAWING AT A WEEK

BY AROUSAL LEVEL AND GSR

Arousal Level	GSR	Square	Circle	Lines	Angle	Mean Rank
High	High	2	1	1	3	1.75
High	Low	1	3	2	2	2.00
Low	High	4	2	3	1	2.50
Low	Low	3	4	4	4	3.75

Accuracy of reproduction

Since the subject drew each figure initially and again at a later time, the change between these drawings can be taken as an indication of accuracy. By analyzing these changes, it is possible to evaluate two predictions from the model, one concerning a short term or concurrent effect, and the other concerning a relatively long term effect. As indicated previously, GSR, as opposed to BRL, should be the relevant index of such changes since it reflects primarily the speed dimension of trace activity. Since the predictions deal with size of change independent of direction, the following analyses are based on absolute changes.

The concurrent prediction is that at the time when decrement should be taking place (expected to be at 2 and 10 minutes on the basis of previous research), high GSR subjects should show the greatest change, or lowest accuracy. This follows from the idea that higher GSR leads to greater speed increase, resulting in deeper decrement. It can be seen in Table 4 that with the exception of a single reversal (2 minute condition, parallel lines), the data support this hypothesis. It seems from these results that decrement in the case of the angle occurs somewhat earlier than it does for the other figures since the differences between high and low GSR is greater at 2 minutes and almost tied by 10 minutes.

TABLE 4

MEAN ABSOLUTE CHANGE BETWEEN INITIAL DRAWING AND DRAWING AT 2 AND 10 MINUTES, FOR HIGH AND LOW GSR

	Square		Circle		Lines		Angle	
	Mean	N	Mean	N	Mean	N	Mean	N
2 Minutes:								
Hi GSR	3.0	5	9.7	6	3.3	4	15.3	3
Lo GSR	2.0	6	3.8	5	7.0	7	9.0	8
10 Minutes:								
Hi GSR	7.0	6	12.0	1	8.6	5	9.7	7
Lo GSR	2.2	6	5.7	11	5.0	7	9.2	5

A signed-ranks test (Senders, 1958) comparing high and low GSR for these two intervals (using standard score units to combine figures) indicates that the difference at 2 minutes is not significant, while at 10 minutes, $p = .05$ (one-tail).

The long term prediction, applying to the week interval, is in the opposite direction from the prediction for the concurrent effect. While high GSR should produce deeper decrement and thus a greater change over a brief interval, it should also produce better learning of the original trace because of the effect of increased speed in strengthening the trace. Thus cases where the subject shows a large momentary arousal change when first seeing the stimulus, should result in a drawing a week later that is more accurate and consequently not as different from the initial drawing as in cases where the GSR is low. The results, Table 5, indicate that the change in figure drawing for each figure is greater in the low GSR cases than for the high ones. A signed-ranks test on these data shows significance at p = .05 (one-tail).

TABLE 5

MEAN ABSOLUTE CHANGE BETWEEN INITIAL DRAWING AND DRAWING AT ONE WEEK, FOR HIGH AND LOW GSR

	Square		Circle		Lines		Angle	
	Mean	N	Mean	N	Mean	N	Mean	N
One Week:								
Hi GSR	6.0	7	10.3	3	5.7	4	4.5	2
Lo GSR	9.8	5	12.7	9	7.4	8	13.6	7

Combining the short term and long term predictions leads one to expect an interesting pattern of changes for the high GSR subjects. At a time of decrement the change is larger, while a week later it is smaller. Thus it would be expected that subjects showing a change at 2 and 10 minutes should show an opposite change between this second drawing and the one at a week. This effect appears across all figures, being strongest at 10 minutes and next at 2 minutes.

DISCUSSION

This study was designed to illustrate the way in which the model developed previously may be applied in an empirical situation. The major predictions evaluated in the study concern the effect of momentary increase in arousal (measured by GSR) upon the absolute change in figure size between the initial drawing and the test drawing. GSR is predicted to cause deeper decrement due to increased trace speed. Thus for high GSR there should be greater change (less accuracy) when testing occurs during the times when the trace is likely to be in decrement. However, the long-term effect of high GSR should be a smaller change (greater accuracy) since the higher trace speed facilitates consolidation, thus leading to better learning or the originally perceived pattern.

The expected short term effects were reflected in the consistent tendency of a bigger absolute change to occur for high GSR during the times when the trace is likely to be in decrement (2 and 10 minutes). Out of the eight cases where this comparison can be made (four figures for each of two test intervals), all but one were in the predicted direction. The results at 10 minutes, but not at 2 minutes, are significant at $p = .05$, for the combined figures. As expected, the long term effects were in the opposite direction. Instances in which the subject responded with a high GSR when initially presented with the figure, resulted in greater accuracy (smaller change) when the figures were drawn a week later. This was true for all four figures (combined figures $p = .05$).

Somewhat more tenuous predictions were made concerning the size of drawing as opposed to change or accuracy. By including several additional assumptions, it was predicted that the size of the drawn figures might reflect the proportion of visual units in the trace. Given these assumptions, BRL is seen as having a major influence on the degree to which visual system units are a part of the trace, since arousal level supports stimulus input. A smaller but parallel effect is attributed to GSR because of its role in the speed of the trace. Increased speed results in increased connection strength thus reducing the rate of drop out of units initially associated with the trace.

Since these effects would be obscured by decrement, the analysis was made for the week subjects when it can be safely assumed that all trace activity will have terminated. At this testing interval, subjects with high arousal level drew larger than the low arousal level group ($p = .01$ for combined figures). Inspection of the BRL-GSR interaction for these subjects tends to support the expected secondary effect of GSR on drawing size.

Another result suggested by the data is that each geometric figure may have its own unique time course. This finding, although not in conflict with the theory, certainly complicates attempts to relate the theory to data.

CHAPTER V

EPILOGUE

Although it is too early for any extensive evaluation of the theoretical position developed in this dissertation, an attempt will be made to estimate its promise along a number of dimensions.

The aim of theoretical rigor is approached in two different ways. The more straightforward rigorous aspect of the theory as presented here, is the flow diagram spelled out in Chapter III. While it is a necessarily simplified version of only a portion of the theory developed in Chapter II, there is little doubt that it provides a statement sufficiently explicit to be programmed on a computer. The functions indicated in Appendix I, although based on educated guesses, further contribute to the feasibility of programming this part of the model. It should be noted that such an explicit statement is not necessarily developed with the intention of programming. Although this would undoubtedly be of interest, the primary value of expressing a theory in this fashion is intrinsic. It makes clear to the theorist what he is actually asserting and what additional decisions are necessary before the model can function.

The theory represents an approximation to rigor in another, less easily demonstrable way. This involves the rather complex relations within and between the different chapters representing different levels and aspects of the theory. The major theoretical statement of this dissertation is in the network level presented in Chapter II. It uses all the principles at the neuron level, and a few additional ones. It may seem that certain neuron level principles, particularly factors influencing the firing of an individual neuron (input, recency of input, and spatial and temporal summation, for example), are not explicitly utilized at the network level. It should be noted however, that the central concept at the network level is the fact of reverberation, and this depends upon a system of units with these properties.

One factor necessary to the network level that does not follow from the neuron level is, of course, the way in which the units are interconnected. A high level of interconnection is generally assumed in the cortex. An additinnal assumption made here and in similar models is that the interconnections are initially random. While undoubtedly false, such an assumption is useful given the current state of knowledge on this issue.

The introduction of arousal at the network level may seem to be a major addition. In this simplified model, however, it is treated as a kind of input which has its effects through temporal and spatial summation. Thus its mode of action is essentially defined in terms of neuron level concepts.

There are undoubtedly other assumptions made at the network level which have no basis in the neuron level. These are, unfortunately, not evident to the author at this time.

An issue of particular importance is the relationship of the concepts within the network level. The intention in Chapter II is to build network mechanisms upon the basis of network properties, and to use these to build higher level implications, particularly those concerning the modulation of arousal. Most likely here too some links are missing, but they are not now apparent to the author.

The bookkeeping system is one possible realization of the major network level mechanisms in flow diagram form. Thus it can be looked at as a magnification of a portion of Chapter II. It intentionally focuses upon certain aspects of the network level. Given the magnitude of the task represented by Chapter III, a diagram for the entire model would likely require many years of work.

The portion of the network level dealt with in the bookkeeping system has been altered somewhat in the magnification process. It has been simplified where it seemed appropriate to keep the diagram in reasonable bounds. It adds detail since this is necessary in a flow diagram. Although this additional specification seems reasonable and in keeping with the rest of the model, it contains apsects not explicitly dealt with in the initial two chapters.

Chapter IV builds on the aspects of the network model elaborated in the bookkeeping system. In addition two new assumptions are introduced to relate the model to the remembered size of a figure.

The issues of parsimony, richness, and predictive value, all desirable traits of theory, are difficult to evaluate separately. Parsimony does not refer to the fewest possible concepts, but to the fewest concepts per implication or prediction. The richness of a theory is closely related to its predictive value. Richness is a somewhat nebulous quality if experiments are not implied by it.

One indication of the predictive value of the theory is that it does predict something; it leads to the empirical work discussed in the previous chapter. But this empirical work does not begin to exhaust the possibilities of the theory. The theory was not devised to deal with this particular empirical situation, but, on the contrary, had to be narrowed considerably to deal with this specific study.

But a young theory must, above all, show potential. These are two factors that provide some encouragement in this direction. First, the theory utilizes constructs already shown to be fruitful empirically and theoretically. Such concepts as perseveration, arousal, and action decrement are each powerful in their own right, and in combination they should lead to a variety of interesting hypotheses. Second, the theory specifies quite a few interrelations of relatively few concepts. Such a relatively dense structure should lead to ample opportunity for empirical test.

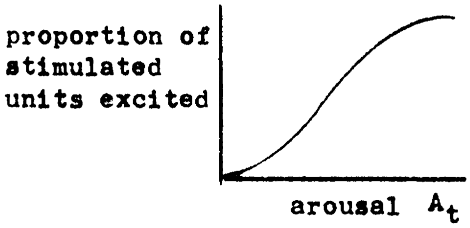
Thus the theory as it stands is incomplete, unfinished, and undoubtedly mistaken in many respects. It is hoped, however, that it offers sufficient clarity and potential to give promise of future growth.

APPENDIX I

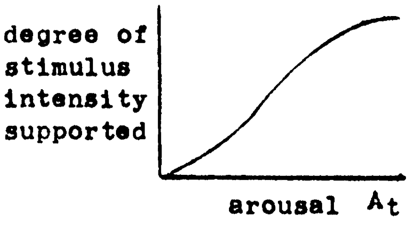
FUNCTIONS INDICATED IN THE FLOW DIAGRAM

Some of the statements made in the flow diagram (Chapter III) depend on the specification of functions relating the variables. Suggestions are made here for the form these functions might take. However, because of the state of physiological knowledge to date, the functions presented here must be considered as suggestions only.

I. Functions concerning the effect of arousal on stimulus input



E(x)



G(x)

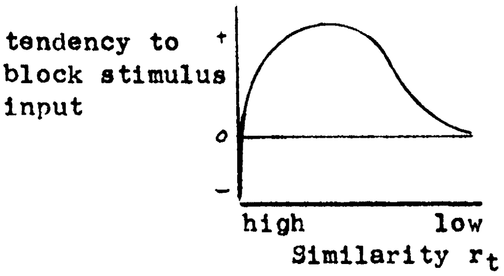
E(x) is the function concerning the effect of the current level of arousal on the <u>size</u> of the potential trace that might be established by the new stimulus. It specifies the proportion of units stimulated by the new stimulus that will be excited, given a particular level of arousal.

G(x) is the function concerning the effect of the current level of arousal on the <u>speed</u> of the potential trace. It specifies the degree to which the intensity of the stimulus will correspond to the speed of the potential trace, given a particular level of arousal.

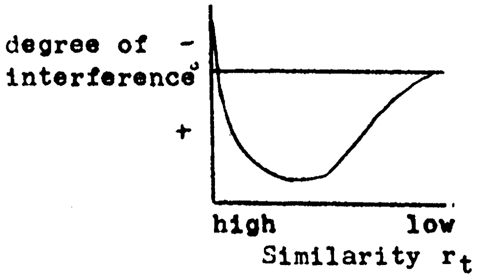
The shape of these functions is essantially the same. In both cases a certain level of arousal is necessary to support the new stimulus efficiently. Below this level the nonspecific support may only infrequently coincide with the units stimulated by the new stimul

Thus the functions are initially positively accelerated. As arousal continues to increase it will reach a level beyond which it will have less and less additional effect, since inhibition will approach a level at which no additional increment in size is possible. Likewsie the timing properties of the neuron set a limit on the maximum speed of trace activity (Hodgkin, 1948). Thus both functions become negatively accelerated and asymptotic to one.

II. Blocking and interference functions



B(x)



R(x)

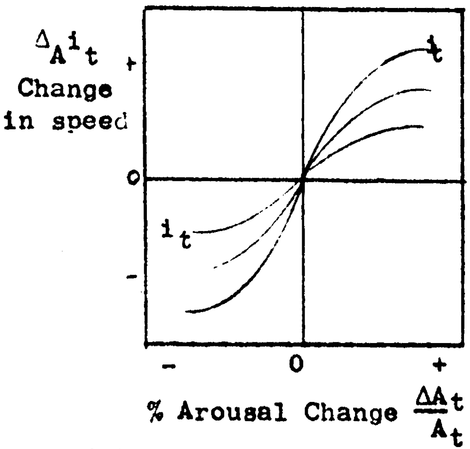
The blocking function, B(x), specifies the effect of similarity (or overlap) upon the tendency of the ongoing trace to block stimulus input. The probability of an identical stimulus pattern being blocked is low, since none of the units stimulated by the pattern would be under inhibition, and not all of the units would be refractory at once. With only a slightly different pattern, however, the probability of blocking rises sharply, since the new input is likely to run into both refractory units and units under inhibition. With decreasing similarity, more units independent of the ongoing trace are involved, and the probability of blocking decreases. The horizontal line "0" represents the probability of a stimulus pattern failing to register given no competing specific activity.

R(x), the interference (or retroaction) function, specifies the effect of similarity upon the degree of interference to the ongoing trace produced by a newly established trace, given, of course, that the ongoing trace has failed to block the new stimulus. Interference results from fractionation, and thus depends upon the degree of similarity. The shape of the function and the accompanying explanation are comparable to those for the blocking function. An identical trace to the ongoing one makes a positive contribution (i.e., "negative interference") by augmenting the pre-existing perseveration. A slightly different one, however, fractionates the initial trace, and a dissimilar one has little or no effect (at "0").

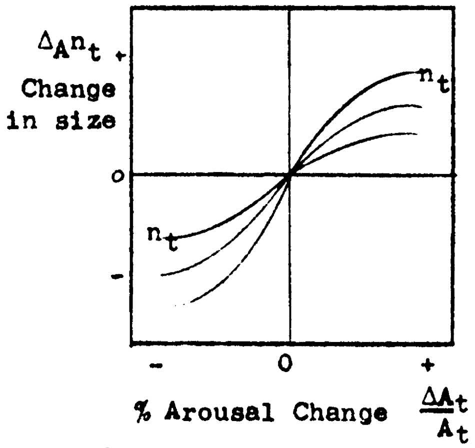
III. Change functions

The remaining functions deal with the changes in speed, size, connection strength, and fatigue. Since they all deal with changes in key parameters of the system, they have a number of characteristics in common. First, they neither increase indefinitely, nor stop increasing suddenly. Thus all of these functions are negatively accelerated and asymptotic to some limit. Secondly, the change in any given parameter is influenced by the current level of that parameter. This results in a family of similar functions for each kind of change, since the shape of the function will be slightly different for each different current value of the parameter. For example, the degree to which the speed of trace activity can be increased depends, among other things, upon the current speed.

In each case three curves will be shown representing the form of the function for high, mid, and low levels of the variable. The label for this variable will always be placed beside the <u>low</u> value.



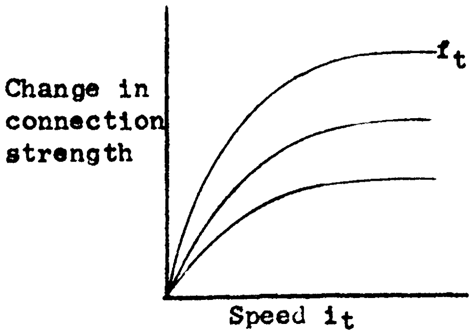
$A_i(x)$



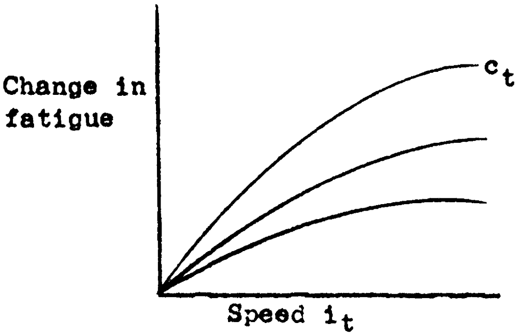
$A_n(x)$

$A_i(x)$ specifies the component of the overall change in speed produced by the percent arousal change occurring at time t. If the arousal change is negative, indicating a decrease in arousal, the speed change is negative. The function is negatively accelerated since there is a limit on the possible increase (or decrease) in speed due to arousal alone. The rate of firing per unit time per neuron, as noted previously, is limited by refractoriness and by the timing properties of firing. Likewise a lack of arousal can only reduce the firing to a certain degree.

Since the homeostatic neural space limits size increase due to arousal, $A_n(x)$ follows a comparable pattern.



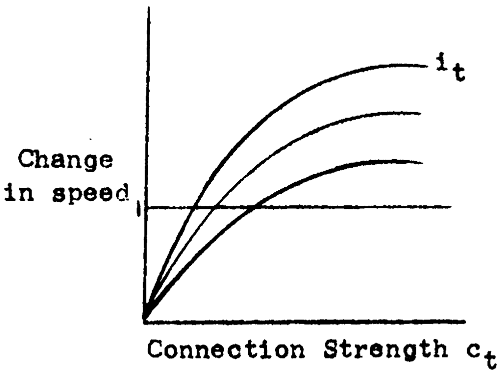
$I_c(x)$



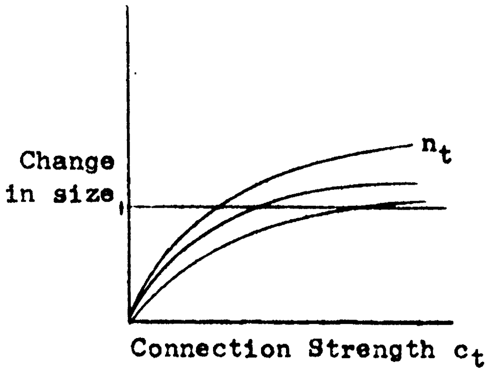
$I_f(x)$

$I_c(x)$ specifies the increase in connection strength as a function of the previous level of connection strength and the current speed of trace activity. The increment in connection strength is presumed to be positively related to the speed of the trace and negatively related to the previous level of connection strength. In other words, following most learning postulates, as trials increase, the size of the increment in connection strength decreases. It should be noted that in this context "trials" refers not to overt practice, but to the trace activity occurring during each time step.

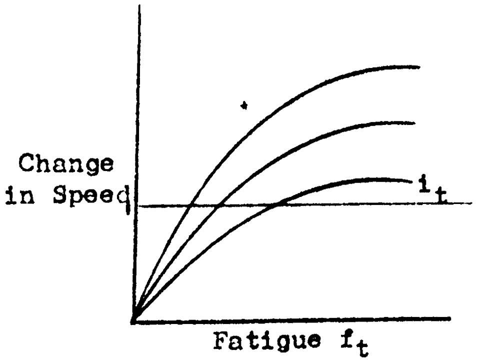
$I_f(x)$, the function specifying the increase in fatigue based on the previous level of fatigue and the current speed of trace activity, parallels the previous function in form and rationale. Note, however, that fatigue increases more slowly than connection strength as a function of speed,but continues to increase beyond the point that connection strength has become asymptotic. In this way trace activity is at first enhanced and later terminated as speed operates through time.



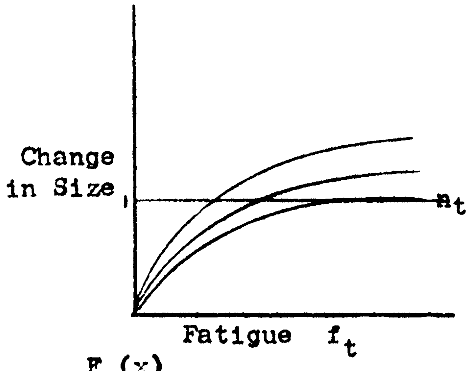
$C_i(x)$



$C_n(x)$



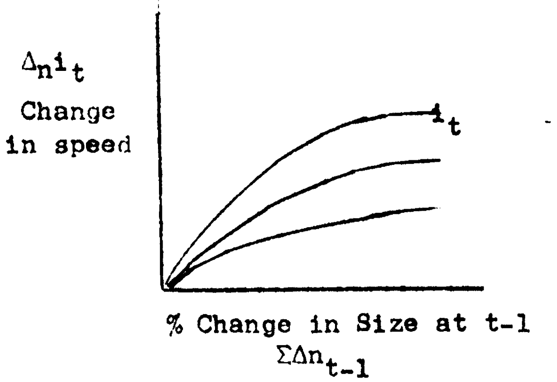
$F_i(x)$



$F_n(x)$

These functions concern the effects of fatigue and connection strength on the size and speed of trace activity. As before, the previous levels of size and speed are important factors since a higher level leaves less room for increase and a lower level, less room for decrease.

Note that in the case of both size and speed, it is the ratio of some value representing connection strength to some variable representing fatigue that determines the change, since these two variables counteract each other. Thus the value of one indicated on the ordinates of these functions represents a neutral point.



V(x)

V(x) specifies the effect that the percent change in the size of the trace at the previous time step has on the speed at time t.

APPENDIX II

RAW DATA

			SQUARE				CIRCLE				LINES				ANGLE			
C	S#	BRL	%D	5	C	W	%D	5	C	W	%D	5	C	W	%D	5	C	W
2	6	48	0	8	11	8	0	20	15	12	0	38	42	46	0	120	113	146
	8	110	*	8	8	8	*	42	39	23	*	35	32	23	*	132	116	94
	7	124	2	8	10	8	5	38	40	42	6	47	56	51	1	108	83	83
	10	128	2	12	8	10	16	55	47	47	4	33	37	41	22	130	142	131
	4	139	2	9	12	12	8	39	37	34	10	29	31	26	6	131	140	Δ
	9	153	1	11	10	24	11	42	42	38	1	31	34	40	7	121	105	113
	67	170	1	11	10	10	16	67	35	34	12	35	37	39	3	138	132	128
	62	178	12	11	13	7	8	47	55	50	13	37	39	40	10	141	146	--
	1	181	18	10	8	10	6	72	73	57	6	59	42	40	8	133	115	121
	3	190	2	23	18	17	2	50	61	21	0	46	45	38	0	138	130	116
	12	258	0	8	9	11	0	40	43	62	0	40	47	53	0	140	139	145
	69	335	13	7	10	--	3	54	50	35	0	45	58	39	0	130	119	120
10	41	39	3	10	14	6	2	58	59	60	5	57	56	73	3	141	145	140
	46	61	3	7	15	20	2	26	23	23	2	47	31	51	5	132	111	Δ
	43	69	6	8	10	9	3	29	40	48	15	40	50	37	7	113	106	109
	48	78	6	9	12	13	1	45	46	55	3	40	38	47	6	119	128	120
	42	93	9	12	22	16	7	67	52	21	14	50	45	35	7	134	135	Δ
	45	111	0	11	14	13	0	41	42	41	0	40	42	43	1	111	130	115
	47	119	3	10	12	11	1	48	40	42	10	40	57	71	3	135	131	123
	44	126	8	11	12	9	20	52	40	45	2	42	44	55	12	125	107	90
	39	135	11	11	16	13	5	48	57	48	3	36	37	34	17	113	116	100
	38	200	3	12	27	47	1	56	61	55	3	30	40	27	0	130	112	Δ
	37	233	12	13	14	13	4	64	62	67	0	49	51	50	11	142	132	139
	40	254	1	11	10	10	0	44	37	42	1	40	50	46	10	123	123	115
40	32	83	11	11	15	--	13	47	60	--	20	40	41	--	7	117	114	--
	27	115	2	9	9	7	4	49	59	62	7	25	24	20	0	126	129	138
	28	119	8	11	16	15	8	45	55	54	29	28	25	25	15	129	111	107
	25	130	14	12	16	34	8	48	45	41	14	49	42	40	15	127	129	121
	61	131	5	9	11	13	7	62	56	40	3	38	30	42	14	125	117	108
	31	141	6	11	12	14	15	57	60	58	7	42	59	57	8	127	130	126
	35	153	10	11	12	12	6	47	38	41	2	46	44	42	4	120	116	101
	26	155	14	9	8	10	25	53	52	41	35	41	29	17	4	141	131	138
	33	183	12	10	17	16	17	40	40	39	14	38	41	32	16	117	116	105
	30	184	16	9	11	9	16	48	39	44	14	42	36	43	17	113	116	119
	29	250	4	8	8	17	8	44	31	16	0	50	60	40	4	119	124	128
	34	306	14	12	12	11	3	49	54	53	6	41	38	41	3	140	137	142

* No GSR record for S #8 because of machine failure.
Δ-S drew acute triangle instead of angle; data omitted.
Underlined GSR values indicate that they are designated High.
BRL values greater than 145 are considered Low arousal level.
%D = GSR deflection; 5 = initial drawing (5 seconds); C = drawing at condition; and W = drawing at a week.
BRL values are in 1,000 ohm units

			SQUARE				CIRCLE				LINES				ANGLE			
C	S#	BRL	%D	5	C	W	%D	5	C	W	%D	5	C	W	%D	5	C	W
D	18	51	55	10	12	13	15	45	42	35	80	46	33	37	78	127	110	117
	16	96	22	10	13	10	21	44	30	35	18	42	42	40	29	111	118	134
	64	116	2	6	6	7	4	46	45	29	18	32	36	45	4	137	125	140
	22	116	23	13	14	15	68	50	59	61	19	39	41	34	32	122	112	121
	17	125	10	9	10	14	10	49	44	47	13	32	39	41	7	135	151	151
	63	129	25	12	14	36	16	48	54	58	3	53	60	49	10	144	138	141
	19	136	31	12	11	14	11	60	61	51	10	40	47	42	9	120	118	121
	20	150	27	9	18	22	28	40	31	27	23	32	35	32	20	128	141	Δ
	23	161	30	11	17	10	27	40	62	60	21	35	41	26	40	102	112	122
	24	185	1	11	13	12	4	52	38	37	30	53	42	42	12	133	131	145
	65	209	8	8	9	8	14	45	44	44	10	33	36	38	7	131	137	135
	15	328	6	8	10	9	3	51	55	55	0	38	47	45	0	138	134	136
W	70	79	7	13	24		0	46	52		5	44	43		3	135	128	
	54	118	0	8	32		1	51	46		1	41	38		1	125	149	
	59	120	6	10	14		2	32	26		1	54	54		2	121	132	
	68	136	6	10	10		9	84	94		8	36	22		20	141	134	
	58	158	13	8	20		13	50	36		2	54	27		16	109	Δ	
	13	185	29	11	18		19	53	60		16	36	34		14	120	124	
	66	186	18	6	6		11	55	70		20	43	48		10	135	111	
	49	193	0	9	23		1	45	30		8	40	31		1	125	131	
	53	205	5	11	18		0	57	22		0	53	45		0	120	Δ	
	60	219	1	11	9		0	35	34		0	36	39		5	135	137	
	55	253	65	11	12		2	42	12		18	30	32		29	110	Δ	
	52	300	0	11	20		0	53	52		20	38	30		0	112	131	

APPENDIX III

MEAN FIGURE SIZE BY CONDITION, GSR, AND BRL

Condition		SQUARE		CIRCLE		LINES		ANGLE	
		Mean	N	Mean	N	Mean	N	Mean	N
5 Seconds		10.2	60	48.4	60	40.9	60	126.6	60
2 Minutes		10.6	12	44.3	12	41.7	12	123.3	12
10 Minutes		14.8	12	46.6	12	45.1	12	123.0	12
40 Minutes		11.7	12	49.1	12	39.1	12	122.5	12
One Day		12.3	12	47.1	12	41.6	12	127.3	12
One Week		17.2	12	44.5	12	36.9	12	130.8	9
By Arousal Level									
5 Sec.	High	10.0	31	47.5	31	40.8	31	126.2	31
	Low	10.4	29	49.5	29	41.1	29	127.0	29
2 Min.	High	9.8	5	35.6	5	39.6	5	118.8	5
	Low	11.1	7	51.3	7	43.1	7	126.6	7
10 Min.	High	14.1	9	44.3	9	44.4	9	123.2	9
	Low	17.0	3	53.3	3	47.0	3	122.3	3
40 Min.	High	12.0	6	55.8	6	36.8	6	121.7	6
	Low	11.3	6	42.3	6	41.3	6	123.3	6
Day	High	11.4	7	47.9	7	42.6	7	124.6	7
	Low	13.4	5	46.0	5	40.2	5	131.0	5
Week	High	20.0	4	54.5	4	39.3	4	135.8	4
	Low	15.8	8	39.5	8	35.8	8	126.8	5
By GSR									
5 Sec.	High	10.7	29	51.3	26	40.0	24	123.2	25
	Low	9.8	30	46.3	33	41.7	35	129.0	34
2 Min.	High	12.2	5	45.8	6	40.7	4	120.7	3
	Low	9.7	6	44.6	5	43.6	7	125.3	8
10 Min.	High	17.7	6	40.0	1	49.6	5	117.6	7
	Low	12.0	6	47.2	11	41.9	7	130.6	5
40 Min.	High	12.8	4	48.3	9	33.2	6	119.8	6
	Low	11.1	8	51.3	3	45.0	6	125.2	6
Day	High	13.3	7	49.7	7	37.2	5	116.6	5
	Low	10.8	5	43.4	5	44.7	7	134.9	7
Week	High	16.0	7	63.3	3	38.0	4	135.5	2
	Low	18.8	5	38.2	9	36.4	8	129.4	7

REFERENCES

1. Breen, R. & McGaugh, J. L. Facilitation of maze learning with posttrial injections of pictrotoxin. J. comp. physiol. Psychol., 1961, 54, 498-501.

2. Burns, B. D. The production of afterbursts in isolated unanesthetized cerebral cortex. J. Physiol., 1954, 125, 427-446.

3. Cronbach, L. J. The two disciplines of scientific psychology. Amer. Psychologist, 1957, 12, 671-684.

4. Cronbach, L. J. & Meehl, P. E. Construct validity in psychological tests. Psychol. Bull., 1955, 52, 281-302.

5. Crossland, J. Chemical transmission in the central nervous system. J. pharm. Pharmacol., 1960, 12, 1-36.

6. Eccles, J. C. The neurophysiological basis of mind. Oxford: Clarendon Press, 1953.

7. Eccles, J. C. The physiology of nerve cells. Baltimore: Johns Hopkins, 1957.

8. Feldman, R. S. & Neet, C. C. The effect of electroconvulsive shock on fixated behavior in the rat. J. comp. physiol. Psychol., 1960, 53, 532-534.

9. Glickman, S. E. Perseverative neural processes and consolidation of the memory trace. Psychol. Bull., 1961, 58, 218-233.

10. Hanawalt, N. G. Memory trace for figures in recall and recognition. Arch. Psychol., 1937, 31, 5-89.

11. Hebb, D. O. The organization of behavior. New York: Wiley, 1949.

12. Hebb, D. O. & Foord, E. N. Errors of visual recognition and the nature of the trace. J. exp. Psychol., 1945, 35, 335-348.

13. Hodgkin, A. L. The local electric changes associated with repetitive action in a non-medullated axon. _J. Physiol._, 1948, _107_, 165-181.

14. Kaplan, S. Modes of mediation. University of Michigan, 1960. Unpublished.

15. Kleinsmith, L. J. & Kaplan, S. Paired associate learning as a function of arousal and interpolated interval. Submitted to _J. exp. Psyhhol_.

16. Levy, E. Z., Thaler, V. H., & Ruff, G. E. New techniques for recording skin resistance changes. _Science_, 1958, _128_, 33-34.

17. Lykken, D. T. Properties of electrodes used in electrodermal measurements. _J. comp. physiol. Psychol._, 1959, _52_, 629-634.

18. McGaugh, J. L, Westbrook, W. & Burt, G. Stain differences in the facilitative effects of 5-7-Diphenyl-1-3-Diazadamantan-6-01(1757 I.S.) on maze learning. _J. comp. physiol. Psychol._, 1961, _54_, 502-505.

19. Madsen, M. C. & McGaugh, J. L. The effect of ECS on one-trial avoidance learning. _J. comp. physiol. Psychol._, 1961, _54_, 522=523.

20. Milner, P. M. The cell asembly: Mark II. _Psychol. Rev._, 1957, _64_, 242-252.

21. Paré, W. The effect of caffeine and seconal on a visual discrimination task. _J. comp. physiol. Psychol._, 1961, _54_, 506-509.

22. Ratliff, F. Miller, W. H., & Hartline, H. K. Neural interaction in the eye and the intagration of receptor activity. _Annals of the N.Y. Acad. of Sciences_, 1958, _74_, 210-222.

23. Senders, Virginia. _Measurement and statistics_. New York: Oxford, 1958.

24. Thomson, C. W., McGaugh, J. L., Smith, C. E., Hudspeth, W. J. & Westbrook, W. H. Staain differences in the retroactive effects of electroconvulsive shock on maze learning. _Canad. J. Psychol._, 1961, _15_, 69-74.

25. Rochester, N., Holland, J. H., Haibt, L. H. & Duda, W. L. Tests of a cell assembly theory of the action of the brain in using a large digital computer. IRE Trans. of Inf. Theory, 1956, 80-95.

26. von Neumann, J. The computer and the brain. New Haven: Yale, 1958.

27. Walker, E. L. Action decrement and its relation to learning. Psychol. Rev., 1958, 65, 129-142.

28. Walker, E. L. Lecture in Basic Concepts course. University of Michigan. 1958a.

29. Walker, E. L. & Veroff, J. Changes in the memory-trace for perceived forms with successive reproductions. Amer. J. Psychol., 1956, 69, 395-402.

30. Walter, W. G. The living brain. N.Y.: Norton, 1953.

31. Woodworth, R. S. Experimental psychology. N.Y.: Holt, 1938.

32. Woodworth, R.S. & Schlosberg, H. Experimental psychology, second edition. N.Y.: Holt, 1954.

33. Wulf, F. Ueber die Veränderung von Vorstellunge (Gedächtnis und Gestalt), Psychol. Forsch., 1, 1922, 333-373. Quoted in Koffka, K. Principles of Gestalt psychology, 1935, 493-506.

RULES COVERING USE OF MANUSCRIPT THESES IN THE UNIVERSITY OF MICHIGAN LIBRARY AND THE GRADUATE SCHOOL OFFICE