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**TASK - INDUCED STRESS:
A LITERATURE SURVEY**

**James E. Robins
James M. McKendry
Paul M. Hurst**

HRB-Singer, Inc.

27 October 1961

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AERONAUTICAL SYSTEMS DIVISION
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James M. McKendry
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HRB-Singer, Inc.

27 October 1961

Contract Monitor: Frederick H. Kresse

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**AEROSPACE MEDICAL LABORATORY
AERONAUTICAL SYSTEMS DIVISION
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FOREWORD

This report was prepared by HRB-Singer, Inc. as a portion of the work carried out under Contract No. AF33(616)-7892 during the period 1 February to 22 August 1961. Dr. Paul M. Hurst was the Principal Investigator and the authors of the report are Mr. James E. Robins, Mr. James M. McKendry, and Dr. Paul M. Hurst.

This contractual work was performed under Project 1710, "Training, Personnel and Psychological Stress Aspects of Bioastronautics" and Task 71605, "Human Factors in the Design of Devices for Operator Training and Evaluation." Dr. Ross L. Morgan was the Project Scientist and Dr. Theodore E. Cotterman was the Task Scientist. The contract was initiated and monitored during the most of this work period by Mr. Frederick H. Kresse of the Operator Training Section, Training Research Branch, Behavioral Sciences Laboratory, Aerospace Medical Laboratory.

ABSTRACT

The purpose of this report is to review the literature concerning psychological stress. Emphasis is placed upon experimental evidence, with particular emphasis upon task induced stress.

An attempt is made to define psychological stress in terms of the published material bearing the "stress" label, and thus provide an overview of the field. In the subsequent detailed coverage, individual-difference material, such as might be used in personnel selection, is treated separately from treatment effects. Task induced stress is treated as a separate topic, with an attempt to draw relationships between this phenomenon and those of psychological stress in general. Implications from the literature for control of stress are presented. In summarizing the findings reviewed, a formulation is presented of the relationships believed to be involved in the phenomenon of task induced stress. The parameters which determine information overload are discussed. A conceptual model is presented concerning the "emotional" component of psychological stress. A relationship is derived between this emotional component and information overload in the production of the performance effects typical of "task induced stress." Implications for control are derived from the foregoing conceptualization, together with suggestions of avenues for future research, much of which remains to be done.

TABLE OF CONTENTS

	Page
FOREWORD	iii
ABSTRACT	v
I. INTRODUCTION	1
COVERAGE	1
BACKGROUND	1
TOPIC OUTLINE	2
II. THE MEANING OF STRESS	3
INTRODUCTION	3
CONCEPTUALIZATIONS OF STRESS	3
DESIGNS EMPLOYED IN "STRESS" INVESTIGATIONS	6
ILLUSTRATIVE STUDIES	7
SUMMARY	15
III. INDIVIDUAL DIFFERENCES IN STRESS REACTIONS	17
PSYCHOLOGICAL INDICES	17
PHYSIOLOGICAL INDICES	26
SUMMARY	33
IV. TASK INDUCED STRESS	35
DEFINITIONS AND SCOPE	35
TASK DIMENSIONALITY	36
CHANNEL CAPACITY	43
PERCEPTUAL ANTICIPATION	46
STAGES OF INFORMATION PROCESSING	47
LOAD EFFECTS	49
SPEED EFFECTS	52
CRITICAL FACTORS	57
SUMMARY	63

TABLE OF CONTENTS (Cont'd)

	Page
V. CONTROL OF STRESS	65
GENERAL TECHNIQUES: BEHAVIORAL ADAPTATION	65
SELECTION TECHNIQUES	65
PHARMACOLOGICAL TECHNIQUES	67
TRAINING TECHNIQUES	68
VI. SUMMARY, CONCLUSIONS, AND RESEARCH IMPLICATIONS	71
A CONCEPTUALIZATION OF STRESS	71
IMPLICATIONS FOR STRESS CONTROL AND FOR FURTHER RESEARCH	77
BIBLIOGRAPHY	81

SECTION I

INTRODUCTION

COVERAGE

The purpose of this report is to clarify the meaning of the term "stress." At the present time it is a concept of recognized importance but not well understood. Once the term has been defined, it is possible to identify the major variables which seem to cause it, and to describe the way this effect seems to occur. Only when such an effort has been completed will it be possible to determine ways in which stress can be reduced--or even eliminated--by training. Thus, the ultimate goal is one of overcoming stress by means of training. The intermediate goal is the specification of the conditions necessary and sufficient for the production of stress. If the intermediate goal is satisfied, the probability of achieving the ultimate goal is considerably increased.

The initial stage of the project entails sifting through past experimental studies in an effort to ascertain whether or not hypotheses have been logically evolved, experimental designs soundly developed, and results produced that are significant for present and future research. The literature review has been divided into two major sections: (1) a review related to research conducted in the general area of stress, and (2) a more specific review of research directly related to task induced stress.

BACKGROUND

Military science has moved swiftly to develop new and modern weapon and aircraft systems. With an eye toward outer space, present and future military requirements have led to the production of many highly technical, extremely complex weapon systems. In most cases, the success of a particular weapon or aircraft system hinges on the efficient operation of the various system mechanisms plus man. Actually, the role of the military man has shifted to one where more complex equipment is used routinely. As a consequence of this shift in role, increased research emphasis has been placed on man's ability to store, process and attend to various sources of information.

The concept of task induced stress, especially in terms of speed and load of information processing requirements, is related to the human in almost any task that can be imagined. The opportunity for this kind of stress to be operating ranges all the way from tasks performed by an astronaut to those performed by a radar traffic director who may have to direct too many targets at once, or to such everyday tasks as operating a motor vehicle in the press of heavy traffic. In general, experiments in the area of task induced stress are attempts to present information in a manner assumed to exceed the subject's ability to process information, and then to record the effects on performance. Studies in the general area of stress have encompassed a wide variety of research topics. These include: the failure of men on the battlefield, prisoner of war reactions, behavior at the controls of complex machines, decision making, information processing, and many others (c.f. Bideman and Schein, 1961; Field and Davis, 1952; Taylor, 1953; and Tyhurst, 1950). Even a cursory glance at these topics shows that stress is now considered to be induced as a function of task changes as well as a function of environmental changes.

The present literature review is organized in such a way that ideas as well as results are integrated in order that the reader may gain a perspective which will be useful in the future. Bibliographies by themselves, such as Applezweig and Moeller (1957), cannot fulfill such a function nor can reviews which have been concerned with only selected aspects of stress, such as Holtzman and Bitterman (1952). Still others, such as Katchmar (1954) are in need of being brought up to date. It is to fill these omissions, in an integrated conceptual framework, that the present paper is intended. In reading past research literature, it becomes readily apparent that the connection between situationally induced and task induced stress is a loose one. It is hoped that the chapters in the present text will provide the means for reconciling the two.

TOPIC OUTLINE

1. Chapter II. This chapter enumerates some of the basic approaches to stress. An effort is made to illustrate the multidimensionality of stress, as currently conceived. This is done by: (1) presenting a systematic overview to stress research; (2) sorting available research into a set of loose methodological categories; (3) illustrating the breadth of each category; and (4) specifying the types of measurement employed in each case.
2. Chapter III. This chapter shifts attention away from a general "treatment effect" of stress across individuals, to examine the role of individual differences.
3. Chapter IV. In this chapter a particular type of stress is defined as the effect induced by shifts in task demands in the direction of making the task more closely approach (or surpass) the limitations of human capacity. From the review of the experimental data it can be seen that the primary emphasis has been placed upon speed and load demands. The nature of each of these stresses is discussed in detail in order to show that it is possible to express stress as a function of demands imposed upon such basic functions as perception, coding, translation, and effector activities.
4. Chapter V. The purpose of this chapter is to review what direct implications have been found, in the literature review performed, for the control of stress. The indirect method (personnel selection) is discussed in addition to direct methods such as pharmacological techniques, environment modification, and training.
5. Chapter VI. The chapter represents an attempt to summarize what has been learned, from the present review, about the nature of psychological stress. The relationships among the more basic parameters are summarized in a non-quantified but potentially quantifiable model. Implications of the model for the control of stress are discussed separately here, since these represent a higher order of derivation than those presented in Chapter V.

SECTION II

THE MEANING OF STRESS

INTRODUCTION

Psychological stress is an extremely broad concept, and an exceedingly loose one. It has evolved from a study of physical, physiological, and psychological phenomena, all of which seem to be related when they are examined intuitively. Since diverse approaches were employed, conceptual evolution has been slow; and, for the most part, it has not progressed beyond a level of loose integration. Just a simple review of topics included under "stress" is needed to demonstrate the validity of this last statement. In order to correct this deficiency, attempts at systematization have been made, especially within the past decade, c.f. Chiles (1957). As a result of these efforts a certain amount of conceptual closure has occurred, but it is not great. Connections between studies are often more a matter of "common sense" than empirical fact and systematization seems to be little more than an intrapersonal affair. Furthermore, there is still no real agreement on the conditions necessary and sufficient for the production of stress. This makes it difficult to integrate alternative approaches to the problem.

This chapter is concerned with enumerating some of the basic approaches to stress. The approach taken is as follows: (1) presenting systematic overviews to stress research; (2) sorting available research into a set of loose methodological categories; (3) briefly illustrating the breadth of each category; and (4) specifying the types of measurements employed in each case. When this is done, the multi-dimensionality of the "stress" notion can readily be seen.

CONCEPTUALIZATIONS OF STRESS

A physiological interpretation of the concept of stress has been provided by Seiyee (1950) who developed a concept involving homeostatic functioning of the bodily processes. He defined stress as any stimulus which causes the activation of the General Adaptation Syndrome, which in turn attempts to restore the organism to its normal state of homeostasis. However, as Chiles (1957) has pointed out, this approach represents an analysis of interrelated physiological indices which, though fruitful within its discipline, does not provide the necessary relationships for predicting the behavioral aspects of stress.

A second viewpoint was set forth by Grinker and Spiegel (1945), who related psychological stress to a physical concept which was defined in terms of the restorative forces exerted by an elastic body when external force deforms that body. Concepts such as this, though interesting mental exercise, have not produced significant psychological research because they have not as yet been bound to measurable consequences.

A third approach, that of a "neurophysiological hypothesis" (Schaffer, 1954) proposed that stress be considered as the "functional decortication" of the organism. This concept is similar to the first one presented in that it is based on the notion that stress is related to a disruption of the homeostatic relationships between the organism and its environment and suffers (thus far) from the same limitations. Another theory that considered stress to be involved in the disruption of homeostasis was provided by J.G. Miller (1953). His working definition of stress,

"...any marked increase or decrease in some characteristic of the environment which affects the individual, "carries on the homeostatic approach but does not differentiate between "psychological" and "physiological" stresses. Though not logically necessary, such a distinction will probably turn out to be convenient.

Defining stress as it relates to the functioning of the human organism is a complex task. Investigation of the literature indicates that a major portion of the studies of "stress" have defined it in terms of operations which were assumed, by the authors, to be stress provoking; therefore, they might be described as a "stress by definition" approach. This revelation is not entirely unique. Holtzman and Bitterman (1952) complained that stress had come to represent almost any type of environmental stimulus capable of producing a reaction.

In many studies psychological stressors may be better considered under the title "experimental procedures for producing stress." Holtzman and Bitterman (1952) classified the methods of producing stress according to seven categories: (1) disruption of physiological homeostasis; (2) unpleasant or physically painful stimuli; (3) distraction, razzing, and time pressures; (4) real, contrived or anticipated failure; (5) social conflict and related procedures; (6) conflicting perceptual cues; (7) realistic situations threatening the individual's safety.

Harris, Mackie, and Wilson (1956) in their review of the representative stress literature defined stress by the operational or stimulus conditions which characterize each study. They considered the duration of the stress stimuli and the temporal relationship of the stress stimuli to the performance measure to be the two most important variables of the stimulus conditions. They presented experimental paradigms for the various stimulus sequences involved. Short-term stress was subdivided into five categories: (1) failure stress, (2) distraction stress, (3) fear stress, (4) physical discomfort stress, and (5) pacing stress or speed stress. Long-term stress was subdivided into four categories: (1) combat stress, (2) hazardous duty stress, (3) confinement and isolation stress, and (4) biological stress.

Stressors which are typical of the short-term stress studies are: failure induced by false norms; unsolvable problems; task interruptions; use of bells, buzzers, sparks; fear induced by shock; personal threats; discomfort caused by high intensity visual, auditory, or tactual stimulation; and finally, the various methods of "pacing."

Stressors which are typical of the long-term stress studies are: combat stress when attacking or under attack; duty in the presence of an objectively real hazard such as enemy action at the front; confinement and isolation in prison; submarine duty; carbon dioxide toxicity; cold, heat, starvation and fatigue caused by long-term performance without sufficient rest.

Lazarus et. al. (1952) in a comprehensive review of the stress literature, thought of stress in terms of an intervening variable. They stated:

The additional concept that is necessary is that of motivation. Stress, therefore, is really a secondary concept, built upon the relationship between a primary concept motivation, and the situation in which motivated behavior appears. We would then think that stress occurs when a particular situation threatens the attainment of some goal. The actual responses

that the individuals may show will depend partly upon the kinds of mechanisms that have been previously established.

By taking this approach considerable simplification is achieved. The authors were able to classify all stressful situations into two groups: (a) stress induced by failure or threats of failure and (b) stress induced by working conditions and the task itself. In a later paper, Deese and Lazarus (1954) provided further material concerning their concept of psychological stress. In this paper stress was conceptualized as involving a number of essential conditions: (1) an ungratified state of motivation, (2) a secondary affective state that occurs whenever a powerful motive remains ungratified, and (3) the cognitive aspect of the problem, which refers to the way an individual perceives a situation as facilitating or obstructing the gratification of a motive. They had this to say about their expanded concept: "We will use the term 'stress' to describe the total event which includes the original motive and the problem created by the thwarting of this motive, its cognitive concomitants, and the responses that result from both the problem and the affective state. Stress is then defined as a complex condition occurring when the thwarting of a powerful motive results in the production of a strong affective state. What is measured in any stress experiment is some behavioral product of the situation we have just described."

In a more recent treatment Deese (1960) presented a stimulus definition of stress which reflects a return to a more simplified approach. He considered stress as a class or collection of stimulus events. By way of definition the author said, "The properties of stressful stimuli are defined by a set of correlated responses. It will be useful, I think, to characterize as stressful those conditions which elicit reports of discomfort or which elicit correlates of discomfort. Such a notion, I believe, will make it easier to understand the varieties of social and psychological situations in which the term stress has been used."

This new "stimulus definition" of stress appears to closely approximate an intervening variable, more so in fact than the original Lazarus et al. (1952) concept. In the original concept stress, for all practical purposes, was considered to be a separate state with emotional and motivational properties, giving rise to characteristic stimuli of its own. In such a case it seems that this concept of stress could very nearly be termed a hypothetical construct. In Deese's current definition the focus is on stimulus (antecedent) conditions and their relationships to response (consequent) conditions, without any speculation on the nature of the state which mediates this relationship.

Katchmar (1954) pointed out the difficulties inherent in attempts to define stress in terms of either stimulus or response operations, or as an intervening variable. One of the difficulties with stimulus definitions involves the subjective aspects of the judgments as to whether or not a stimulus condition is actually stressful. He felt that a stimulus definition would only apply if people were perfectly homogeneous with respect to background and previous experience. On the other hand, difficulties arise in attempting to define stress in terms of response operations when deciding what responses are to be considered indicative of stress. In such a case, the definition becomes snarled with questions regarding motivation, frustration and aggression, etc.

Katchmar considered the response definition espoused by Darrow and Henry (1949) and Haggard (1949) to be extreme. These authors defined an individual as "stressed" when his responses were no longer appropriate to the situation at hand. This was considered extreme because it only seemed to apply to situations where the individual was in immediate physical danger, and was motivated toward self-preservation.

Katchmar had this to say about defining stress in terms of an intervening variable: "In this sense we can define stress as a condition existing within the organism resulting from internally or externally imposed goal frustration which results in a change in normal integrative behavior." This dictates that the intervening variable be anchored to directly observable and operationally definable antecedent and consequent conditions. An approach such as this entails all the ramifications involved in selecting the proper independent variables and dependent variables and in assessing the changes in performance on the dependent variables which may or may not be related to changes produced by the stress-provoking aspects of the independent variables. It may, however, be a necessity.

In summary, most attempts at integration would appear to fall short of the goal. Most of the previously mentioned basic questions relevant to stress research remain unanswered. The criticism leveled by Lazarus, et al. (1952) still holds true. There are still no adequate ways to define psychological conditions that would correspond to a homeostatic steady state. There are still problems in controlling for the subjects' motivational state while trying to induce stress. There is still a problem of introducing realism into the procedures used to induce stress. Despite these many problems, it would seem that the intervening variable approach is potentially the most fruitful. Later in this report (Ch. 6) a modification of the Lazarus-Deese-Katchmar approach will be adopted. Such a step appears to be necessary for an analysis of "task-induced" stress, an area which is very difficult to approach from any other viewpoint.

DESIGNS EMPLOYED IN "STRESS" INVESTIGATIONS

To address the problem of measuring "stress" most investigators have made one of the following sets of assumptions, although the theoretical formulation has not always been explicit. These assumptions clearly indicate different foci of interest.

1. The task or task situation is assumed to be stressful, and the experiment is designed to determine which dependent variables are manifested as "stress effects." In this case interest is focused on the consequences of particular "stressful" situations. The various dependent variables thus investigated may be numerous and many different conceptualizations of stress consequences are reflected by them; e.g. physiological indices, inventories of subjective experience, scores on personality tests, etc. Some studies have been concerned with the identification of "stress syndromes." Using this approach, physiological indices have been obtained and compared.

Also to be included here, but where overt performance measures have constituted the dependent variables, may be listed the work of a host of investigators. Conditions presumed to be stressful were imposed, and effects on performance noted, in the following situations: reaction times, color naming, verbal learning,

perception of incongruities, voice intelligibility, levels of aspiration, psychomotor performance, higher intellectual functions (reasoning, concept formation, etc.), and perceptual rigidity.

2. Certain measures (physiological indices, subjective experience, personality tests, or measures of performance decrement) are assumed to measure "stress effects," and the experiment is concerned with determining the extent to which certain tasks, task situations, or task variables effect changes in these presumed measures of stress. The independent variables thus investigated include task complexity, speed/load, and task duration; physical factors such as noise, temperature, and humidity; and situational variables such as instructions designed to produce ego-involvement, failure stress, etc.

3. Stress is treated as an intervening variable or hypothetical construct. Such a theoretical formulation may or may not be explicitly stated, but in any event the aim is to observe relationships between task or task situation variables (antecedent conditions) and potential stress indicators (consequent conditions). This procedure may be used in one of two ways: (1) when the experimenter is concerned with studying stress itself or (2) when the experimenter is concerned with the effects of stress as a moderator variable, i. e., a variable that interacts with important variables in given situations.

Note that this approach is distinguished from the other two by the fact that multiple measures are involved in both the antecedent and consequent conditions. The significance of this distinction is that the "intervening variable" approach allows, potentially, the isolation of stress dimensions, while the other approaches do not. If only one aspect of the situation (for example, data input speed or load) is manipulated, one can infer that related changes in behavior are, indeed, caused by this manipulation, but not necessarily by "stress." If, however, several aspects (as, input speed, load, outcome risk, etc.) are manipulated independently and observed to produce similar changes over a variety of behavioral situations, some justification is afforded for relating these observations on the basis of some notion such as "stress."

In subsequent subsections research performed under each of the foregoing categories will be discussed. These discussions are meant to be illustrative, not exhaustive.

ILLUSTRATIVE STUDIES

1. Situations Considered "Stressful"

a. Field Studies. The terms stress and threat are often assumed to be synonymous. When concern is focused upon threatening situations, it is difficult to conduct meaningful research in the laboratory; and, as a consequence, studies are often made in real life situations. Because of the lack of manipulative control which is a basic characteristic of field observations, experimenters can remove one difficulty, i. e. obtaining a meaningful stress situation, only at the expense of adding another. Obtaining a favorable trade-off between these two factors is extremely difficult. In most cases, experimenters have little chance even to

identify the myriad of factors present in these field situations. When this occurs - and it often does - they can do little more than take a position of "stress by definition." The logic employed is something of the sort that stress is threatening, situation X is threatening; therefore, situation X is stressful. The problem of comparing stresses under situations X, Y, and Z, and of weighting their various levels and types of threats, is often overlooked in such studies largely because their major concern is with the specific situation being studied. Thus, a study can be adequate for the purposes for which it was designed and still be difficult to interpret in the light of other studies aimed at other purposes, e.g. a specification of important factors in situation Y instead of X.

Studies included in this section differ in regard to (1) the type of environment studied and (2) the focus within the environment studied. The first of these differences will form the discussion basis.

An obvious, and important, stress situation involves men in battle; many studies have examined it. Davis (1954) reported the reactions of men in combat in Korea, and Taylor (1953) edited a report which covers much of the same material. Both articles were concerned with the nature of battle stress and discussed various physiological and psychological measures administered to personnel who had performed under various conditions of battle. Marren (1956) provided strong evidence of the power of this type of stress by reporting a statistical comparison of the incidence of psychiatric syndromes for the periods immediately before and immediately after the cessation of hostilities. He found that battle stress was directly related to psychiatric incidence, and evacuation and hospitalization rates. Such rates increased during and decreased after a combat period. In general, psychiatric incidence rates were approximately 25 per cent higher during combat.

Other studies have also been conducted to determine the effects of stress occasioned by extended periods in refugee or prisoner-of-war camps. Sinha and De (1956) studied group reactions to stress in refugee camps in an attempt to assess the nature of it. They classified the individuals' stress reactions as "adaptive" or "maladaptive" and contended that the maladaptive reactions are comparable to those of disassociation, regression, identification, delusions, and hallucinations. Their study included examples they found in a refugee camp at Bihta. Strassman, Thaler, and Schein (1956) reported a study based on 201 psychiatric interviews and 80 test protocols made on former prisoners-of-war immediately after their release. It was found that apathy was one of the most prevalent reactions.

Basowitz, et. al. (1955) performed an extensive study of a third situation, viz. the psychosomatic and psychiatric processes related to anxiety in paratroop training. After reviewing the results of an inter-disciplinary research team's extensive psychological and biochemical studies of personnel, the authors concluded that the fruitful nature of the transactional approach was much more evident than was the significance or implication of the findings.

Very extensive clinically oriented literature exists in which stress reactions to chronic or severe illnesses are discussed. Typical of these is a volume by Sparer (1956), who intensively studied the manner in which personality variables relate to the stress of hospitalization for tuberculosis. Meyer (1956) has also described the acute psychological disturbances which occurred in a course of hospitalization by patients with certain other chronic illnesses.

Still other studies have been made in attempts to isolate the reactions of individuals to other less obvious stressful situations: (1) industry, which has been studied by Neel (1955); (2) college life which has been studied and reported by Funkenstein, King, and Drollette (1957); (3) penal institutions, as observed by Nord (1956), who studied the reactions of 500 youthful offenders at Ashland's Federal Correction Institution; (4) childhood, as viewed by Clements (1956) who studied the physical, psychosomatic, and emotional health of pre-school children; and (5) senescence, as studied by Gerty (1957).

b. Laboratory Studies. Despite the fact that it is difficult to create meaningful stress situations in the laboratory, numerous studies have been concerned with this problem. One group has dealt with thermal stress (c.f. Aiken, 1956; Bartlett, 1950). These studies have shown consistent effects of thermal stress; as temperature deviates from optimal conditions [e.g., critical "stress" regions lie between 83° F and 87.5° F, (Bartlett, 1950)], performance deteriorates significantly. This has been found for a number of tasks including both perceptual motor and mental activity. Representative findings of studies of different factors are given below. The following independent variables have been studied as potential causes of stress, where the latter is measured by a variety of physiological indices and measures of task efficiency:

(1) Environmental stresses: Aiken (1956) found mechanical dexterity to be significantly depressed by stresses of low temperature, intense sound and low illumination. Bartlett (1956) summarized briefly the main important conclusions that can be drawn from a large amount of work on the effects of noise, heat and humidity, and sleeplessness on human performance. He stated, "...all three forms of stress may, unless special precautions are taken, seriously affect human behaviour when great accuracy and speed are required." Blockley and Lyman (1951) have found that heat has a detrimental effect on pilots performing a complex psychomotor task simulating instrument flying.

(2) Fatigue and Noise effects: Loeb and Schmidt (1960) asked their subjects to respond rapidly to infrequent, randomly presented brief low frequency tones over four 50-minute periods on successive days. Subjects responded to 10 db and 60 db tones during two periods. For one period at each intensity subjects were given information supposedly, but not actually, bearing on their performances (simulated feedback). The authors found that reaction time tended to increase as a function of testing time except when simulated feedback was provided at the 60 db intensity. Also, simulated feedback appeared to produce an over-all reduction in latency and decrease in errors at the 10 db intensity.

(3) Psychometric procedures: Deese and Lazarus performed an experiment designed to investigate the following questions: Do ordinary psychometric procedures produce stress effects? What effect does failure stress have when introduced early in learning as opposed to late in learning? What are the personality correlates of the effects of stress upon performance? It appears that failure-stress introduced early produces a small decrement in performance. When introduced late in learning, it produces a small facilitation. Both kinds of stress produce greater performance variability within subjects. They found no relationship between performance under stress and Rorschach

variables or tension ratings.

(4) Motivation: Bahrick, Rankin, and Fitts were interested in whether or not an increase in motivation would result in increased perceptual selectivity which would favor the parts of the stimulus field which were perceived as most relevant to existing motivational conditions. They found that a condition of high motivation facilitates a performance of a central task, but generally interferes with the performance of peripheral tasks.

(5) Fear of shock: This type of stressor appears often as an independent variable in psychological stress studies. An experiment which is representative of the various studies that treat fear of shock as an independent variable was performed by Lazarus, Deese, and Hamilton (1954). They used three stress conditions: (1) no threat, (2) shock for incorrect response, (3) random shock. The subjects were chosen on the basis of being in the upper and lower quartiles of Taylor scale scores. The task was learning a list of nonsense syllables. The authors felt that the results of their experiment support the hypothesis that task difficulty reverses the usual anxiety - avoidance learning relationship.

(6) Falling hammer: An interesting device was developed to produce the threat of actual physical harm to subjects. The device reported by Buel (1944) is called the "Falling Hammer" and displays the extent to which experimenters have gone to try to induce stress as realistically as possible. The "hammer" was a large block of metal suspended at the end of an arm. When the arm released, the hammer fell until stopped just short of the subject's hand. Subjects seemed unable to avoid flinching even when they knew that the apparatus could in no way harm them.

2. Measures Considered as Stress Effects

a. Physiological and Subjective Indices. A number of studies represent attempts to determine under a particular assumed "stresser" condition, the relationships among various "stress effects": (1) by way of physiological indices, (2) by way of inventories of subjective experience, and (3) by way of scores on personality tests. Ax (1953) performed an experiment falling under the first category in which 43 subjects responded to fear of shock, and anger generated by a lab assistant. Seven physiological reactions were recorded: (1) heart rate (2) ballistocardiogram, (3) respiration rate, (4) face temperature, (5) hand temperature, (6) skin conductance and (7) integrated muscle potential. On the basis of "profile difference scores," the authors rejected the hypothesis that there is no difference in physiological reaction between anger and fear. Other representative studies in this category are discussed below.

Kramar, Peetz, and McCarthy (1954) investigated the capillary response to emotion. They studied about 200 human subjects and hundreds of rats and other animals under conditions of stress which included restraint, exercise, cold, and other environmental stresses. Two effects were noted: (1) an effect of short duration immediately upon stimulation and believed neural in origin and (2) an

effect of longer duration believed to be hormonal in origin. Both significantly affected capillary flow. Newton and Bovard (1957) studied the effect of emotional stress on finger temperature. Using two groups of student nurses they found that the group placed in an emotionally negative situation showed a mean fall in finger temperature significantly greater than that elicited in subjects introduced into a positive situation. No appreciable difference in intergroup basal temperature appeared, however. Since finger temperature is intimately related to capillary flow, the results appear to support the findings in the previously mentioned studies. Bursh, Lotterman, and Shoenfield (1957) measured heart-rate changes recorded during conditioning, and compared them with performance measures of a perceptual motor task. Their data were analyzed for differences during the various prestress, stress, and extinction conditions. No conclusive results were obtained.

Baker and Taylor (1954) investigated changes in skin temperature, electrical skin resistance, and pulse rate after their subjects viewed a display of jumping electrical sparks in one experimental condition, and were subjected to a performance-optimizing level of induced muscular tension held on a hand dynamometer in the other condition. They found that skin temperature changes increased significantly over resting states when both spark and tension were involved. Skin resistance showed significant decrease during the spark stimulus and under tension. Pulse change also increased significantly for both conditions. Skin temperature increase and skin resistance decrease were significantly greater under spark stimulation than under tension. Small but significant relationships were in evidence between the various measures. Van der Volk and Goren (1950) studied electrical skin resistance during periods of induced emotional stress. They found that patients with ulcerative colitis, diabetes, essential hypertension, peripheral vascular disease, and peptic ulcer became tense quite easily while being subjected to the experiment. When these diseases were in evidence, a rise of electrical skin resistance was usually observed. The authors thought skin resistance would be a useful method for measuring tension in seemingly quiet individuals. Glassner and Peters (1959, 1960) have extensively explored the applicability of bio-electronic techniques. Their research emphasized the possible use of bio-electronically monitored phenomena as criteria of human performance and well being. They were of the opinion that significant differences in physiological response can be bio-electronically monitored when the difficulty level of an intellectual task is systematically varied.

Conducting physiological research often necessitates developing new equipment. Johnson (1959), for example, has developed an automatic measuring device for detecting and measuring the arterial diastolic and systolic pressures to provide physiological information about an individual while he is being subjected to stress. Another improved device has been developed by Custance (1960) for continuous measuring and automatic recording of sweating rates. The author felt the technique was equally applicable to mental and emotional sweating. An earlier experiment by McCleary (1953) explored the possibility of using a bag of crystals which shift color with increasing hydration as a method for measuring palmar sweat. McCleary recognized the many sources of error involved in such an experiment; yet he still felt that the SAM Manual Perspiration Test was sufficiently reliable to detect statistically significant differences in anxiety as indicated by palmar sweat.

In a purely physiological effort Ryan and Cottrell (1952) simultaneously recorded muscle potentials from two body areas, as well as palmar skin resistance. It was found that skin resistance tended to decrease with increased effort, but that changes in muscle potential were more reliable than changes in skin resistance. Hyman (1960) has shown that stationary objects may be perceived as containing objects which jump periodically when these displays are viewed with periodic intermittent and periodic alternate exposure of the eyes. With a rate increase of intermittence or of alternation, it is possible to reach frequencies at which the jumping will just disappear. He suggested the exploration of eye-movement latency as a possible indicator of physiological stress.

Bliss, et. al. (1956) investigated the relationship of adrenocortical function to emotional stress. For the most part, anxiety or fear was "judged" as being present by the investigators. Under conditions of judged life stress, the level of the 17 hydroxycorticosteroid in the peripheral blood and 17 hydroxycorticosteroids conjugated as glucuronides in the urine served as adrenocortical function measures. The authors found consistent but modest increases in 17 hydroxycorticosteroids in the blood and urine.

Some investigations have been concerned with relating physiological and psychological (overt behavioral) indices. For example, Selye and Fortier (1950) suggested that there is a relationship between pituitary-adrenal activity and mental processes, although they are not able to state the exact relationship. In an experiment to measure stress in younger and older men, Pincus (1950) asked his subjects to undergo a series of four stress tests: (1) glucose tolerance test, (2) a pursuit meter test, (3) target ball frustration test, (4) adrenocorticotropin injection test. The blood constituents were then measured for a pre-stress, stress, and a post-stress period. His analysis of the urinary and blood constituents suggests that men surviving to old age in good health may preserve relatively intact pituitary-adrenal mechanisms involved in response to acute stress. Domanski, et. al. (1951) studied esinophil output associated with selected forms of treadmill exercises. They indicated that there was a minimal relationship between the esinophil count obtained and any emotional stress arising from the various exercises. In a very subjective and clinical experimental treatment Stevenson and Ripley (1952) performed a pneumographic study of 22 patients (15 with asthma and 7 with anxiety states). The respiratory patterns were found to vary closely with emotional stress.

In reviewing physiological work, one may acquire the impression that many of the experimenters were too "subjective" in their research methods. Subjectivity alone, however, is not sufficient to negate the results of research which inter-relates bio-electronic, chemical, physical, and subjective indices of stress, assuming that adequate measurement procedures obtain. There is considerable evidence that these will be valuable measures in future stress research and that as a consequence of this work, stress might shift from an intervening variable to a hypothetical construct. In some cases practical problems arise, e.g, the funds available to a particular scientist may restrict the use of adequate devices, since some of the equipment is extremely complex, expensive, and often requires the services of highly trained technicians. Because of the potential promise to be gained by using physiological indices, especially to help understand individual differences, these are discussed in more detail in the next chapter.

b. Performance Measures. The literature abounds with studies which use performance measures as dependent variables. In general, the subjects are introduced to situations which are presumed to be stressful and effects on experimental

task performance are noted. Some representative examples of studies of this nature are as follows:

(1) Reaction time: Wener (1954) performed an experiment in which the stimulus was mild shock, strong shock, or a buzzer. The subjects' task was simply to depress a reaction-time key. The subjects were 84 undergraduates from the University of Iowa. The independent variables were stimulus intensity and anxiety as measured by the Taylor scale. The dependent variable was drive level in the Hullian sense as it was related to performance on the reaction time task. The results indicate that manifest anxiety and stimulus intensity might be regarded as having motivational effects. However, there was no significant decrease in the difference in speed of reaction between anxious and non-anxious individuals with increased stimulus intensity. This was possibly due to the fact that either both groups responded at relatively high anxiety levels, or that the stimulus may not only have varied in intensity but may also have affected different modalities.

(2) Verbal learning: Chiles (1958) reported an experiment which involved determining the effects of shock on learning two types of verbal tasks: (1) a high degree of association between the stimulus and response (synonyms), and (2) no association or unrelated words. The findings show electric shock produces significantly better performance on both types of tasks. The data tend to support results reported by Spence, Farber, and Taylor (1954). The author concludes that mild stress can lead to improved performance on a verbal task.

(3) Voice intelligibility: Harris (1948) presented a study concerned with the effect of distracting conditions on the intelligibility of voice communicators. The distracting conditions were threat of electric shock, and addition of an unrelated task to be performed simultaneously with the experimental task (reading a list of words). In analyzing the research results, the author found that in general, there is a tendency for the intelligibility of communicators to deteriorate under stress.

(4) Level of aspiration: A study designed to investigate effects of failure induced stress upon the aspirations of differentially motivated subjects was reported by Versace (1954). The subjects, who were allowed to interrupt a tracking task with periods of exercise or rest, were chosen according to the levels of aspiration they displayed in a group-administered verbal intelligence test. The results show that there is a transient lowering of proficiency when stress is introduced. This is particularly true for subjects who have an initially low level of aspiration. These subjects also seem to lower their aspirations the most.

(5) Perception of incongruities: An experiment was performed by Smock (1955) in which the dependent variable was the recognition of incongruous stimulus configurations. Stress was defined by the experimenter as threat of failure and personal rejection of the subject by the experimenter. The author stated, "psychological stress results in: (a) premature closure, and (b) a tendency to adhere to expectancies in ambiguous task situations, i. e., stress or anxiety results in cognitive and perceptual processes that tend to preserve a 'familiar' perceptual and behavioral field for the individual."

(6) Perceptual rigidity: In studies related to perceptual rigidity the approach is in general, to provide subjects with such tasks as the Luchins water jar test, induce stress, and observe performance. Cowen (1952) in a report of an experiment of this nature indicated that increasing stress does in fact elicit increasingly rigid problem-solving behaviors.

In an experiment using several tests of rigidity [(1) California (F) Scale, (2) Luchin Einstellung problems, (3) Closure Test I (tests ability to shift perceptual set), (4) Closure Test II, (5) Changing Figure Test, (6) Design Preference Test, (7) Forced Choice Anxiety Scale, (8) Test of Insight, (9) Air Force Qualification Test Scores (Intelligence)], French (1955) reported that ego involved conditions did not produce an increase in rigid behavior. Achievement motivation did, however, increase under the ego involved condition. Smock (1955) found support for his hypothesis that psychological stress would result in decreased tolerance for ambiguity. Vince (1950) failed to confirm the hypothesis that an "unexpected" response habit may be thoroughly learned, but will be more likely to disintegrate under conditions of stress than an "expected" habit.

3. The Intervening Variable Approach

The following studies focus upon the complex relationships between antecedent and consequent conditions from which it might be possible to abstract an "intervening variable" or "hypothetical construct:"

Beam (1955) varied the antecedent conditions and obtained several different performance measures, thus treating stress as an intervening variable. The author was of the opinion that the effects of stress on a serial learning task were in the direction predicted by Hullian theory, in terms of increased "drive." Combs and Taylor (1952) allowed their subjects to establish their own perceptions of how threatening any stimulus might be. From the results the authors concluded, "Threat is what appears to one as threatening, irrespective of what outside observers think of the situation." In another study in which several antecedent conditions were varied Coppock (1955) reported that suggestion and stress can influence the extent of an individual's overreaction to information about his own autonomic responses. A study reported by Falk and Bindra (1954) dealt with stress, serial position gradient, and their relationship to the judgment of time. The subjects were divided equally into experimental and control groups. The production method of temporal judgment was used. The subjects were tested individually and given no clue as to accuracy of their time judgments. G.S.R. electrodes were attached to the right hand of the subjects in the experimental group. The left hand was wired to an inductorium. The subject viewed a memory drum which had either a red or a blue mark appearing in the window. When a subject heard the memory drum click, he was supposed to look at the particular mark in the window and estimate when 15 seconds had passed by depressing a chronometer key. A statistically significant serial position gradient was found in both groups. The anxiety-producing situation led to significantly greater overestimation than a comparatively neutral situation. Further, the direction and slope of the serial position gradient was not significantly altered by differences in treatment.

Other examples of studies which treated psychological stress in terms of intervening variables are provided by Farber and Spence (1953) who studied the relationship between anxiety and complex learning and conditioning. Also relevant is that of Glassner and Peters (1959) already mentioned, and finally that of Rosenbaum (1953) who was interested in determining the relationship between

experimentally induced anxiety and stimulus generalization. The subjects were trained to make a motor reaction response to a visual stimulus; they were then tested on other stimuli, differing in height from the training stimulus. The frequency amplitude and latency of the responses to these generalized stimuli were used as measures of generalization. The subjects were 72 psychiatric patients, and 72 male introductory psychology students. There were three levels of experimentally induced anxiety effected by different intensities of shock and a buzzer. The shapes of the generalization gradients for frequency and amplitude were highly similar in both groups. Strong shock resulted in significantly higher generalization gradients than either weak shock or buzzer with both types of subjects. No differences were found between the effects of weak shock and a buzzer.

SUMMARY

This chapter has been concerned with the illustrating the breadth and scope of stress research via examples. The purpose of the presentation was to point out conceptual and methodological difficulties encountered in studying stress. The position taken by the writers is discussed in Chapter VI. For the present time, however, it seems worthwhile to point out that the original Lazarus and Deese approach appears fruitful, in that it succeeds in reducing a vast conglomeration of specific events to a few unifying concepts. However, much work remains to be done in order to link the conceptual structure to the plane of observation. For a general discussion of the procedure necessary and the problems involved, see Hempel (1952).

SECTION III

INDIVIDUAL DIFFERENCES IN STRESS REACTIONS

Prior chapters have been concerned with the development of the stress notion and its progress toward a scientific concept. In these and in the ensuing chapters the primary focus has been upon "stress" as a general effect, across individuals, associated with certain environmental changes and/or experimental manipulations. The present chapter departs from the "treatment effect" approach in order to consider the role of individual differences: Why are some people stressed more readily than others?

PSYCHOLOGICAL INDICES

A number of researchers have directed their efforts toward deriving measures which will permit the prediction of an individual's reaction when placed in a stressful situation. A sizable portion of this research has been aimed at determining the effectiveness of projective tests as stress reaction predictors. Many experimenters who based their research on projective tests as stress reaction predictors have made the tacit assumption that these tests provide reliable and valid measures of the various personality traits, in the absence of critical validation data. Thus, the rather tenuous nature of many such instruments as measuring devices has not curtailed efforts to establish them as predictors.

1. The Rorschach Test: Some attempts have been made to predict stress reactions from Rorschach scores. Williams (1947) reported a high degree of relationship between performance under stress and Rorschach measures of emotional and intellectual control. Carlson and Lazarus (1953) repeated Williams' study, however, and found no relationship between Rorschach measures and a decrement in performance under stress. They concluded that the correlation reported by Williams is not representative of the relationship between Rorschach variables and performance under stress. Charles (1955) tested a group of 30 students with the Rorschach and divided them into three groups: well adjusted, moderately well adjusted, and mal adjusted. He then placed the subjects in stress situations in which a card sorting and a digit-symbol task were performed. Success was made impossible by falsifying the subjects' scores. "Unacceptable" responses made by the subjects were classified in terms of verbal aggression, physical aggression, and rationalization and an analysis of variance was performed to determine whether the different groups had essentially different reactions. Significant differences were obtained, being more pronounced for the digit symbol task.

Lofchie (1955) studied the performance of adults under distraction stress. He utilized a population of 35 male industrial workers and tested a hypothesis that subjects scoring higher on the Rorschach index of perceptual maturity would be better performers on a psychomotor task under conditions of distraction stress. The results of the experiment supported his hypothesis.

2. Miscellaneous Personality Measures: Several other personality correlates have been used as a basis for research relative to predicting behavior in emotional stress situations. These researches have involved such measures as: the Minnesota Multiphasic Personality Inventory (M. M. P. I.), Bender Motor Visual Gestalt, Winne scale, need achievement inventories, and several newly developed personality inventories.

Deese, Lazarus, and Keenan (1953) studied the relationship between experimentally induced stress and personality factors. They chose 90 subjects using a questionnaire by Winne composed of 30 items from the M. M. P. I. These items supposedly differentiate between normal and neurotic individuals. The subjects were divided into three experimental groups of 30 subjects each. In each experimental group 15 subjects had scored low on the Winne inventory and 15 had scored high. All of the subjects learned the 12 consonant nonsense syllables for 12 trials. The control group was told that they were serving as the control group, and learned the syllables without threat or punishment. The avoidance learning group read through the list once, as had the controls; they were thereafter shocked for failure to respond or for making an incorrect response. They had been told that this was going to happen beforehand. The non-avoidance learning group was treated the same as previous conditions except that they were shocked irrespective of whether or not they made a correct response. The shock frequency was matched to that in the avoidance group. This shock condition was also explained to the subjects before the trials. The researchers found that high anxiety groups gave consistently more correct responses than the low anxiety groups. This difference occurred early in learning and was maintained throughout the experiment. An interaction between the personality inventory and the experimental conditions was such that the largest difference between the high and low "anxiety" groups occurred in the avoidance learning situation.

French (1955) studied the relationship between rigidity and behavior under stress and non-stress conditions. In her study, 40 male airmen were measured with seven tests of rigidity, a test of achievement motivation, and an intelligence test. Ego-involvement (stress) was introduced by telling the subjects that the results of the test would be important to their Air Force careers. She found no increase in rigid behavior under ego-involved conditions. Ego-involvement did not produce an increase in the degree of relationship among the various measures of rigidity. Achievement motivation increased under ego-involved conditions.

Bitterman and Holtzman (1952) were interested in discovering whether or not conditioning procedures might provide them with objective indices of emotional stability that could be used as psychiatric screening devices for the military. They chose 37 university men at random from a list of volunteers. The subjects were rated for susceptibility to anxiety on the basis of the M. M. P. I. and performance in a laboratory stress situation; they were then divided into two groups on the basis of this combined criterion. The experimenters discovered that the galvanic skin response to shock was more easily conditioned and less easily extinguished in the high anxiety group. The authors suggested that the results of the study were significant indicators of the need for further research to establish the relative worth of conditioning procedures for psychiatric screening of military personnel.

J. G. Miller (1953) was also interested in developing stress sensitive tests for predicting military task performance. He reviewed the literature on stress reactions and selected twenty testing procedures which he thought might be effective in determining the presence of stress reactions:

- (1) Korchin's test. Tachistoscopic presentation of broken circles with some complete circles interpolated, the observer being required to designate the location of the break, if any.

- (2) The Wisconsin concept-formation test.
- (3) A level of aspiration test, the ball-and-slot test of Rotter. The total achievement score, as well as goal-discrepancy scores, may be studied.
- (4) Critical Flicker Fusion, in which both rate of flicker and percentage of time the light is visible can be varied.
- (5) The Digit-Symbol subtest of the W-BIS.
- (6) The Digit span subtest of the W-BIS.
- (7) Cancellation of Cs from a page of Os.
- (8) A tapping rate personal tempo test.
- (9) Leg-swinging personal tempo test.
- (10) Word Fluency subtest of the SRA primary mental abilities test.
- (11) The number subtest of the SRA primary mental abilities test.
- (12) The ergograph, employing a single finger and measuring both strength and tempo.
- (13) The myokinetic test, involving two-hand coordination.
- (14) The Luria Technique.
- (15) The pneumograph.
- (16) A sentence-completion test, scoring the total number of fear responses.
- (17) The auditory Flutter Fusion test of Davis.
- (18) The Taylor A scale of the M. M. P. I.
- (19) The trembleometer test, measuring microtremors of a finger.
- (20) The tracking test, in which subject taps at a line or target over a moving paper strip.

These twenty tests were pretested to 48 paratroopers making their first jump from a 34-foot mock tower. From the analysis of the data gathered under these conditions, four tests were selected as being likely to be the most predictive of performance under stress:

- (1) Critical Flicker Fusion
- (2) Cancellation of Cs

(3) The Primary Mental Abilities Word Fluency Test.

(4) The Trembleometer Test.

These four tests were administered to 500 pre-inductees under ordinary testing conditions and also under conditions where stress was induced by continuously sounding an 8000-cycle, 90-decibel noise. The results were inconclusive. The author thought the trembleometer and the Critical Flicker Fusion tests appeared to warrant further study.

Erikson, Lazarus, and Strange (1951) in a follow-up study of an experiment which investigated the effects of failure stress upon performance on the Digit Symbol test, attempted to predict performance under stress from various personality measures. No significant relationships were found between the various personality measures and performance under stress. Nor was there any significant relationship between performance under stress and any Rorschach variable. Some nonsignificant trends were found on the Guilford-Martin Inventory of Factors GAMIN and the Bell Adjustment Inventory. From this it was concluded that subjects who improve in performance under stress are more ascendant and have greater self-confidence. The authors also found that subjects who characterized themselves as calm were more likely to show impaired performance under stress than those reporting themselves easily upset under stressful conditions.

The authors discussed their results as follows: "It was demonstrated that subjects who are rated as overtly disturbed in stress situations need not be those who show impaired performance. The full implication of this fact has not previously been recognized by psychologists interested in psychological stress. The psychiatric screening of military personnel has, in the past, greatly depended upon such signs of emotional upset as tremor, excessive sweating, and other anxiety indicators. It is possible that these criteria are inappropriate or less important than supposed should further work substantiate the lack of positive relationship between outward signs of disturbance and impaired performance under stress conditions."

Applezweig (1953-1957) was active in promoting a study of the relationship of motivation to psychological stress. He and others developed the Behavior Interpretation Inventory, which at the outset was only meant to be an aid to the study of the motive-stress relationship. However, Applezweig stated, "As the standardization, revision, and restandardization of the BII proceeded, we became more and more convinced that development of this type of measure was worth the major part of our efforts, and that it was yielding results of sufficient promise to warrant its continuance."

The Behavior Interpretation Inventory is a 59-item forced-choice scale designed to measure the following four dimensions of human motivation: (1) Escape from present pain or discomfort, (2) Avoidance of future pain or discomfort, (3) Social approval, or belongingness, and (4) self realization, or self-approval. A basic assumption underlying the rationale of the BII is the notion that a person will be psychologically stressed when faced with a conflict of motives. By use of the criteria of interchangeability and choice in the construction of the BII, motive classes which must conflict when aroused simultaneously were automatically created. The forced choice format of the scale also forces the subject to employ his own criteria of interchangeability in choosing between item alternatives. In terms of conflict theory, the greater the absolute strength of opposing tendencies, and the longer the person is caught in the conflict situation, the greater will be the

effects of conflict; i. e., stress. Applezweig felt that from knowledge of a particular situation and an individual's BII file, it should be possible to predict typical behavior for each of the several kinds of conflict situations described. It seems that this inventory should be investigated as a potential personnel selection device.

Barry, Fulkerson, and Sells (1956) undertook an experiment in which they studied the McKinney Reporting Test as a screening device. The test was included in a battery administered to 428 co-pilots entering training at Randolph AFB in 1951-52. The pilots were rated according to their adjustment to the training program. The final research group was comprised of the 100 pilots who were rated as having made the best adjustments to training and the 100 rated as having made the poorest adjustments. The researchers accepted McKinney's premise that the test was a measure of frustration proneness, and proceeded to test the hypothesis that the less well-adjusted pilots would show a greater decrement in performance efficiency (reaction to stress) than the better adjusted pilots. The comparison of the performance of the two groups on the test did not substantiate the hypothesis and the researchers discarded the notion that the test was sensitive to the effects of stress.

Eriksen (1954) performed an experiment designed to investigate "some personality correlates of stimulus generalization under stress." The stimuli were squares of various dimensions and the response required was horizontal arm movement. The subjects were 18 hysterics, 12 assigned to an avoidance condition and 6 to non-avoidance, and 21 psychasthenics, 14 in the avoidance condition and 7 in the non-avoidance. In the avoidance condition a subject received shock if the response to the training stimulus was not quick enough. In the non-avoidance condition shock was received regardless of the propriety of the response. It was determined from the results that hysterics showed significantly more stimulus generalization under both experimental conditions, and both the hysterics and psychasthenics displayed significantly more generalization in the avoidance condition. The clinical grouping of the subjects for the experiment was arrived at through use of the M. M. P. I.

Korobow (1955) was interested in studying the relationship between personality traits, attitudes, and reactions under audiogenic stress. He administered three attitude and personality scales to his subjects. Two of these relied heavily on introspection. The scales were: (1) Introspective rating scale A to uncover probable responses to stress conditions. This was administered one week before the experiment. (2) Introspective rating scale B designed to obtain subjective reports on the subjects' felt reaction to induced stress. This was given after the experimental stress situation. (3) T. N. Jenkins' "How Well Do You Know Yourself" Form 2A, an 825-item test, factorially designed to yield relatively discrete personality categories, given one week before the experimental stress situation. The experimenter required the subjects to respond to cards containing simple proverbs by fully explaining and also giving examples of applications of the proverbs. Audiogenic stress was induced by recording the subject's voice and playing it back while he was still talking. He was confident that the delayed auditory feedback effectively induced various degrees of stress, and that the subjects reacted to the stress in accordance with the subjective reports of their interpretation of the audiogenic stress situation. The author presented the following interpretation of his results: "A significant relationship between the type of verbal errors made under stress and personality traits suggested the probability that stress behavior reflects a hierarchical level of trait organization which is dependent upon the pattern of traits which are operant at that time."

Brozek and Taylor (1954) investigated the predictive value of strength tests, speed tests, and a coordination test in combination with certain physiological indices of the ability to do hard work. They found that a combination of the speed, strength, and coordination tests with the physiological indices provided a meaningful measure for use as a basis for the predicting of behavior in deteriorating biological stress situations. Voas, Bayer, and Ambler (1955, 1956) studied the extent to which behavior in a stress situation could be used to predict failure in a highly stressful flight-training situation, where later separation was associated with an expressed anxiety toward flying. Results for more than 1500 cadets showed that there is a significant relationship between anxiety reactions during simulated high-altitude flying in a decompression chamber and eventual withdrawal from the flight-training program with an expressed anxiety toward flying.

Weybrew and Alves (1959) explored the feasibility of using Electrodermal conductance (EDC) measures or other autonomic nervous system indicators as predictors of ability to tolerate the stresses of long submarine submergence. They obtained EDC measures from 23 enlisted submariner candidates during forced hyperventilation and breathholding. The subjects were also rated on the following trait rating scales: adaptability to change, emotional stability, anxiety, muscular tension, talkativeness, acceptance of authority, self-concern, excitability, fatigability, maturity, self-confidence, emotional tone, motivation, recklessness, likeability, alertness, leadership, industry, problem sharing, aggression, mood, frustration tolerance, and an over-all rating scale as a potential submariner. They found basal conductance level to be negatively correlated with ratings on adaptability to change, motivation, likeability, industry and self-confidence. Relative recovery to basal conductance levels was positively correlated with the ratings on emotional stability, absence of hypochondriacal symptoms, adaptability to change, likeability, and absence of tendency toward depression. Further, the lability of basal conductance level and ratings of the trait dimension of excitability were negatively correlated. Rated anxiety as it was measured had no correlation with any of the EDC measures. On the basis of these findings, the authors felt there was some indication that the EDC-derived measures could be used as predictors of ability to tolerate the stresses of long submergence.

If the environment from which Ekman (1960) drew his subjects can be considered stressful, his experiment is worth consideration. He studied the disciplinary behavior of stockade prisoners and their adjustment to the stockade environment. He examined their behavior before entering the service, their military records, and their responses to the M. M. P. I. and the Bender Visual Motor Gestalt Test (BG). He found the same type of personality pattern present in the most severe disciplinary offenders and the model prisoners. The M. M. P. I. did differentiate the various groups of disciplinary offenders or model prisoners, while the Bender Gestalt did not.

Ekman also reviewed the responses of recruits to the M. M. P. I. in the first, fourth and eighth weeks of basic training. He found a slight but significant movement in the direction of pathology--an increase in aggressive, impulsive characteristics--as a result of basic training. If basic training can be viewed as a stressful condition, an implication that one might consider is that it may be important to study the way performance under stress modifies the individual's personality as well as how personality traits determine the reaction to stress.

Flaherty et. al. studied the reactions of four subjects to thirty-six hours of confinement in the School of Aviation Medicine Space Cabin Simulator. They found two of their four subjects unable to continue the simulated flight. In their discussion they presented a psychiatric evaluation showing why the two men failed to complete the flight. The authors did not indicate whether they made any attempt to predict the future behavior of these or other individuals from their psychiatric protocols.

3. Anxiety as a Measure of Stress Susceptibility: The Taylor Manifest Anxiety scale has been the subject of a great deal of controversy and research. The scale was originally constructed by asking clinicians to select the items for the questionnaire from a pool of M. M. P. I. questionnaire items. These were grouped together into a scale, which was called the Manifest Anxiety Scale. Whether the title of the scale is accurate or not, the M. A. S. has been viewed by some researchers as a predictor of the way a person will react to stressful situations. Studies relating performance on the M. A. S. to performance on a wide variety of tasks have produced both positive and negative results.

Hilgard, Jones, and Kaplan (1951) described an experiment designed to examine the relationship of conditioned discrimination to anxiety. The stimulus consisted of changes in illumination on adjacent windows of flash glass. During the reinforcement trials the increased illumination of the right window was followed after 650 m. sec. by an air puff to the right eye. The independent variable was anxiety as measured by the M. A. S. The authors reported that simple conditioning was obtained in one period. This was followed by discriminatory conditioning in a second period. During this second period the air puff always followed the illumination of one window; illumination of an adjacent window was never followed by an air puff. The authors found a positive, non-significant correlation between anxiety and simple conditioning. Correlations that approached significance were found between anxiety scores and two measures of discrimination. These were taken as evidence that more anxious subjects did not discriminate as well as less anxious ones.

Taylor and Spence (1952) investigated the relationship between serial learning performance and anxiety. They used drive strength as indicated by the scores of the subjects that fell within the upper and lower 15 percent on the M. A. S. They found that the high drive (anxious) subjects required a larger number of trials, and made a significantly greater number of errors in reaching the learning criterion. Spence, Farber and McFann (1956) found that "anxious" subjects required significantly more trials to reach criterion on a paired associates learning task.

Holtzman, Calvin, and Bitterman (1952) considered the Winne scale to be a valid index of anxiety. They correlated it with portions of the Taylor scale and, due to the high correlation between the two scales, presented their results as evidence for the validity of the Taylor Manifest Anxiety Scale. (At least it would appear that these two scales are measuring the same thing, whatever that is.) Spence and Taylor (1953) reported an experiment in which the independent variables were the diagnostic classification of the subjects: i. e., normal, neurotic, and psychotic, plus their M. A. S. scores. The subjects were 45 normals from an introductory psychology course, and 55 patients, 34 neurotic and 21 psychotic. The dependent variable was eyelid conditioning. The experimenters found the psychotic group to be significantly higher in conditioning performance than either neurotics or normals. The neurotic group displayed a slight,

statistically insignificant superiority over the normals. Patients with high scores displayed a higher performance than did the low-scoring patients. Normal subjects with extreme anxiety scale scores differed significantly in conditioning performance. It appears that as the anxiety scores increased, the level of conditioning became greater.

Wesley (1953) provided some comparatively negative results in relation to the M. A. S. She used rigidity as defined by a questionnaire, and anxiety as defined by the revised Taylor scale as her independent variables. The dependent variable was performance on a concept formation task. The author did not find a significant relationship between manifest anxiety and rigidity as defined by the paper-and-pencil questionnaires. Further, there was not a significant difference in the number of trials taken by the rigid, anxious, and normal groups to reach criterion in the original learning series.

Meyer, Bahrick, and Fitts (1953) were interested in the relationship of incentive and anxiety to the human blink rate. The subjects that performed in their experiment completed portions of the Taylor inventory, and also the Potter completion test which was scored for maladjustment by an expert clinician. The experimenters used monetary incentives throughout the experiment. The independent variables in this experiment were incentive and personality test scores. The dependent variable was the human blink rate. Their results showed significant changes in the blink rate when incentives were introduced. However, the only significant correlation between blink rates and the personality measures was found with scores on a maladjustment index based on the Potter Sentence Completion Test.

Katchmar (1953) reported an experiment in which the subjects were chosen on the basis of high and low scores on a modified form of the Taylor Manifest Anxiety Index. The experiment examined the effects of three independent variables--level of anxiety, ego-involvement, and failure stress--on performance at a highly repetitive task which required a shifting between two well-practiced acts: the Woodworth-Wells form naming and substitution test. Performance was measured by the time to completion, the difference between pre and post stress time to completion, number of errors and number of blocks. The analysis of variance indicated that subjects who were high in anxiety showed significantly poorer performance as measured by time to completion, errors and blocks. The difference between pre and post stress performances showed that anxiety also has the effect of increasing susceptibility to stress. A test experience inventory indicated that high anxiety subjects experienced stress to a greater degree than the low anxiety subjects.

Goldstone (1955) examined the relationship between Flicker Fusion Thresholds and anxiety. He plotted the following four measures of FFT on normal probability paper: (a) FFT, (b) slope or precision of judgment, (c) difference in FFT between the first and last ten runs of the flicker test, (d) the difference in slope between the first and last ten runs. His interpretation of the results disclosed that the high anxiety subjects had a lower FFT than those with low anxiety. They also had a greater decline in FFT associated with continued exposure to the flicker test.

In an experiment relating discrimination apparatus stress to the Taylor scale, Kamin (1955) found manifest anxiety unrelated to discrimination task performance. He stated, "The pattern of intercorrelations, and the fact that Taylor Scale score is related to mechanical aptitude, suggested the speculation that data of studies relating the Taylor scale to eyelid conditioning may be attributable to the mechanical aptitude-Taylor scale relation, or 'apparatus stress'."

Kerrick (1956) found no significant difference between high and low manifest anxiety groups in relation to discrimination performance on a form of Osgood's semantic differential. The author also found that increased anxiety in high I. Q. subjects tended to make them less "discriminating." The reverse was found to be true for low I. Q. subjects.

Burns (1960) compared the scores on the M. A. S. with scores on a time estimation test. It was hypothesized that the high M. A. S. scorers would have difficulty withholding a response, as revealed by performance on the Time Estimation Test. The significant correlation obtained between the M. A. S. and TE scores for the longer time intervals to be estimated substantiated the hypothesis.

It can be seen from the many attempts to assess psychological stress from the standpoint of the Taylor scale, that the scale itself is often accepted at face value. It may have applicability for predicting performance in a task induced stress situation. However, attempts to use it in such a manner should be viewed with skepticism in the absence of direct supportive data. The need for careful study of the Taylor scale before its incorporation into objective experimentation was emphasized by Jenkins and Lykken (1957):

The theory underlying the M. A. S. has never been clearly enunciated. The test was originally constructed by asking clinicians to select from a pool of standard personality questionnaire items, those items which would likely be endorsed by persons suffering from high manifest anxiety. Some of the postulates which would appear to be involved, therefore, in the theory of this test include: (a) that there is some unitary state (or response) with respect to whose intensity people vary, which may reasonably be called manifest anxiety; (b) that the clinician-judges had reasonably isomorphic notions of the nature of the variable; (c) that the clinician-judges were able to predict validly the normal questionnaire behavior of persons high on this variable (which, in turn, implies the assumption that the clinicians were able to assess validly the intensity of this variable from clinical observation of individuals), and (d) that the total number of such items which an individual testee endorses approximates to some monotonic increasing function of the intensity of the variable in that subject at that time, over the full range of such intensity observable in the general population.

Deese (1960) indicated the weakness inherent in current attempts to predict skilled behavior from personality measures. He pointed out the fact that though numerous investigators have found such correlations which did indeed vary as a function of the conditions of stress, "...the obtained correlations are almost without exception small, and in some cases, contradictory evidence concerning both their direction and magnitude is available." Deese suggested that possibly a very narrow range of personality measurements has been tapped in the studies of correlation of personality and skilled performance. This was evidenced by the fact that though a large number of personality scales have been used (Winne Inventory, Taylor Scale, Psychasthenia Scale), little has been learned because these scales are highly correlated. He referred to

this when he said, "Even investigators who have used scales not derived from the M. M. P. I. have failed in the attempt to escape personality tests which correlate highly with the Psychasthenia Scale." He concluded, therefore, that despite the plausibility of the notion that there should be an association between performance stability and objective personality dimensions, the evidence in support of such a notion has been weak.

PHYSIOLOGICAL INDICES

Understanding and control of the effects of psychological stress have been much impeded by the absence of techniques for measuring stress itself. As has been indicated, this must usually be effected on a highly inferential basis. The possibility of defining "stress" in terms of some objectively observable process has intrigued many investigators. The most obvious possibilities are the various physiological changes, which do bear some known interrelationship: i. e., they show correlated changes as an individual is exposed to stressful stimuli. A plausible assumption (usually not made explicit) is that because these measures co-vary as state changes within subjects, they should also co-vary as trait measures descriptive of differences between subjects. For example, if electrical skin conductance is known to increase when a particular subject is stressed, then those subjects with higher skin conductances (when at rest) must be those who are "under more of a stress." But stress or stress-susceptibility, when considered as a relatively permanent individual difference feature, may have an entirely different dimensionality than the pattern of changes that occur within an individual. To defend the use of such measures in personnel selection requires, therefore, the same experimental evidence as is required for less objective measures.

Studies relating physiological variables to the presence of stress may be considered under the headings of (1) blood, (2) urine, and (3) miscellaneous physiological conditions. In reviewing these studies, emphasis will be placed upon individual differences. However, some "treatment effect" material is also included, where applicable, to permit comparisons between these two lines of evidence.

1. Blood: In general, studies correlating various characteristics of the blood supply with stressful behavior either relate to some aspect of the circulation or to some aspect of the blood chemistry.

a. Circulation: Various investigators have attempted to relate blood pressure to distress situations. Stevenson, Duncan, Flynn and Wolf (1952) studied hypertension as a reaction pattern to stress and attempted to correlate circulatory hemodynamics with changes in the attitude and emotional state. Seventy-four persons were studied. Among the subjects were 30 hospitalized patients with resting blood pressures of 150/90 mm Hg or more, 16 patients without hypertension and 28 normal persons. Personality data on each subject were obtained and correlated with symptoms and with measurements of circulatory function. During overt emotional disturbances the hypertensive subjects showed a greater rise in blood pressure in proportion to the increase in cardiac output than did the normotensives. The results suggest a greater vasoconstrictive response in this group.

Funkenstein and Meade (1954) studied 100 psychiatric patients with elevated systolic blood pressures and 25 normotensive students with a response of elevated systolic blood pressure to a stress-inducing situation. The groups were compared after intra-muscular injection of standardized doses of mecholyl chloride. In this article and in a later article by Funkenstein (1955) blood pressure reactions and their implications were discussed. It was determined that blood pressure was raised under stress conditions by secretion of adrenaline and noradrenaline. Further analysis suggested that these hormones are differentially secreted during "anger" and "fear" situations.

Lovett-Doust (1956) studied the mean capillary blood-oxygen saturation of 45 stutterers while at rest and when in stressful situations involving a series of auditory verbal stimuli. He found significantly different oximetric scores which enabled him to differentiate between traumatic words and neutral words. Anoxemia was greatest when the parent of the same sex or his surrogate was given as a stimulus. Stutterers as a group were also extremely sensitive to a simple breath-holding procedure.

Schneider (1951) investigated six patients with recurrent thrombophlebitis. He found that they reacted to the major and minor stresses of daily living with anxiety, fear, and anger; and that these reactions were commonly accompanied by a shortened blood clotting time. Lovett-Doust and Schneider (1955) also made oximetric studies of various groups including neurotics, schizophrenics, depressives, idiopathic epileptics, senile demented, mental defectives, and healthy controls. They found no significant difference between the groups with respect to verbal and aurally presented non-traumatic stimuli. However, significant anoxemia accompanied the presentation of potentially stressful stimuli in all groups except the psychotics.

Pulse rate has been extensively investigated since it is an easily obtained and very responsive measure. Knobloch (1951) measured automatic and motor reactions of persons under emotional stress. Using a group of neurotic patients as a comparison group and normals as controls, he measured pulse rates during rest, physical exercise, and two situations of emotional stress; electrical stimulation and the Hull-Eysenck body-sway test. There was no difference in resting pulse rates, but in both physical exercise situation and the emotional stress situation the neurotic group was more labile in autonomic and motor reaction. The small number of cases involved in the study made the results more suggestive than conclusive, however.

Goldsmith (1957) performed an experiment directly related to the physiological correlates of stress. She used mirror drawing, a modified Carl Hollow Square Test, and delayed speech feedback as stressors, and investigated their effects upon the galvanic skin response, respiration rate and pulse rate. The experimenter was also interested in determining the relationship between individual differences in physiological recovery from stress, expressed in terms of Friedman's recovery quotient, and anxiety proneness measured by a paper and pencil test. One further goal of the author was to determine the relationship between anxiety proneness and initial psychological reactivity measured by paper and pencil inventories.

One hundred and twenty introductory psychology students volunteered for testing and were randomly assigned to experimental and control groups. The Saslow Screening inventory (supposed to measure anxiety proneness) and the inevitable Taylor Scale were administered to the subjects as a group before they were individually tested in the experimental situation. Physiological measures

were taken during the initial and final 5-minute rest periods and in two intervening periods. The control subjects rested throughout the 19-minute experimental period. No significant relationship was found between R.Q. scores and scores on the M.A.S. or Saslow Screening Inventory. There were no significant correlations between scores on the M.A.S. or the Saslow Inventory and initial psychological reactivity to stress. The galvanic skin response, respiration rate, and pulse rate all appeared to be significantly increased under stress conditions.

b. **Blood Chemistry:** The literature contains many reports relating stress to eosinophil count. Results appear to indicate that there is a relationship, but the studies reported to date do not permit derivation of the exact nature of the relationship. Domanski (1956, 1957) has studied the human stress response in jet aircraft operation. Blood and the eosinophil counts were used to estimate the stress preceding and following one-hour flights. Subjects were studied prior to and following flights in F-86D and F-94 aircraft, and in flight simulators. Various types of personnel were tested including experienced pilots, pilots in different stages of transition training, and radar observers. In general, results tended to support the conclusion that the eosinophil count could be used to estimate individual differences in response to a given stress and the relative severity of a particular in-flight stress or stress complex.

Kerr (1956) studied the effect of mental stress on the eosinophil count in man. He used dental students taking dental surgery examinations as subjects and made four eosinophil counts at hourly intervals while they were being examined. Results were rather inconclusive. In two subject groups the eosinophil counts showed apparently random fluctuations. In the other group, eosinophil counts in four subjects appeared to fall steadily while the counts on the fifth subject showed almost no change. The first four subjects were judged by observers to be suffering considerable mental stress, while the fifth was judged to be unworried or very confident.

Dreyfuss (1956) studied coagulation time, eosinophil level and thrombocyte level under emotional stress. Biochemical measures were made of blood samples taken from 36 students immediately before and 24 hours after final medical college examinations. The blood samples showed a very significant decrease in coagulation time and in eosinophil count during the examination. Thrombocyte counts showed no variation under the two conditions. Wheeler, et. al. (1954) studied the effects of stress, as measured by a decrease in the number of circulating eosinophils, in a group of normal subjects and in a group of patients suffering from atopic dermatitis. Stress conditions included direct physical stress, conscious psychological stress, and hypnotically suggested stress. Results were complex, but the general indication was that both groups responded to stress with eosinophil drops, with larger drops in the normal group than in the dermatitis patients.

Board, Persky, and Hamourg (1956) analyzed blood samples from acutely disturbed mental patients in order to determine blood levels of adrenocortical and thyroid hormones. They found that intense stress, as evaluated by interview methods, and extensive personality disintegration such as that shown in psychotic depressive reactions, were accompanied by high levels of these hormones. Beischer (1956) determined the serum cholesterol, phospholipid and lipoprotein levels before and after exposure to physical exercise, low and high atmospheric pressure, mental stress, and hyperventilation. He used five human subjects and found that none of the values measured after stress deviated significantly from the values measured before stress or from the mean value of the control period.

Persky (1954) measured glutathione metabolism in men under psychological stress. Biochemical analyses performed on blood samples from four groups of subjects indicated that glutathione concentration was significantly reduced five to ten hours after psychological stresses which included jumping from a 34-foot tower while in harness, parachute jumping, and participation in night infiltration exercises. The effect was not observed after hard physical work.

Van de Water (1954) in summarizing findings of a team of investigators who spent seven weeks studying soldiers in a combat area, indicated that despite wide individual differences, there were certain reliably predictable reactions. Blood studies showed that after extensive exposure to a stress situation, such as combat, there was a shortage of white blood cells. They also found that men in combat sweat profusely, urinate frequently, and yet, in spite of losing water, do not show increased drinking behavior. Consequently, a certain amount of involuntary dehydration takes place. The findings also indicate that it takes 5 to 12 days to recover from these combat strains.

Halmos (1953) also studied the modifications of the blood which occur during emotion. He made studies of blood leucocytes, electrolytes, glucose and protein in medical students before, during and immediately after examinations. His results indicate that blood leucocytes appear to vary considerably during the stress of examinations, varying by as much as 140 percent. During a difficult test, the leucocyte count goes up and during a period of relaxation it decreases. The data on electrolytes, glucose, and protein are incomplete and inconclusive as are data obtained from use of the Rorschach F scale.

2. Urine: A portion of the research effort in the area of psychological stress has been directed toward comparing individual differences in 17 hydroxycorticoid output or 17 ketosteroid output. In general, a urinalysis is performed just prior to, or after the individual has been in a stressful situation. In such cases the investigators are primarily interested in ascertaining whether or not emotional stress influences adrenocortical function.

Hetzel Grace and Wolff (1956) made determinations of the gaseous exchange and total nitrogen excretion made before, during, and after "acute stressful interviews." Euthyroid, hypothyroid, and adrenalectomized subjects were studied. They found a significant rise in oxygen consumption and a fall in respiratory quotient. This pattern suggests increases in the urinary nitrogen excretion. Hetzel et. al. (1956) studied the changes in urinary nitrogen and electrolyte excretion during stressful life experiences and its relation to thyroid function. Their studies on normal and hyperthyroid subjects indicate an increase in nitrogen and potassium excretion in normal subjects without any difference in urine flow.

Schwartz and Shields (1956) correlated the urinary excretion of formaldehydogenic steroids and creatinine with self-evaluations of stress. Their subjects were medical students interviewed and tested after final examinations. The students' evaluation of the stress associated with the final examination were positively correlated with increases in formaldehydogenic steroid levels. Similar patterns of a rise and fall were noted in creatinine excretion, but the correlation with tension estimates was poor. Bliss, et. al. (1956) studied the adrenal cortical reaction to a variety of natural and experimental stress situations using several classes of subjects. The affective disturbances aroused were accompanied by consistent but modest increases in 17 hydroxycortico-steroids in the blood and urine. They found that the changes were less than the changes

following intravenous administration of ACTH or insulin, electro-shock treatment, or moderate exercise. Clark, Lahn and Holmes (1954) found in a study of 109 hospitalized patients that there was a relationship between 17 ketosteroid secretion and emotional states during treatment for tuberculosis.

A study undertaken by Fox (1959) incorporated many indices in addition to the analysis of the urine. His study provides a thoroughgoing example of an attempt to link the function of the psychological mechanisms in the human organism to some of the seemingly parallel biochemical functions which are in evidence during periods of mild stress. The working hypothesis which was the basis of the experiment was stated as follows:

Measurable substances in the blood and urine representing activity of the adrenal medulla or of the adrenal cortex provide a humoral indication of the homeostatic responses to stress. Functional balances in the central nervous system--for instance, hypothalamus and cortex--may reflect the same disturbance. The psychological manifestations may include primitivation of personal defenses expressed in behavior and thinking with corresponding demonstrable alterations in the quality of perception. In accordance with this hypothesis the investigation has relied on methods for observing the human organism under stress which attempt to correlate disturbance in relatively constant biological and psychological rhythm, equilibria, and defensive balances.

The subjects were volunteers over 21 years old at Harvard, all of whom were anticipating eventual military service. Two weeks was established as an adequate control period for urinary collections. These were divided so that one week of control collections was made prior to the first interview with the psychiatrist, and the second control week after the last interview. This was done with the speculation that some biochemical change might be reflected in the emotional response to discontinuing the relationship with the psychiatrist. Various phenomena were studied during the course of the experiment: 3 weeks of psychiatric interviews, sleep deprivation with concomitant electroencephalographic studies, changes in the blood and urine, flicker fusion, time sense, perception tests and the ubiquitous Rorschach. Finally, each subject underwent an 8-hour intravenous ACTH test.

The author found that no subject changed significantly in urinary 17 hydroxycorticoid or 17 ketosteroid output over a five-week period; however, individual differences were very significant. The subjects were separated into high and low steroid output groups for correlation with personality structure. The high hydroxycorticoid subjects displayed intense but undifferentiated quality in personal relationships. Subjects in the low group evidently establish personal adaptation through emotional detachment. High 17 hydroxycorticoid subjects displayed a large number of color responses on the Rorschach with the answers being primarily determined by color rather than form. The subjects who exercised extreme control over their feelings displayed a relatively low steroid output. Finally, Fox ascertained that sleep deprivation produced a decrease in the 8:00 a.m. level of circulating blood corticoids.

Cohen, Silverman, and Shmavonian (1960) placed their subjects in a low sensory input experimental environment. The 29 subjects were evaluated and categorized for "body" or "field" orientation on the basis of the Rod and Frame test and the Draw-a-person test. The experimenters observed the following

reactions by the subjects to the low sensory input environment; emotional and cognitive responses, hormonal secretion rates, hormonal excretion rates following the experiment, central nervous system, vascular and respiratory system responses, sensory discriminative and perceptual threshold characteristics, and the specific personality correlates of the "body" and "field" perceptual modes.

The subjects were brought to the laboratory without being informed of the nature of the experiment; after a one-hour rest urine was collected for catechol amine specimens; they were led blindfolded into the testing chamber where they were tested by a series of clinical neurological tests for sensory discrimination, touch threshold, and pain tolerance. The subjects were then left alone in a dark, sound-attenuated room without instructions for a two-hour period. During this period records of EEG, skin resistance, peripheral plethysmograph, respiratory and cardiac rate were obtained. The authors concluded from the results of the study that individual differences reflected in the body-field perceptual dimension may be related to the response to an environment which exaggerates these differences and which ultimately leads to more arousal in one group (field dependent).

3. Other Indices: A number of miscellaneous physiological variables have been investigated in conjunction with stress situations. The literature contains numerous research articles in which the investigators have employed bioelectronic techniques to study differences in reaction to stress. In the present state of psychological stress research, approaches such as these appear to be worthy of consideration and study.

Lewinsohn (1956) studied duodenal ulcer patients, patients with essential hypertension, and patients with neuromuscular tension. The subjects were tested under stress conditions consisting of exposure to cold and failure stress. Various measures were taken including heart rate, skin conductance, salivary secretion, and finger tremor. The cold and failure stresses produced significant increases in finger tremor and skin conductance. The cold test also increased salivary output, and the failure test increased heart rate. Although no differentiation between the test groups was secured as a correlate of stress, there were differences between the stress and non-stress conditions within the various groups. Mitchem and Tuttle (1954) studied the effect of exercise and emotional stress on the static neuromuscular tremor. They recorded the static tremor of the index finger of the outstretched arm supported by voluntary resistance against gravity. Subjects were tested after being exposed to graded bouts of exercise and before and after a stress situation induced by written examinations. It was found that stress increased neuromuscular tremor to a significant degree. They also analyzed tremor as a function of the age of the subjects and found that there were significant differences in neuromuscular tremor between elderly and young males.

In a study which investigated the relationship of stress situations to the galvanic skin response Piercy et. al. (1955) studied a group of 36 psychiatric patients. The subjects were divided into two equal groups termed less anxious and more anxious. Pain tolerance and the galvanic skin response to three types of stimuli - deep breath, an electric shock, and a warning light - were taken. The measures were not significantly different for the two groups. When the psychological responsiveness was considered in relation to the physiological responsiveness, however, it was found that the former was relatively much greater in the more anxious group. Under equal conditions of stress the more anxious group was distinguished by a tendency to form anticipatory sets which were accompanied by relatively greater degrees of autonomic disturbance.

Another study of the galvanic skin response to stress was that of Williams (1953). In this study, which involved a group of 18 schizophrenic patients and a control group, three psychological stress situations designated as non-personal, personal, and interpersonal were presented and the galvanic skin response continuously recorded. Although significant differences in the galvanic skin response were found between the normal and the abnormal group both during rest and during the stress intervals, the response measured was not adequate for differentiating between stress and non-stress situations or among the various types of stress.

McCleary (1953) studied subjects under both "anxious" and "nonanxious" conditions at three ambient temperatures (40°, 70°, and 100°F). He found that palmar sweat is sensitive in a systematic way to both thermal and psychological influences. He also described a method for using the palmar sweat index while studying infantry troops under simulated combat conditions and concluded that the method was practical. Lewinsohn (1956) in the previously cited study also measured skin conductance and as has already been indicated, found a higher initial skin conductance which assisted in identifying his ulcer group, but found no change in skin conductance as a result of stress.

Mundy-Castle and McKiever studied the galvanic response in order to investigate its psychophysiological significance. The GSR measures for 109 normal subjects in relation to auditory and visual stimuli were recorded. The records were classified as follows: (a) Stable; GSRs only to observed stimuli, consistent resistance change pattern, no endogenous responses. (b) stable/Labile; a few endogenous responses and/or unstable resistance level. (c) Labile; many endogenous responses, often accompanied by unstable resistance level. They found that stables showed adaptation to the stimuli whereas the labiles did not. The adaptation rate of the stables was significantly correlated with the EEG alpha frequency.

Ulett, et. al. (1952) were interested in determining the effect of experimentally induced anxiety (electric shock) upon the EEG response to photic stimulation. Their goal was to develop an EEG indicator for detecting anxiety proneness under stress. The experimental subjects were screened by psychological tests and psychiatric interviews and rated on an 8-point scale for anxiety proneness. The subjects were studied under conditions of intermittent photic stimulation, both with and without the introduction of shock stress. The authors presented the following results: "There was a significant correlation between the criteria of anxiety proneness and the following: (a) the amount of subjective dysphoria produced by intermittent photic stimulation; (b) the amount of harmonic EEG response in the 20-30 cps range to stimulation with flicker frequencies one-half or one-fourth this rate; (c) the displacement of the centroid driving from the normal range; and (d) the percentage of abnormal and low alpha records as detected by the electronic analyzer and by clinical inspection of the electroencephalogram."

They found no relationship between the amount of change in response to photic stimulation at 14 fps during "stress" and the ratings for anxiety proneness. However, anxiety proneness was found to correlate 0.48 with a check list of anxiety indicators derived from basic and photically driven EEG which included evaluation of induced subjective sensations. Despite the equivocality of some of their results, the authors felt that these findings were sufficiently promising to justify continued research along these lines. Their object was the development of an EEG measure as a military screening device.

Other attempts to relate physiological variables to stress include that of Mahl and Brody (1954), who compared the fasting gastric acidity levels of seven chronically anxious subjects to the acidity levels of seven symptom free subjects. By comparing the subject groups under conditions of pain and pain anticipation, it was found that the acidity was greater for the "anxious" group than for the control group. This suggests that stress is accompanied by an increase in HCl secretion.

Holtzman and Bitterman (1956) took a factor analytic approach to the study of individual differences in stress susceptibility. They obtained ratings of personality and officer aptitude, objective and projective personality test scores, measures of performance under stress, galvanic skin response conditioning indices, perceptual test scores and analyses of urinary components from 135 Air ROTC Cadets at the University of Texas. Analysis of the intercorrelation matrix yielded seven factors. In general, the degree of relationship among the measures derived from the different types of tests was very low.

SUMMARY

In summary, it would appear undesirable, at the present state of knowledge, to attempt to use physiological indices as selection devices for performance under stress unless operational validation studies are to be conducted--and the latter are rarely done, due to the general unavailability of criterion measures. As with personality test measures, the correlations with task performance are low, and the different indices do not appear to be measuring the same thing.

Another possibility, not contradictory to the preceding one, is that susceptibility to stress is not a unitary or general trait. Persons highly susceptible to one type of stressor may show little susceptibility to another. In this event, attempts to correlate individual-difference trait measures, physiological or otherwise, will be met with scant success. Changes in eosinophil count caused by fear or shock may fail to correlate with Taylor Manifest Anxiety not because either measure fails to indicate "anxiety" but because individual differences in "shock anxiety" have little relationship to the degree of anxiety with which a subject views the everyday vicissitudes of existence. One must distinguish between differences in the stress responses being measured and differences in the stimuli which are producing these differences.

Until better understanding is achieved of dimensionality, both of stressors and of stress reactions, it would appear advisable to conduct selection and training programs on a highly task-specific basis. The aptitudes and skills needed to withstand various types of psychological stress may be entirely different. It would appear wise to seek not for high "stress tolerance," but for the ability to maintain a high level of performance in the face of the particular conditions most likely to be encountered operationally. Later, when the dimensions of stressors and stress-sensitivity have been resolved, it will be possible to generalize findings over "classes" and consequently effect a great improvement in research efficiency.

SECTION IV

TASK INDUCED STRESS

DEFINITIONS AND SCOPE

Previous chapters have provided ample evidence for the statement that stress is an extremely loose concept. Despite this looseness, most uses of the term contain a common thread, the presence of something like emotion or "activation" as described by Malmö, 1959. Both of these states have physiological manifestations which, although they are gross in nature, are discernible to some extent. It is not of paramount importance to a behavioral theory of stress if the activation occurs by way of stimulation of the ascending reticular activating system (ARAS) or by means of secretions of ACTH from the anterior pituitary (Bovard, 1961). It is sufficient to note that there are physiological mechanisms which seem adequate to satisfy demands raised by use of such a concept as stress (at least at some future time).

However, many studies loosely classified under task induced stress do not contain this component of emotionality. Most manipulate such factors as speed or load and care little about concomitant emotions aroused via such task aspects as fear of failure. It seems that for the moment the best way to define task induced stress is as a state of varying intensity produced by task demands which approximate or surpass human channel capacity. The degree of stress is a function of the difference between channel capacity and input demands. When such a definition is offered, it becomes apparent that the main issue is one of determining the effects of such changes in task demands, and the ways in which undesirable effects can be eliminated.

These changes may or may not take place in the presence of an emotional component. (Previous chapters have discussed at length when this component can be expected to occur.) If they do, there is evidence that an interaction can be expected (c.f. Easterbrook, 1959; Kausler and Trapp, 1960). Easterbrook for example, presented an interesting argument for the belief that emotion serves to reduce the range of cues an organism uses. He cites data to substantiate this conclusion. While his point is sufficiently well made to merit careful attention there is doubt as to the conditions necessary for the arousal of emotion. Mere incentive alone does not seem to be enough (Kausler and Trapp, 1960; Young, 1959). However, the point to be emphasized about these emotional consequences for cue utilization is that they may or may not be beneficial to performance depending upon the nature of task demands. It would appear that as task difficulty increases, the chances of obtaining a performance decrement are enhanced. The only likely exception to this rule would be a case where emotional restrictions helped the organism adopt an effective strategy which would decrease task demands without greatly affecting performance level.

In this chapter, attention will be focused on research where certain task variables were manipulated in order to discern their resultant effects on human performance. Despite the fact that numerous studies of this type have been performed (and the problem of concomitant emotionality has been laid aside for the present), it is still difficult to assess their meaning because of the existence of a number of sources of confusion. Foremost among these are the following:

- (1) It is well known that human performance in a specified experimental situation is a function of (a) characteristics of the physical and social work environment;
- (b) characteristics of the task itself; (c) characteristics of individuals performing the tasks; and (d) interactions occurring between the environment, task, and

person. Thus, it can be expected that a "stressful effect" produced by a change in task demands will be modified by the particular environmental and human operator characteristics present at the time an experiment is conducted. Such modifications which are present in all behavioral studies are likely to produce discrepancies between experiments employing analogous tasks, and these discrepancies are extremely difficult to interpret; e. g., whether they are variations caused by subject population differences, or variations caused by peculiarities of specific environments, etc. Within this chapter such difficulties will be termed environmental and human modification effects.

The second major source of confusion is even more basic in nature. The problem of task dimensionality has rarely been attacked systematically and only recently have suggestions been made concerning how such a problem might be solved eventually (Cotterman, 1959, 1960). The upshot of this oversight is that it is extremely difficult to compare one task to another or to arrange tasks along some meaningful comparison dimension. Thus, nearly everyone agrees that task variables are of critical importance in the deviation of quantitative predictions but practically no one has outlined a way of taking them into account.

These two problems provide difficulty which is bothersome but not insurmountable. While they are not serious enough to stop conclusions from being drawn, they are sufficiently serious to restrict greatly the generality of such conclusions. The first one, i. e. environmental and human modification effects, can be handled by taking account of population differences in regard to both the environment and subjects employed. This may be done on any basis ranging from a superficial to an exhaustive level; but, because of the lack of details concerning this problem and because of the pressing need for integration of past work, a superficial treatment of environmental and human modifiers has been accorded here by focusing attention on studies using normal persons (not neurotics, etc.). The second problem being more troublesome is given a more detailed discussion below.

By reviewing the definition proposed earlier, it can be seen that task induced stress bears a close relation to a number of topics which can be loosely grouped under the heading "information processing in human systems." Thus, task induced stress is really a part of this larger question. It differs only in relative emphasis, i. e. while information processing studies are concerned with human transmission capacity under a wide range of conditions, stress studies focus on overload points only. The discussion of information processing given here is not meant to be exhaustive and some troublesome factors have been deliberately overlooked; the main effort has been expended in providing a generalized overview with specific reference being made to the key variables of speed and load. However, in order to understand the causes of task induced stress, it is necessary to have a reasonable grasp of means by which human data processing is accomplished. When this is done, it is possible to identify when overloads can be expected to occur; and, even more important, there is an increased possibility to discern a way whereby training of subjects might help solve the dilemma met by the need to increase task complexity and yet maintain performance.

TASK DIMENSIONALITY

While numerous authors have pointed out the urgent need in psychology for the development of a task classification scheme (c. f. Duncan, 1959), few systematic attempts have been made to satisfy this requirement. Probably the best known

approach is concerned with developing a single dimension of "task difficulty" along which all tasks can be ordered. Two different classes of methods have been employed in this approach: (1) those which focus upon aspects of the subject's response, and (2) those which focus upon aspects of the stimulus situation. Both of these methods agree on a basic point. If one task is more difficult than another, it should have manifestations which can be observed in a subject's behavior, e.g. a decrease in the probability of an appropriate response, an increase in response latency. The first approach is more directly empirical. Tasks are given to a population of individuals and differences in response probabilities and times are noted. For example, it might be found that for a representative population of college sophomores, $RT(A) > RT(B) > RT(C) > \dots > RT(N)$. The second approach utilizes objectively quantifiable S (stimulus) variables which produce varied levels of response probabilities and reaction times. Then, since $RT(A) \dots, RT(N) = f(S_i)$ and all tasks can be measured on S_i , all tasks can be described in terms of a position on S_i . (S_i refers to stimulus dimension "i.")

Spence is probably the outstanding proponent of the first approach. He views task difficulty as being determined by the relative strengths of competing responses (R 's) elicited by a stimulus, difficult tasks having strong competing responses and simple ones having weak ones. The second approach is more "stimulus bound" and not as "individual bound;" it concentrates on task measures (S measures) which are best described in information theory terms, e.g. load, input rate, redundancy, etc. Such measures have been used by a number of investigators (c.f. Brush, 1956; Noble, 1955; Riley, 1952; French, 1954).

It is felt that the latter approach has decided advantages over the former. The "subject" method requires gathering response data to predict other response data. It also requires the development of a scale, which is a time-consuming operation (c.f. Furneaux, 1961). In order for the data to be accurate, they must be gathered on a group of subjects similar to the population used in a later study. Use of the same subjects to be tested to derive a scale results in being placed in the embarrassing position of being able to predict data only by using portions of the very data to be predicted. The disadvantages of such an approach have been discussed numerous times (c.f. Estes, 1959; Anderson and Grant, 1957). It is difficult to see how such an approach can lead to anything beyond $R_1 \rightarrow R_2$ type laws. These are useful in certain areas where only prediction of behavior is needed but in order to control and manipulate behavior directly (as opposed to indirect means, as through personnel selection), S-R relationships must be established.

The second technique has the promise of being amenable to an intervening variable approach. A set of S variables can be related to a set of I variables (of the perceptual and cognitive variety) which in turn are related to R variables. This method seems very appropriate since there are many S variables to be used; and, as Miller, N.E., (1959) has pointed out, the power of the intervening variable approach increases as the number of S variables increases.

While the stimulus method seems more promising than the subject method, it is necessary to point out that it does not eliminate all problems. In fact, it is more a matter of potential promise than present gain. First of all, a great deal of knowledge concerning interactions of S variables is required even after they have been reliably quantified. Secondly, it is still necessary to consider the effects of subject moderator (e.g. past history) variables in order to obtain precise predictions. Considering these practical deficiencies, it can readily be seen why experimenters tend to use a shorter range view when their concern with task difficulty is only ancillary to consideration of other factors, e.g. drive.

The first step necessary to use the stimulus approach is to specify a set of quantifiable S variables in reasonably rigorous terms. Table I contains a partial listing of such S variables along with some I variables; the list obviously is large.

A number of the variables in Table I are amenable to a cybernetic approach (c.f. Ashby, 1959). Here, operator transforms (I variables) e.g. compression of information, are specified by which aspects of the stimulus (S variables), e.g. load and rate, are changed to aspects of a response, e.g. P of selecting R₁ instead of R₂. Cotterman (1959, 1960) has proposed a similar approach (which can be interpreted in cybernetic terms) and has specified the way in which it could be implemented.

TABLE I
A PARTIAL LIST OF TASK VARIABLES

<u>Variables Describing Tasks</u>	<u>Potential Measures</u>
A. Stimulus Variables	
1. Amount of information per stimulus	1. Binary bits
a. Average	a. Mean
b. Variability	b. Variance
2. Stimulus dimensionality	2. Mean number of bits per stimulus dimension = <u>Total No. of bits per symbol</u> Log ₂ No. of stimulus dimensions
3. Sequential dependency of stimuli	3. Autocorrelation; alternately, Ratio of contingent to prior probability, $\frac{P(S_n/S_{n-1})}{P(S_n)}$
4. Rate of presentation of stimuli	4. Bits per second; alternately, Stimuli per second
a. Average	a. Mean of above measure
b. Variability	b. Variance of above measure
c. Acceleration	c. Second derivative of above measure
5. Stimulus persistence	5. Time before fade or removal of stimulus
6. Stimulus overlap "O": Occurs when the same stimulus element is a member of the sets required for the identification of two or more mutually independent	6. $O = \sum_{i=1}^N \frac{N_{c_i}}{N_{t_i}}$ where N_{c_i} = No. of stimulus elements composing

TABLE I (Cont'd.)

Variables Describing Tasks

Potential Measures

stimulus patterns in a series.
(Mutually independent stimulus patterns are defined as those requiring separate responses).

stimulus i which are shared with one or more other, independent, stimuli, N_{t_i} = total number of stimulus elements composing stimulus i .

7. Stimulus redundancy (C)

$$7. C = 1 - \frac{H}{\log_2 r}$$

where $H = \sum_{i=1}^r p(i) \log_2 \frac{1}{P(i)}$

" i " representing any possible state of the stimulus and " r " being the number of such possible states

8. Stimulus certainty

8. An index, " D ", dependent on the signal and noise distributions¹

¹Consider a set of M possible stimulus inputs $I_1, I_2, \dots, I_i, \dots, I_M$, occurring with probabilities $P(I_1), P(I_2), \dots, P(I_i), \dots, P(I_M)$, each of which represents the sum of a discretely variable noise component and a member of the set of N signals, $S = (s_1, s_2, \dots, s_i, \dots, s_N)$ which occur with known probabilities $P(s_1), P(s_2), \dots, P(s_j), \dots, P(s_N)$. Consider also the set of contingent probabilities $Q(I_1), Q(I_2), Q(I_i), \dots, Q(I_M)$, defined as

$$Q(I_i) = P(s_i/I_i)$$

where $P(s_i/I_i)$ is the probability of s_i given that I_i has occurred, and s_i is defined as that member of S for which the value $P(s_j/I_i)$ is a maximum. It is now possible to define "stimulus certainty" as

$$D = \sum_{i=1}^N P(I_i) Q(I_i),$$

with " D " representing a weighted average, over a series of inputs, of the likelihoods that the various perceived signals have indeed occurred.

TABLE I (Cont'd.)

<u>Variables Describing Tasks</u>	<u>Potential Measures</u>
B. <u>Intervening (processing) Variables</u>	
1. Amt. of information compression	1. No. of bits in S minus No. of bits in R
2. Rate of information compression	2. Value obtained in above/time interval between successive stimuli
3. S R compatibility or transformation load	3. No. of common cue references on a scale of 0 to 6 ¹
4. Task repetitiveness	4. No. of similar cycles required per unit time
5. Short-term storage requirements	5. Measures concerning an interval between receipt of first stimulus symbol and N th symbol, where a sequence of N symbols is necessary and sufficient to determine the response
a. Temporal	a. Temporal duration of this interval
b. Symbolic	b. Number of symbols requiring storage presented during the interval
c. Informational	c. Number of binary bits requiring storage presented during this interval. (Various statistics in addition to means and variances should be computed describing the frequency distributions of these three measures. There may be a critical cut-off region where storage demands are exceeded.)

¹No. 3 scale includes communality with respect to: size, brightness, color, space, position reference, and form.

For example, Cotterman (1959) has proposed the following definitions:

Tracking (continuous adjustment) - Concurrently with continual quantitative variation in one or a set of specified input qualities, continual quantitative variation through infinite degrees in one or a set of specified output qualities occurs, such as to continually minimize the input variation.

Skilled act (single criterion response) - For each succeeding occurrence of essentially the same discrete input, a discrete output drawn from an infinite set occurs, such as to result in a secondary input event which deviates minimally from a specified limit expressed in terms of an input quality.

Simple skill (multiple criterion response) - For any one of a set of discrete inputs orderable according to a specified quality, one or several discrete outputs drawn from an infinite set occur(s), the order of occurrence remaining invariant such as to result in a secondary input event which deviates minimally from a specified limit expressed in terms of an input quality.

Concept formation - For each succeeding discrete input drawn from a finite set of discrete inputs orderable according to multiple qualities; such that a given output always occurs when any input, member of that subset of inputs, bearing a specified ordinal relation to the other inputs as ordered according to a specified quality, occurs.

Cotterman has subsequently developed this approach into a formal task classification based upon the characteristics of component stimuli, required responses, and the invariances involved in their relationships. A listing of the variables forming the basis of this classification is provided in Table 2 (from Cotterman, 1960).

TABLE 2

TASK CHARACTERISTICS AND THEIR CODES

STIMULUS

1. Number
 - (a) one (1)
 - (b) more than one (X)
2. Stimulus
 - (a) undifferentiated (no special coding)
 - (b) continuous (c)
3. Size of stimulus set
 - (a) one (1)
 - (b) finite set greater than one (X)
 - (c) infinite denumerable set (X)

TABLE 2 (Cont'd.)

RESPONSE

1. Number
 - (a) one (1)
 - (b) more than one (X)
2. Response
 - (a) undifferentiated (no special coding)
 - (b) ordered (o)
3. Size of response set
 - (a) one (1)
 - (b) finite set greater than one (X)
 - (c) infinite denumerable set (X)

INVARIANCE

1. (a) Nominal (N)
- (b) Ordinal (O)
2. (a) Exact (no special coding)
- (b) Limited ("L" under N or O)
3. (a) Individual (no special coding)
- (b) Collective ("C" following N or O)
4. (a) Stimulus (no special coding)
- (b) Cue ("c" following N or O)
5. (a) Open (no special coding)
- (b) Closed or feedback ("F" following N or O)

The approach offered in Table I obviously is related to that proposed by Cotterman but it is worthwhile to spend time pointing out the nature of the relationship. Table I contains measures of (1) the stimulus situation and (2) measures of human generation activities (transform). Table II contains a description of a few familiar psychological tasks in terms of operator transforms; these in turn are related to the generator measures in Table I. Perhaps it is possible to reduce the endless enumeration of specific tasks to a few basic transforms. A recent report by Hostetter and Grant (1961) took this approach to aero-surveillance tasks, apparently with some success.

However, this chapter is not an appropriate place to consider a question of this magnitude in great detail. We do not know the basic human transforms - although it is not an insurmountable task to synthesize these from Cotterman's work. Even if this were done, it would still be necessary to relate specific transforms and their actions when combined. Therefore, it was decided to use classes of transforms concerned with the same general function, e.g., detecting input data, translating input data to response data, etc., as one of the discussion bases. The second discussion basis develops from the information measures describing the stimulus situation. The approach employed was one of identifying the most important S variables influencing performance in situations involving operator transforms of a class "X" and to specify (where possible) the nature of the influence. When this approach is followed, a few interesting generalizations begin to appear in the wealth of past data.

CHANNEL CAPACITY

1. **The Concept:** Human beings have been viewed as communication channels in a number of studies. In fact, a great many psychological experiments fall into this category because the interest of the researcher is focused upon the transform, T, that an operator, O (or Subject), makes upon an input, I (or Stimulus), in order to produce an output (or Response). Both traditional and information theory type studies can, therefore, be expressed in terms of a reasonably adequate common language of stimulus variables, organism variables, and response variables. If such an approach is adopted, information measures can be integrated into such a scheme to raise the level of quantitative description. In the preceding subsection entitled Task Classification this is the approach which was followed. Remaining portions of this chapter will continue along this line of analysis.

Information can be considered as that which removes or reduces uncertainty (c.f. Attneave, 1959). Consider an input situation which has a series of possible states, S_1, S_2, \dots, S_n . Requirements can be placed upon an operator so that he must choose one of a possible set of outputs R_1, R_2, \dots, R_n on the basis of these inputs. Discrimination learning tasks are an excellent example of such a situation. If a subject (operator) knows nothing about the situation (maximal uncertainty exists), he might select any of these R_s . However, in most cases, some of these R_s are more appropriate than others; and over time, he will learn to choose the more appropriate ones on the basis of the stimulus cues. This behavioral shift from random choices of R_s to a systematic choice represents a gain in information.

A simple measure of information load can be expressed as $\log_2 N$ where N represents a number of equally possible alternative states of either stimuli or responses. By utilizing this and other measures, it is possible to derive some estimates of maximal transmission capacity. Obviously, numerous task variables will influence how much information can be transmitted in those cases. Therefore, selection of tasks is normally done in such a way that there is a maximal potential for information transmission. Quastler (1955) has listed a number of necessary conditions for such situations: (1) the stimuli must be easily perceived; (2) the response is easily executed; (3) the subject should be competent and thoroughly familiar with his task; (4) the subject must understand what he is to do and be properly motivated; (5) the subject must be allowed to organize activities in the best fashion; and (6) the task must be chosen such that a large fraction of the subject's effort goes into measurable information transmission. Unfortunately, studies concerned with maximal channel capacity have not always paid heed to these restrictions.

The discussions of channel capacity which follow have been subdivided into two rough categories; or, stated another way, they have been grouped into two basic task types. The first is restricted to studies of discrete tasks where there are fixed S-R connections which start and end abruptly. The second, non-discrete tasks, includes sequential and continuous activities. When these discussions are completed, consideration is given to various factors influencing channel capacity in a wide range of situations.

2. Channel Capacity for Discrete Tasks: The case for considering human organisms as limited capacity channels in processing information has been well stated by numerous authorities (c.f. Broadbent, 1957; Hick and Welford, 1956; Welford, 1960). In addition, many writers have surveyed literature concerned with human information processing in general and/or channel capacity in particular (c.f. Miller, 1956; Broadbent, 1958; Welford, 1952; Welford, 1960; Howell and Briggs, 1959; Herman, 1961; Hostetter, 1961). Because of the existence of such discussions, it is not necessary to cite more than the main findings here.

Studies have been conducted over a wide range of tasks, e.g. presentation of a number of tones or auditory frequencies, (Pollack, 1953), fluctuations in amplitudes within a single tone (Garner, 1953), or a number of scale indicator settings (Hake and Garner, 1951). Generally speaking, in the case of stimuli varying along a single dimension, all such work shows that the amount of information transmitted is dependent upon the range or number of categories represented in the stimulus dimension. However, a sort of "law of diminished marginal transmission" has been noted as more and more categories are employed and an upper limit is soon reached (c.f. Hake and Garner, 1951; Quastler, 1955). For auditory stimuli this has been approximately 2.5 bits per stimulus dimension and for visual stimuli the limit is higher, i.e. in the order of 3 to 3.5 bits (Herman, 1961). These findings formed part of the basis for Miller's reference to "the magic number 7 plus or minus 2" (Miller, 1956) when he discussed man's limitations in processing information.

These figures seem unreasonably small; and they are. However, the limitations of the experimental situations must be kept in mind, i.e. it should be remembered that (1) only a single stimulus dimension was being varied, and (2) no comparison stimulus was present. It is possible to transmit more information if a number of channels are employed even though the combined transmitted output falls considerably short of simple addition of stimulus input dimensions on most cases. In addition, psychophysical experiments using a stimulus comparison method, e.g., fractionalization, have clearly shown how this 2.5-3.5 bit limit can be raised when comparison stimuli are available to the subject.

Numerous S and R variables have been shown to influence channel capacity in this discrete task situation - and in others as well. These will be discussed shortly. It will suffice at this time to point out that when a subject is confronted with a task, he has to perform a number of operations starting with the basic one of translating stimulus information to response information. Above and beyond fulfilling this simple transduction function, he is often called upon to do much more, e.g. filter, sequence, or compress the input into more meaningful "chunks." These activities take time and effort and the greater the effort

required the higher the probability of making an inadvertent error. For this reason, it is reasonable to expect a close relationship to exist between operator demands and task difficulty.

There also appears to be some reason to expect that the various processing steps of the organism, e.g. detection, filtering, coding, transmitting, etc. (c.f. McKendry, 1961), combine to form a dynamic whole. That is, by expending effort at one of these points, restrictions are placed elsewhere in the system. By examining the factors which make the jobs of transduction, coding, and signal detection easier, it will be shown that they also serve to increase channel capacity; therefore, this idea seems reasonable. Further credibility can be added by examining strategies adopted by subjects in repetitive tasks.

3. **Channel Capacity in Non-Discrete Tasks:** In the previous subsection discussion centered about tasks where a discrete activity took place. These can be grouped together to form repetitive discrete tasks. Also, portions of a task can be spread in time to form sequential activities. Finally continuous activities can be performed. An example of the first type of task is a semi-skilled job on an assembly line; an example of the second is playing a musical instrument; an example of the third is a tracking situation. When purely discrete tasks are fused into repetitive operations, channel capacity is described in terms of bits/sec rather than bits. Obviously this figure will be influenced not only by how much information is processed in a single operation but also by how long it takes to perform a given operation. Closely related to this type of task are those requiring sequential activities. Historically much interest has been centered on the question of channel capacity, and, as a consequence, studies have been concerned with sequential activities having a high degree of repetitiveness. However, it should be remembered that this need not be the case.

Quastler (1955) attacked the question of maximal possible transmission for this type of task. He obtained estimates of transmission rates as follows: (1) for oral reading of coherent English texts - 24 bits/sec; (2) for information yield of mental arithmetic done by lightning calculators - 24 bits/sec; and (3) for playing tennis - 20 bits/sec. He cited data from Licklider which showed rates of (4) 15 bits/sec for matrix duplicating activities, and (5) 25 bits/sec for reading random sequences of words aloud. By an ingenious combination of these latter two activities, i.e. (4) and (5) above, Licklider managed to obtain transmission rates of 35 bits/sec. After examining all these data Quastler (1955) concluded that "... about 35 bits/sec is all that a man can do in the way of conscious and purposeful information transmission - and maybe even conscious information-processing in general" (p. 346-7).

Quastler carefully pointed out that his 35 bits/sec limit does not consider all man's environmental interactions, e.g. information processing aspects of temperature adjustments and other physiological changes. However, such subtleties need not be of concern here since his estimate is considerably higher than estimates obtained in tracking tasks described before. Furthermore, most practical work tasks will not approach this estimated maximum if only for the reason it is not needed. Finally, it must be remembered that a bit is a relative measure. It tells nothing about the size or comprehensiveness of the stimulus or response categories employed. Thus, the number of bits/sec may be small but the activity requirement (and the significance of it) might be great.

For continuous activities transmission rates are lower. Herman (1961) examined data from Crossman (1960) and Fitts (1954) and provided the values of 3.8 bits per sample point in a pursuit-tracking task (or 4 bits/sec. in the same task and 10 bits/sec. for hand movements when decisions are not involved). Obviously, requiring decisions reduces transmission capacity, a finding which is a logical consequence of increased task complexity and is consistent with the notion explained at the end of the preceding subsection. A second finding of major importance is that transmission capacity, when expressed in terms of number of bits per sample point, falls markedly as speed of presentation is increased. However, this reduction in output caused by speed effects can be eliminated entirely if the task is one which allows perceptual anticipation to take place (Crossman, 1960). As a consequence, channel capacity can be increased to better than 7 bits/sec.

PERCEPTUAL ANTICIPATION

Perceptual anticipation refers to the use of previously acquired experience to determine an expectancy of what will occur next. Thus it may be conceived as a conditional probability of the occurrence of B at a time $t + \Delta t$ given the arrival of A at a time t . Poulton (1950, 1952a, 1952b, 1957) has made an important distinction between perceptual and response (receptor) anticipation. "Receptor anticipation implies only that the subject is shown future stimuli before he has to respond to them, i. e. he is allowed to preview the display" (Mackworth and Mackworth, 1959, p. 208). As a consequence, the implications of perceptual anticipation are much greater and merit further discussion.

Perceptual anticipation has been hypothesized by a number of writers including Craik (1947) and Helson (1949). Empirical demonstrations of its importance have been provided by Gettler (1952) and Crossman (1960). Welford (1960) has discussed an interesting theoretical position showing how perceptual anticipation may be used to filter complex stimuli and thereby reduce task difficulty. He has shown that it is possible for subjects to raise their level of transmission by focusing attention upon the most likely response alternatives and interrogating new stimuli only in a rough sense to see that the most probable response, which is being held in readiness, need or need not be given. If it is not, the theory proposed states that a second interrogation takes place, e. g. by selecting the second most probable response or by interrogating the stimulus more completely. Thus perceptual anticipation can provide a strategy which allows an operator to reduce the stimulus load without impairing performance.¹

Leonard (1955) described a study which adds further credibility to Welford's position. He ran subjects under conditions of (1) a straight six choice situation, (2) a three choice situation, and (3) another situation where they first received a two choice and then a three choice situation: i. e., progressive narrowing of possibilities on sequential interrogation of stimuli occurred. Leonard reasoned that "it should be possible to present the two-choice stage just far enough ahead of one of the two three choice stages so that the reaction time to a signal presented in the second stage should be comparable to a straightforward three choice time..."

¹It is known that such anticipations do occur, whether or not the process is that described above is a matter of conjecture.

He found that "... with a separation of about .30 sec. performance with respect to the second stage became comparable to that obtained in the three choice control condition, both in terms of reaction time and ... rate of gain" (Leonard, 1955, p. 310). He also found that near comparable amounts of information could be transmitted under conditions 1 and 3 (7.68 and 7.50 bits/sec respectively) when appropriate adjustments were made for RT and task difficulty differences.

In addition to providing increased channel capacity when load requirements and speeds are increased, there are data which indicate that perceptual anticipation may be particularly beneficial in cases where vague stimuli are presented. Goldiamond and Hawkins (1958) performed a study in which a group of subjects first were taught to recognize an ambiguous stimulus through knowledge of results. After this first test phase the researchers duped their subjects into believing that new stimuli were being flashed when in fact they were not. The group still responded in the same way as they did when actual deteriorated stimuli were provided, i.e. they acted on the basis of anticipation.

Thus, it can be seen that human beings can raise their channel capacities by using information concerning sequential dependencies of stimuli, e.g. $P(S_2/S_1)$, $P(S_3/S_2)$, etc. Their tendency to try to do this is unmistakable even in situations where such activity is maladaptive. One striking example is provided by decision-making studies involving monetary payoffs (c.f. Siegel and Goldstein, 1958). If subjects are asked to predict which of two lights will occur (and if the sequence is actually random around a fixed parameter, say $P(E_1) = .80$ and $P(E_2) = .20$), they will continue to attempt to outguess the sequence even though it costs them money. They rarely adopt a "rational" strategy of playing the more frequent event all the time despite the fact that this is a more efficient strategy in this particular situation. And, as might be expected, college sophomores are more likely to look for sequences than are young children (McMichael and Siegel, 1960). It appears that intelligent subjects have considerable difficulty in accepting a random sequence (Hake, in Quastler, 1955) and they continue to search for sequential dependencies of a highly complex nature when their first hypotheses fail (McKendry, 1961). That this is not merely an artifact of the experimental situation is suggested by the well-known phenomena of the gambling table (attempts to find mathematical dependencies in sequences of roulette rolls, etc.)

It is the occurrence of such phenomena as perceptual anticipation that makes it difficult to assess the stressful effects of such task changes as those involving dimensions of speed and load. In addition, it appears that the operator "can and does trade off speed for accuracy, and vice versa..." (Howell and Briggs, 1959, p. 25). The situation is complicated further if one accepts the argument outlined at the close of the preceding subsection. This may involve a process where one processing activity is restricted in time to allow more time for other activities. This can occur because of task demands or as a consequence of a subject's strategy. The way in which this might occur is complex and it is necessary to take account of variations in immediate memory span. (A detailed discussion of this factor may be found in Broadbent, 1958.) Other factors also influence transmission rates; these will be discussed after a preliminary examination is made of speed and load effects.

STAGES OF INFORMATION PROCESSING

In a paper which has already been cited on several occasions in this chapter, Welford (1960) offered a "tentative block diagram of the chain of mechanisms involved in sensory-motor performance" (p. 192). This is reproduced below in Figure 1. Welford's description of the mechanism was as follows:

"Stimuli from the display impinge upon the sense organs which convert them into patterns of nerve impulses. These are relayed to a perceptual mechanism in which integration and identification take place. At the other end of the chain the effector organs, such as the hands or feet, are activated by impulses from central mechanisms which determine the coordination and phasing of muscular action. Connecting the two ends is what may be tentatively be called a translation mechanism concerned with the choice of action in relation to what is perceived. This receives data previously coordinated at the perceptual stage and passes orders to the central effector stage which then carries out chains of coordinated action." (Welford, 1960, p. 192)

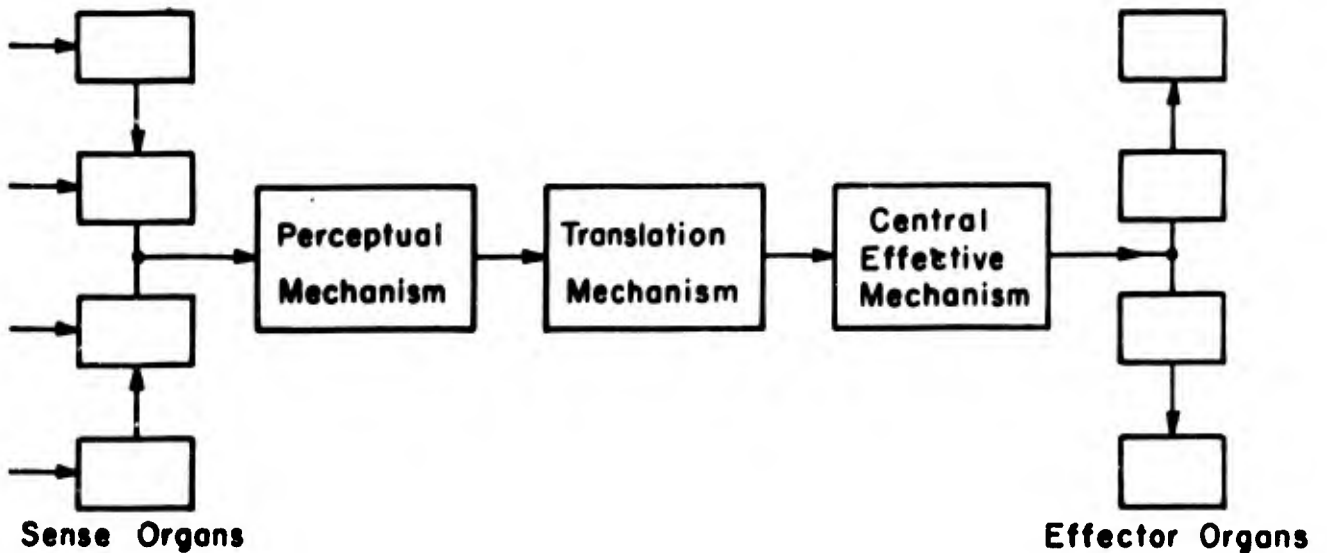


Fig. 1 - Welford's Tentative Block Diagram of the Chain of Mechanisms Involved in Sensory-Motor Performance

In presenting his diagram Welford pointed out that the way in which signals are passed from one stage to the next is not yet known, but it appears that feedback from the effectors "controls the passage of data from the perceptual to the translation stages." Other discussions of feedback loops and a further breakdown of decision activation occurring within the translation mechanism along with possible neurophysiological explanations are discussed elsewhere (McKendry, 1961) and are too complicated (and speculative) to merit summary here.

Welford's diagram can be compared to an earlier one provided by Broadbent (1958) in order to discern more aspects of the important perceptual mechanism. However, Welford's presentation includes something not covered by Broadbent, i.e. a decision loop concerned with response selection which can fall into Welford's translation mechanism. The fact that physiological mechanisms performing these activities have not been identified need not concern us here. Speculative neurophysiological papers have shown that properties such as these are not beyond the capacity of our nervous tissue (c.f. Von Neuman, 1956; Beurle, 1956) and therefore are at least reasonably consistent with our present physiological knowledge.

Also it is apparent that work can continue without waiting for this conceptual reduction. For example, Hebb (1949) pointed out a number of years ago that the notion of a stimulus trace came from behavioral data. Only recently have physiological studies begun to show possible mechanisms for such activities. Thus, Welford's concepts exist for the present at the intervening variable although tentative means have been devised to shift them to hypothetical constructs.

It is the capacity of this type of human information processing channel which has been discussed in the preceding subsection. In considering factors influencing such activities it is convenient to group the variables found to be important under the headings of (1) task factors influencing perception, (2) task factors influencing translation, and (3) task factors influencing effectors. This grouping obviously follows the lines of thought suggested by Welford's diagram. All of the variables discussed have already been enumerated in Table I; but, because of a lack of data, not all of the variables listed in the Table can be included in the discussion.

The discussion will also consider man's responses in terms of RT (reaction time) and response appropriateness (P of a "correct" response). In most instances the latter measure is proportional to a measure of transmitted information but this need not be the case. If a subject adopts a solution which is exactly opposite to the "correct" one, he will transmit a great deal of information but have no correct responses. Even in these cases, however, the measures retain a loose proportionality and they are therefore considered together, with more explicit comments being added when needed.

Two factors, speed and load, have consequences which seem to be important at all stages of information processing. For that reason they will be discussed first.

LOAD EFFECTS

Load is a term having numerous meanings. First of all, it can refer to stimulus load which is the total amount of information present in the stimulus. This can be determined by a knowledge of (1) the amount of information per stimulus dimension, and (2) the number of stimulus dimensions used. The stimuli themselves may be configurations containing many bits or only a few bits. Either use of the term can be called stimulus load.

A second type of load refers to responses demanded of an operator. For example, he may have a number of response alternatives or only two, e.g. "go-no go" decisions. Each of these in turn can contain a single bit of information, e.g. press button no. 1, or many bits, e.g. initiate defensive strategies for type X conditions. Either of these types will be referred to as response load.

The third type can be called translation load. It refers to how much manipulation of the input data is required to produce an output. Unfortunately, this is even more vague than the previously discussed terms, and comparatively little experimental investigation has been done with this type of activity. Table I suggested some potential ways of examining this load, e.g. measuring the amount of and rate of information compression demanded of a subject, or analyzing the extent of the transformation required by an S R compatibility index.

Having differentiated between these types of load it is now possible to turn to an evaluation of their consequent effects on performance. It should be noted that all of these can be manipulated by changing aspects of the task. The experimental literature cited took just that approach.

Miller (1956), in his review, pointed out that the number of distinct stimuli is a more important influence on channel capacity than is the number of bits/stimulus at least where immediate memory is concerned. Other reviewers have come to the same conclusion. This statement should not be interpreted to mean that the number of bits/stimulus is unimportant. It is very important in determining the potential bits for chunk limit. Also, if this compression of "bits" into "chunks" of information has to be done by the subject, it raises the translation load; and, as can be expected, it causes a response decrement by at least increasing RT and by possibly decreasing the probability of a correct response.

The degree of stimulus loading on a subject is influenced by many task variables. One class of variables determine how readily the subject can reduce the load by filtering. These are discussed in the subsection entitled task factors influencing perception. In addition to this (1) filtering potential is a (2) simplifying strategy potential which is determined by allowing such things as perceptual anticipation to take place. To make matters worse, these two potentials seem to be related since specific task variables contribute to both.

The effects of response load seem to be similar to that of stimulus load. However, in many practical cases there is not sufficient time to work out strategies and the subject is restricted to a choice of already well defined response alternatives. When such a situation exists, its implications for response speed are clear. It has been found that as the number N of response alternatives increases, RT increases as a function which with time, approaches linearity with N . Welford has provided several discussions of the implications of this finding (c.f. Welford, 1951; 1960) and because of their importance, they are discussed in more detail in the subsection entitled OPERATOR PACING. The consequence of interest here is what Welford has termed Hick's Law (Hick, 1952) where the disjunctive RT can be expressed as a linear function of the average amount of (response choice) information transmitted. Specifically, the (modified) expression was $RT = K \log_2 (N + 1)$ where N is the number of response alternatives available to the subject and K is a constant dependent upon the nature (difficulty) of the task, e.g. the amount of translation required, etc. As difficulty increases, K increases. However, J. G. Miller (in press) has pointed out that Hick's law does not hold when subjects become very familiar with the task. When they perform the same task over a number of weeks all RTs become similar despite having varied numbers of response alternatives. Miller explained this finding by postulating that subjects adopt simplifying strategies, a view consistent with the position taken in this chapter.

The relationship between number of response alternatives and the probability of a correct response is not as well known as the relation between RT and number of response alternatives. It seems likely that the probability of an incorrect R increases as N_R (number of responses) increases. This relationship can be expected to be nonlinear and probably accelerates rapidly in the vicinity of six Rs. This is exactly what happens when varied numbers of test equipment settings are required by technicians and varied numbers of controls are present on a test panel (Bilinski, 1957). Figures 2 and 3 show these functions. The degree of effector action refinement also seems to be related to response appropriateness. As more control space is allowed for Rs, grosser movement can be made and the probability of an error decreases. Figure 4 shows Bilinski's data on this point.

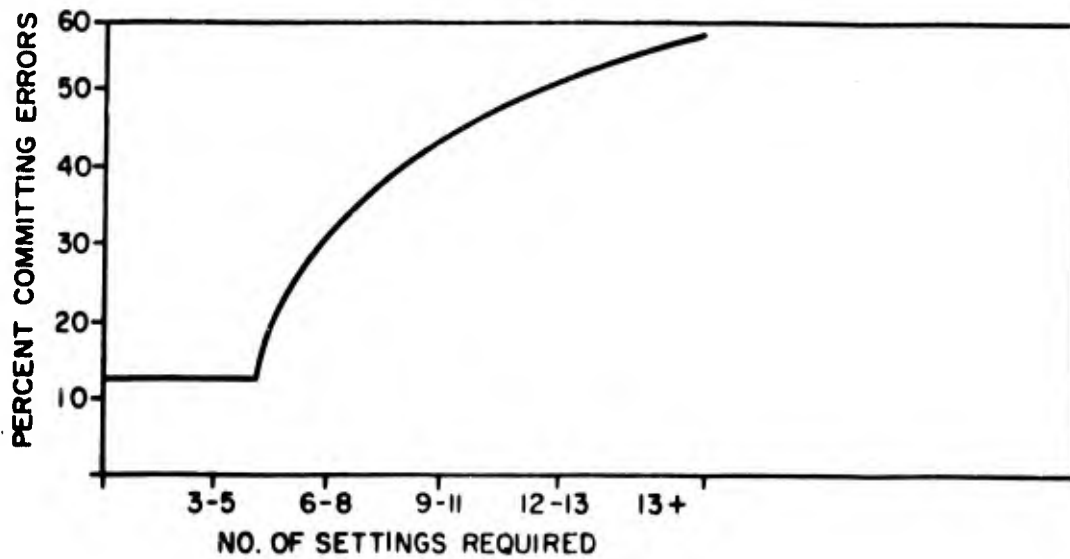


Fig. 2 - Errors vs the Number of Settings Required for Test Equipment as Recorded for 102 Technicians. (Data from Bilinski, 1957)

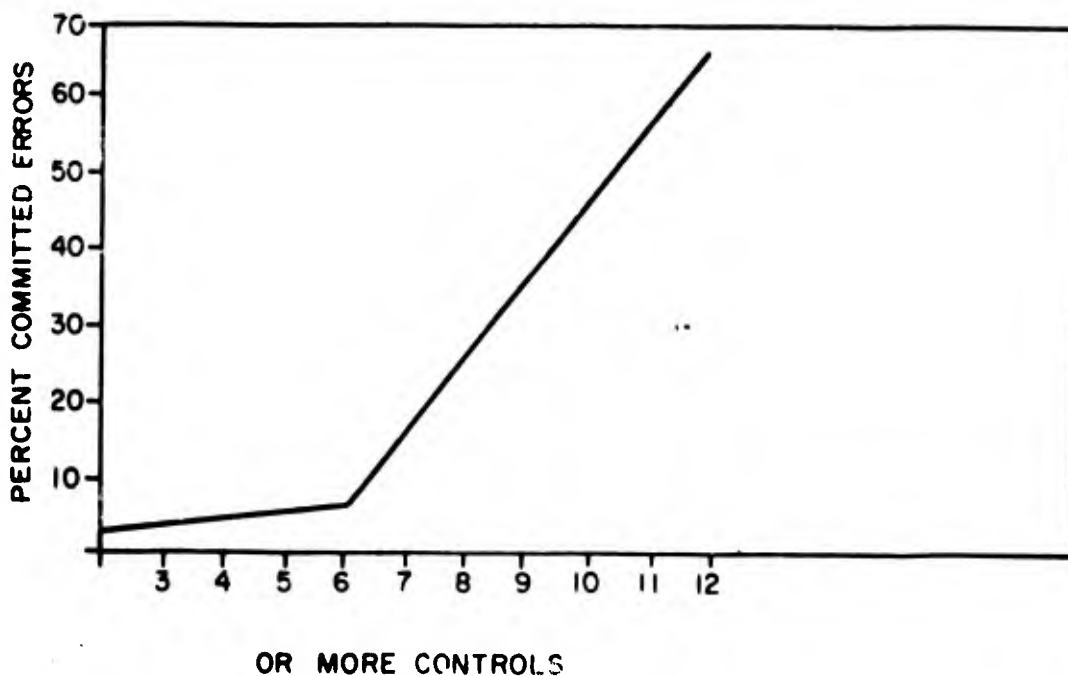


Fig. 3 - Relationship Between Errors and the Number of Knobs on a Control Panel Measuring About 12 by 16 Inches, as Recorded for 300 Men. (Data from Bilinski, 1957)

The reader has been forewarned that few data are available regarding translation load effects. Most of the findings are concerned with specific task variable effects and are discussed in the subsection entitled TASK FACTORS INFLUENCING TRANSLATION (see p. 59). However, it is reasonable to extrapolate from the many human engineering studies performed on control-display compatibility to say that the greater the compatibility the better the performance, and, therefore, the higher the tolerance for load stress.

It is difficult to assess the nature of load stress in general because of the numerous interactions examined above. Obviously, man does have load limits but what happens when these limits are reached is a moot question. Because of possibilities for filtering and load reduction strategies to take place, it appears that man has considerable flexibility in such situations. These can probably be improved considerably by training. However, even without special training, it seems that some of these compensation effects can take place and can prevent total performance deterioration when capacity limits are exceeded. However, if there is no opportunity (or inclination) for them to occur, a rapid performance decline of the type found by Biliński (1957) can be expected. If this latter situation occurs, the effects of surpassing load limitations (load stress) will be disastrous.

SPEED EFFECTS

While there appears to be little enough doubt that load is important - and when increased markedly can cause stress - evidence for speed effects is even more conclusive. In fact, it would appear that speed of presentation is an extremely sensitive variable. Increases in the rate of input presentation always induce marked performance decrements eventually and usually this decrease appears quickly (c.f. Jeantheau, 1959; Alluisi, Muller, and Fitts, 1955). Not only is the arrival rate important, but variation in arrival rate of signals seems to be important.

Hostetter (1961) has provided a short summary of speed effects. He states that "If transmission rate is plotted on the same scale as the input information, then a curve results which begins as a straight line rising at slightly less than a 45° angle, turns smoothly into a plateau, and declines again, the slope of the declination being dictated by individual differences in reaction to the stress involved" (p. II-4). Figure 5 illustrates the general form of the function. An exhaustive documentation of the generality of this curve has been provided by J. G. Miller (in press).

Figure 5 shows a general set of functions, of course; few research findings show exactly this but the picture is an adequate representation of general results. The difference between total human output (---in the Figure) and transmitted human output (-.- in the Figure) is the difference between making any response and making the correct response. Channel capacity (O in the Figure) is inferred from the maximum value of the transmission curve (-.-). Errors of omission are shown, errors of commission lie between the two shaded areas and include the lower shaded area (stress loss). At the present time no differentiation is made within the stress area of losses attributable to different effects. This is done in the next chapter.

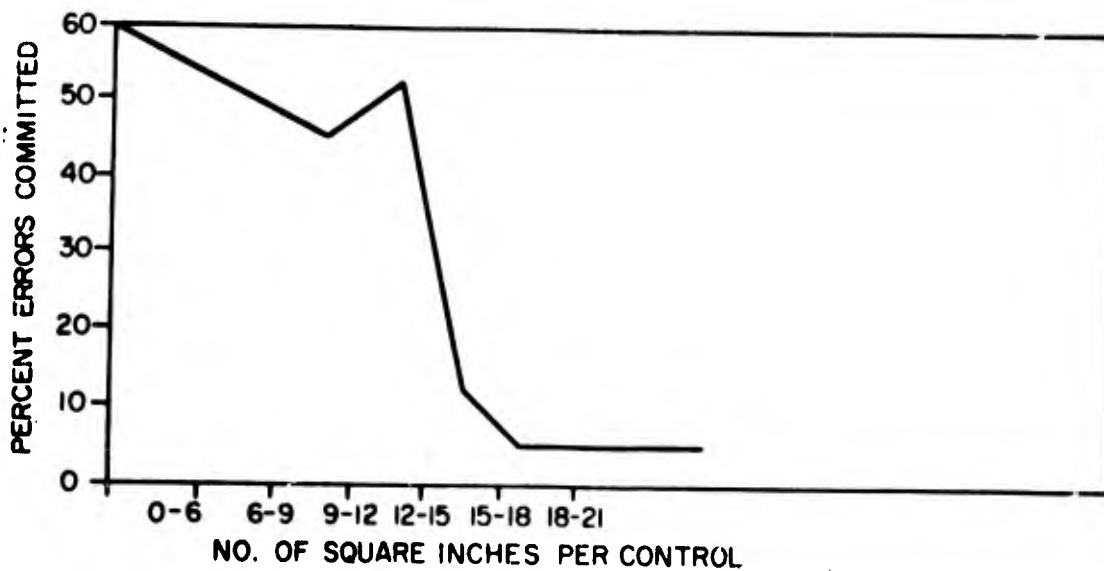


Fig. 4 - Errors Per Control Per Square Inch of Panel Space for 105 Test Equipment Operators. (Data from Bilinski, 1957)

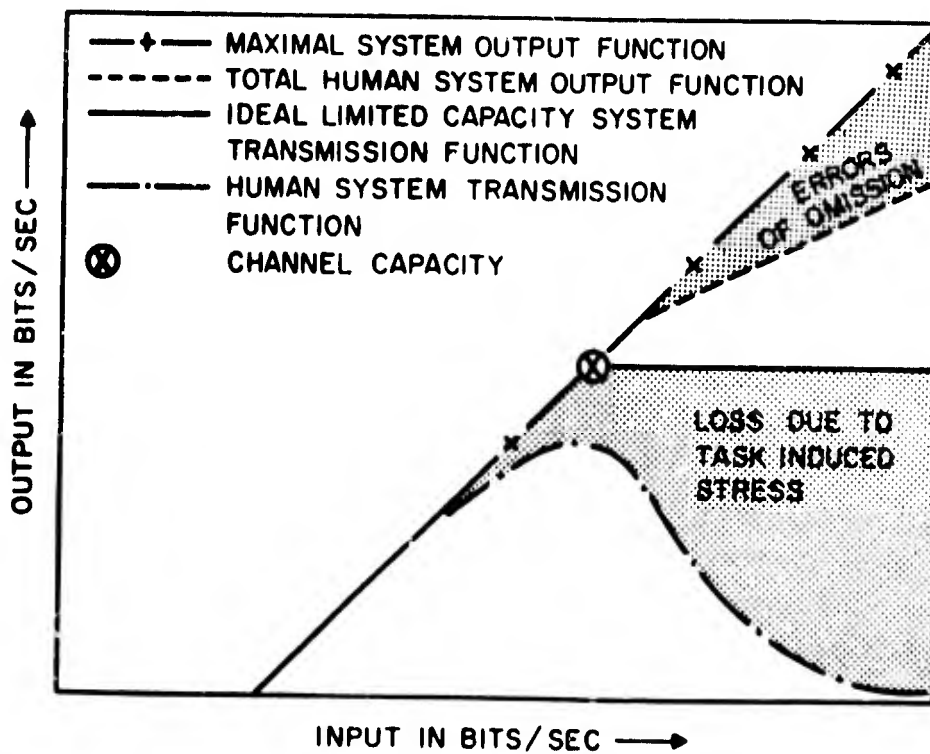


Fig. 5 - Input Speed Effects on System Outputs

Now that the nature of speed load stress has been shown a question arises as to why this happens and why and how speed becomes so important. The remainder of this subsection considers such problems. One of the primary response for this finding of a performance loss seems to be that the imposed input pace deviates from the operator's natural pace. Thus, a number of important aspects concerning operator pacing need to be reviewed.

There seems to be adequate evidence that in an unstructured situation self-pacing does occur. For example, Harding (1932), when studying the speed of work of typists with equivalent training and experience, found a relationship between speed of typing and key stroke rhythm, and concluded that the more rapid workers, in general, tended to pace their own responses rhythmically. (This relationship between rhythm and work output did not hold for erratic workers, who, though not rhythmical, occasionally typed very rapidly.) In another study of typing Augenstine (1958) found definite evidence for pacing - or periodicity as it is sometimes called when a more microscopic approach is employed. Finally, numerous industrial studies, especially those utilizing a movement analyzer (c. f. Tiffin and McCormick, 1958), have shown rhythmical aspects of workers' responses. In fact, development of rhythmical response patterns has even been used as a criterion of worker proficiency in training (Lindahl, 1945).

Since there seems to be evidence for pacing and since related phenomena such as fluctuations in the span of attention are well known in psychology (c. f. Woodworth and Schlosberg, 1954), it seems reasonable to expect that self-paced tasks would yield performance superior to that in externally paced tasks. Most of the evidence substantiates this belief.

Klemmer and Muller (1953) found that self-pacing resulted in as high a rate of information transmission as the maximum reached in an externally-paced task. Fitts and Muller (1955) found that fewer errors occurred when self-pacing was allowed and that information processing was maximized under this condition. Broadbent (1953), requiring subjects to touch a contact corresponding to one of five lights which was lit, found that self-paced subjects showed no decrement in output until nearly an hour had elapsed, while there was a decrease in the number of correct responses after 10 minutes work with subjects in an externally-paced situation (stimuli being presented at a rate of one per second). It should be noted that after 10 minutes work, even the self-paced subjects showed an increase in the number of pauses in responding (those lasting 2 seconds or more), but that they were apparently able to compensate for this and retain their level of work output by working faster between the pauses; externally-paced subjects could not.

Even when the rate of stimulus presentation in an externally-paced situation is chosen so that it is highly similar to that in a self-paced situation, performance is better under the latter condition, as has been shown by Conrad (1956). Though the rate of presentation of stimuli per unit time remained exactly the same for each subject, in the self-paced situation the intervals (pauses) between signals tended to be more normally distributed than in the externally-paced one, where the subjects' pauses between signals were essentially random. It would seem, from an examination of Conrad's data, that self-pacing may be a necessary condition for smooth rhythmical activity in tasks having high input rates.

Three additional studies serve to point out the comparative inflexibility of an individual's work pace - at least after a certain point has been reached. (This appears to contrast with apparent flexibility under conditions of load stress.) In a study conducted by Conrad and Hille (1957), the number of signal sources (load) was varied from 8 to 16. The subjects were allowed to determine their own work

rates and feedback as to the correctness of responses was provided. In spite of the fact that the subjects were informed by feedback that there was a decrease in the correctness of performance with an increase in the number of signal sources at a constant pace, and the fact that subjects had been instructed to proceed at a pace which would give them the best scores, they tended to maintain a constant rate of signals per minute under the different load conditions.

Augenstine (1958) noted similar behavior in his typing study which was previously mentioned. He attempted to improve performance both by making the task easier and by forcing the subjects to type faster. "...various alphabet sizes ranging from 4-32 different symbols were used and the subjects were instructed to type in rhythm with a metronome. Under all conditions tested the subjects took about 250 ms. per letter plus a constant additional time of 200 m sec for the first letter in the sequence." (Augenstine, 1958, p. 35)

Quastler and Brabb (1956) obtained results similar to Augenstine in another study of typing. Their conclusions, which provide ample evidence of inflexibility of pacing, are given below.

"The results of these experiments were not what had been anticipated. The differences between performance for a single, a few, and many letters were very small. Neither did variations in alphabet size produce any marked effect. It turned out that, under all circumstances investigated, the typists stubbornly persisted in taking about the same time for each letter; furthermore the time was about the amount they had learned to use in school.... The investigation turned out to be a demonstration of the two effects of habit. They are: (i) the quality of the performance is good, (ii) the flexibility of the performance is low.... Neither of these findings is particularly surprising. What was surprising...was the overwhelming strength of these effects." (Quastler and Brabb, pp. 4-5)

The rather severe inflexibility in pacing noted in the studies described above could not only be caused by (1) habit (c.f. Augenstine, 1958; Quastler and Brabb, 1956), but (2) channel capacity limitations, i. e. symbols/time vs. bits/time (c.f. G. A. Miller, 1956), or (3) both of these factors working in interaction. Habits can be changed by training. But if decrements are due to channel capacity limitations (or even if it is an important factor in training), it is essential to specify the nature of these limits and to attempt to discern the reason for their appearance.

The obvious starting point is to review studies concerned with the question of how rapidly signals can be registered as input by an individual, i. e. accurately perceived. This seems to be partially dependent on the sense modality employed (Bartlett and Bartlett, 1959). When dealing with discrete events, Taubmann (1950) has shown that eight per second seems to be the limit when employing auditory signals. The limit for visual stimuli seems lower than that for auditory stimuli (Bartlett and Bartlett, 1959). However, it would appear that subjects can resort to approximation procedures to overcome these limits. If it is possible to group the incoming stimuli, the number which can adequately be perceived and responded to markedly increases (Vince, 1949; Woodworth and Schlosberg, 1954; Miller, 1956). A recent study by Allan (1961) indicates that individuals are more likely to use such approximations when speed demands are increased.

*Italics added

In a recent review of the topic of human information processing, Hostetter (1961) mentioned that evidence points to the idea that eye movements are not critical determinants of this limitation. In reviewing a series of studies performed at the Control Systems Laboratory of the University of Illinois (Augenstine and Blank, 1956; Augenstine, 1958; Osborne, Quastler, Tweedell, and Wilen, 1955; Quastler, 1955; Quastler and Brabb, 1956), he stated the following: "...Man's eye movement cycle in reading is such that gross, rapid movements of short duration are alternated with 200-250 ms. stationary periods. A series of studies concerned with flash recognition of familiar displays (Augenstine, Blank, Quastler, and Wagner, 1956) indicated that data input probably occurs during only a small part of each cycle. It was found that more information about complex displays was transmitted for 40 ms. exposures than for 10 ms. exposures, but exposures longer than 40 ms. showed no additional assimilated information until durations exceeded about 250 ms." (Hostetter, 1961, p. V-5).

In addition to limitations imposed by ability to correctly perceive (register) the stimuli, limitations in the response rate of effector mechanisms are also present, even in simple button pressing activity. The normal limit on taps made by a finger is 8.5 per second (Seashore, 1938) though practice can increase this to 9.3. When discussing limitations on simple motor movements such as this, evidence has shown that it is necessary to bring in the concept of some central process (the translation mechanism) operating within the organism, since it is known (Craik, 1947) that the finger is actually capable of making still faster movements (greater than 8 per second) when simple electrical stimulation is employed.

From the above it can be seen that the upper limit in the perception of discrete stimuli and the upper limit in producing motor movements both tend to be no higher than about 8 per second except in unusual cases. When a subject attempts to integrate the two, however, so as to make a series of specific responses to a series of discrete stimuli (not involving perceptual anticipation), the upper limit seems to be a rate of only 2 per second (Vince, 1948; Welford, 1952; Bartlett and Bartlett, 1959). If one stimulus is prevented in close temporal contiguity to another stimulus, the response to the second stimulus is delayed, the reaction time being frequently longer to the second than to the first. This phenomenon of a psychological refractory period has been noted with simple auditory stimuli (LaMay, 1960) as well as visual tasks (Alluisi, Muller, and Fitts, 1957; Hick and Bates, 1950; Vince, 1948) where the subject is required to press a button in response to a stimulus, and in more complex tracking tasks (Craik, 1948; Hick, 1948).

An interpretation of this phenomenon has been offered by Welford (1952) who proposed that there is a central organizing time during which the central mechanisms of an organism are engaged in executing a response and receiving stimulus feedback from this response. During this time, any stimuli, other than motor feedback stimuli, which impinge upon the organism must be held in store until the central mechanisms are cleared from the preceding response. Augenstine's (1958) findings suggest that signals might even be missed entirely if stimulus presentation times were sufficiently short and tightly spaced e.g. less than 40 ms. If this does not occur, however, new inputs can be sent to a temporary store until the subject is ready to process them.

It would appear that while there is a refractory period of approximately .5 sec, it is a relative refractory period. As the interval between stimuli goes below this point, sharp decrements appear. The absolute refractory period would seem to be approximately .2 sec at least for visual stimuli if Augenstine's data are integrated in this fashion. However, it is no simple task to infer performance decrements from these. Temporary storage can be used to extend capacity. This is possibly

what makes the .5 sec - .2 sec interval a relative rather than an absolute refractory period. In addition RTs vary as a function of response load. At least for a fairly long period of time. The discussion given above is speculative and perhaps further empirical data will substantiate or invalidate these ideas. At the present the data can serve as tentative estimates of speed capacities of the human organism.

It is apparent that more information is needed about temporary storage in human systems. Broadbent (1958) has pointed out that this store is very temporary, lasting in the order of 2 seconds only for naval ratings. In addition, it would seem that it is limited in the amount of information which can be stored this way. Hostetter (1961) reported an estimate of about 20 bits; however, it is possible that the limit is not one of amount of information. Perhaps it is reached simply because not all the temporarily stored data can be retrieved before they are lost (a time limit, not an information limit). Thus the limit might well be imposed by this retrieval operation, or by delays associated with putting information in temporary store (Broadbent, 1958).^{*} Existence of the phenomenon of eidetic imagery (c. f. Woodworth and Schlosberg, 1954) seems to reinforce this view. Evidently some rare individuals can exceed the normal time limitations for holding information in temporary storage; when they do, they can transmit much more than 20 bits.

The existence of this refractory period and of limits on temporary storage no doubt contribute to the effectiveness of self-pacing. In such situations, individuals can probably allow for minor variations in feedback time and can also reduce demands placed upon immediate memory. However, in order to circumvent the problem of maladaptive habits being formed about pacing, persons should probably receive training early in high load situations.

CRITICAL FACTORS

1. Factors Influencing Perception

a. Irrelevant Information: One important task variable which directly determines the amount of observed "task induced" stress is the amount of irrelevant information present in the stimulus situation. When subjects are required to locate targets in display matrices of various sizes and composition, there is little doubt that the presence of irrelevant information causes increases in performance time (Erickson, 1955; French, 1954; Green and Anderson, 1956; Pollack and Klemmer, 1954; Pollack, 1955). In all cases studied, results showed that search time increased in linear fashion with increases in irrelevant information which appeared in the form of either non-target dots in some cells or blank cells. A decrement in level of performance has also been noted for increasing amounts of irrelevancy (Mackworth and Mackworth, 1958).

* Broadbent, for example, has estimated that it takes from 1-2 sec to switch from one sensory channel to another. This value is precariously close to the 2 sec. temporary store limit and provide an interesting explanation of why people have such difficulty in "doing two things at once" (c. f. Woodworth and Schlosberg, 1954). One way of avoiding this storage time limitation is by spacing stimulus presentation so that the same information can be continually recirculated until it is used. Unfortunately this recirculation activity ties up the channel so that new input data are not received (Broadbent, 1958).

The reason that irrelevant information hinders performance is easy to understand. It has been pointed out that man has channel limitations in regard to both amount of information processed (or more correctly the number of stimulus units processed) and the time available for processing. Processing unnecessary material will reduce the net effective capacity available for relevant material.

Broadbent (1958) has pointed out a fact which moderates the performance decrement produced by irrelevant information. He proposes that man learns selectively on the basis of what he attends to perceptually. Some elements of any stimulus complex are taken up as input while other features are filtered (disregarded). If man can do this, a question arises as to why he doesn't simply disregard irrelevant information and keep his performance level from dropping.

The answer seems to be that he can do just that provided a number of conditions are satisfied. If it is easy to distinguish between what is relevant and what is not, he can filter. If it is difficult, he can filter only a small amount of irrelevant information or none at all.

The capacity to filter irrelevant information will vary depending upon a number of factors. These can be deduced logically from the very definitions of relevance, irrelevancy, and filtering. Experimental data seem to substantiate these deductions. Consider a certain input load (S). Information in the stimulus situation is given by cues (e.g. form, color, size, etc.) and each of these is correlated with some particular response, e.g. given the appearance of cue 1, R_1 is appropriate. This relationship may vary anywhere between no correlation and complete correlation. Now, if R_1 is the appropriate response and if cue no. 1, C_1 , is perfectly related to it, C_1 is relevant information. If C_2 bears only a partial relation to R_1 , it is only partially relevant. If C_3 bears no relationship to R_1 , it is completely irrelevant.

So far this method of analyzing stimuli is easily understood. Restle (1955) has used the same approach to develop a mathematical theory of concept formation. By combining his basic approach with that of Broadbent (1958), it seems logical to expect that C_3 would be easier to differentiate from C_1 than would C_2 , at least in terms of feedback cues (knowledge of results). However, stimulus cues are also important. If there is at least 1 bit of stimulus information between C_1 and C_2 and another bit between C_1 and C_3 , filtering can take place. It should be even easier for subjects to filter if C_1 can be differentiated from C_2 and C_3 on the basis of a single bit of information, e.g. space separation vs. no space separation. Appropriate past experience, i.e. filter C_2 and C_3 while accepting C_1 , can also be expected to be beneficial while inappropriate past experience, e.g. C_1 and C_2 both are cues to R_1 , should be a hindrance.

All of the notions explained above are easy to understand and it is not necessary to work out the logic in more detail. Experimental results seem to be reasonably consistent with this interpretation. They are as follows: (1) irrelevant information does not always produce response decrements (Archer, 1954); (2) practice seems to reduce decrements produced by irrelevant information (Hodge, 1959) but only to a degree (Mackworth and Mackworth, 1958); (3) inappropriate training, i.e. previous experience where cues now irrelevant were relevant, causes greater decrements than no previous inappropriate training (Hodge and Reid, 1958; Gregg, 1954); (4) when irrelevant information is separated spatially from relevant information, performance is not as poor as in the case where the no separation is present (Senders, 1952); (5) the greater the stimulus similarity between relevant and irrelevant information, the greater the performance

decrement produced by the irrelevant information (Reid, Hodge, and White (1958); and (6) the greater the amount of stimulus information required to filter, the greater the decrement produced by irrelevant information (Kruler and Sinclair, (1953).

The experimental data cited above make a compelling case for the previously stated line of reasoning. Obviously, the problem has been oversimplified by overlooking such factors as interaction effects: e.g., an interaction exists between stimulus similarity between relevant and irrelevant material and the amount of irrelevant material (Reid, Hodge, and White, 1958). However, most such results are probably interpretable in terms of summation of demands on channel capacity.

b. Redundancy: A second important factor influencing perception is stimulus redundancy, e.g. using more cue information than what is needed for responses. The studies on this, (c.f. Turner, Wallace, and Wessel, 1956; Attneave, 1955) have produced seemingly unequivocal results which are well summarized by Hostetter (1961). In his discussion of the topic he stated the following:

"In conclusion, one can say that the effects of redundancy are dependent upon the complexity and required speed of the task. With relatively simple tasks, redundancy tends to cause an increase in reaction time and an increase in the processing time. However, as the speed requirement in a simple task is increased, increased redundancy tends to decrease error."
(p. V-7)

c. Adaptability to Coding: One final factor is the suitability of a stimulus situation for coding into groups or "chunks of information." The significance of this is clear and has been discussed previously in the chapter. However, few systematic studies have been performed on this variable and it is largely a matter of potential promise at the present time.

2. Factors Influencing Translation: Translation may be roughly thought of as a process of selecting appropriate responses on the basis of stimulus information. Obviously, this activity should be facilitated if it is known that certain S's are more probable than others, that certain R's are more likely than others, and that certain S R connections are more likely to be correct than others. All of these processes involve a concept of task anticipation. A differentiation has already been made between (1) perceptual and (2) response anticipation. The extent to which a task permits or encourages such processes was shown to have a marked influence on processing time. In fact, Hyman (1953) found a linear relationship between response time and (1) the relative probability of occurrence of various stimulus alternatives, and (2) the sequential dependencies existing between alternatives.

Perceptual anticipation has been shown to be acquired autonomously (by practice without instruction), and can also be induced to some extent by instructions. However, if this instruction is inaccurate, performance will suffer. Krulee, Podell, and Ranes (1954) and Krulee (1958) found that when subjects are told to expect more S alternatives than actually occur, their performance suffers. This last point shows that inappropriate (injurious to performance) anticipation can occur in certain situations.

The effects of response uncertainty upon performance cannot be stated in any simple fashion because there are not sufficient data upon which to base a conclusion. In many cases it is impossible to differentiate between the effects of stimulus uncertainty and those of response uncertainty. When this occurs, the effects are as those described for perceptual anticipation, i.e. there is a great effect on performance level and time. Also, many "response uncertainty" studies actually seem to be better classified as studies of response load, a topic which has already been discussed. However, before progressing to the next factor, it should be pointed out that response uncertainty can be expected to become more and more important as channel capacity is more closely approximated. That is, as uncertainty increases, performance deteriorates under such near overload conditions. Indeed, it could be very surprising if this were not found to be the case. For the present this is the only seemingly safe generalization to make; no predictions can be made as to how and when this effect is likely to occur.

The job of translation is made easier by other things than simply being able to weight certain S's and R's more heavily than others on the basis of perceptual and response anticipation. A point of major importance is the compatibility existing between S's and R's. If they are not compatible, the translation mechanism is faced with the need to decode the S's and encode into a form compatible with R's. Sometimes this coding step can be beneficial if it reduces the stimulus load greatly. However, it will probably never be as efficient as having an equally efficient compatibility relationship built into the task. Hostetter (1961) has summarized the relevant considerations for S R compatibility. They are ... "(1) the past experience of the human, (2) population stereotypes, (3) the parallelism between the stimulus presentation medium and the response medium and (4) the nature of the encoding or cortical involvement required by the situation" (p. 36).

The points made above can be well documented by research. The interested reader is referred to Hostetter (1961) for a more detailed discussion of literature. However, it is worthwhile to cite a few studies as examples and to mention others that serve to connect points made earlier in this paper.

Results of a study performed by Fitts and Seeger (1953) indicate that compatibility effects in perceptual motor performance are great. An experiment by Ericksen and Hake (1955), which was interpreted by the authors in a different context than the one being done now, found that information transmission remained constant despite the fact that both stimulus and response load (no. of categories) was increased if the number of response categories equalled or exceeded the number of stimulus categories. However, when S load > R load, i.e. the no. of categories in S > the no. in R, a loss in transmission resulted. Expressing this last finding in terms of a variable explained in Table I, it appears that the greater the information compression required by a task, the greater the decrement in performance. Design of research to systematically measure the effects of this variable, which to the author's knowledge has not been done, would seem to offer considerable promise in terms of increased knowledge about tasks.

Knowles, Garner, and Newlin (1953) have also shown that the greater the S R compatibility, the greater the sensitivity to changes in stimulus and response uncertainty. This seems to be consistent with the position taken throughout this chapter that reducing time spent on one activity, e.g. coding, allows time to be spent on other beneficial activities, e.g. making use of anticipating cues and can thereby allow for greater transmission of information. Finally, it has been found that the amount of speed stress, which can be operationally defined as the slope of the decrement in the transmitted information curve after the maxima, is less in incompatible situations (Knowles, et. al., 1953).

3. **Factors Influencing Effectors:** Throughout this chapter the interaction of processing phases has been emphasized. As a consequence, much of the material which would normally be covered here has already been discussed, viz. the factor of response load. Other factors obviously exist such as (1) response preferences in population introduced by social custom and formal education, (2) response speed and smoothness introduced by specific practice, and (3) response complexities introduced by requiring coordination of various muscles. The last factor is a bio-mechanic consideration and this and the other two are discussed at length in standard human engineering references. The consequences of each to response time and proficiency level are obvious and need not be belabored here. However, it is significant to note that this question is not central to the consideration of the human as a single processing channel. Welford (1960) points out that it is possible to begin processing new input data even while the responses given to the previous input are underway. In short, the critical point is selection of a response, not execution of it. The previous subsection has discussed this factor in reasonable detail since by its very nature it is closely articulated with input activities.

a. Speed of Signal Presentation

Errors of Omission: Conrad (1954), studying the effect of increased signal speed by varying the speed of pointers on a series of four dials, found that the number of omissions rose in a positively accelerated manner as the speed of signal presentation was increased, though the latency of responding did not change. Those signals which closely preceded or followed another response were more likely to be missed. This finding seems relevant in view of the concept of the psychological refractory period which has been previously discussed and may also be related to the concept of perceptual span. That errors of omission are significantly related to speed of stimulus presentations seems to have been confirmed in numerous other studies (e.g. Davidson, Andrews, and Ross, 1956; Mackworth and Mackworth, 1956). In the Davidson et. al. study, speed of stimulus presentation was also significantly related to subjective reports of stressful experience.

It seems equally well established that errors of commission are also significantly related to speed of stimulus presentation. Mackworth and Mackworth (1956) showed that errors of commission and errors of omission increased as a positively accelerated function of speed of presentation, a relationship which had been established previously for errors of omission by Conrad (1954).

Both types of errors resulting from speed of stimulus presentation may be subsumed under what Conrad has termed speed stress. A good differentiation between speed stress and load stress (to be discussed next) has been offered by Howell and Briggs (1959): "In the case of load stress, the shortage results from what seems to be a greater amount of work in the same amount of time; in speed stress, the shortage appears to be of time for the same amount of work." (p. 29)

Increased load as has already been noted has a detrimental effect on performance. Conrad (1955) observed that increasing the load resulted in an increase in both the number and duration of errors, and that recovery from error took longer with greater loads. Mackworth and Mackworth (1956) found that errors increased as a linear function of load. Other than this, not too many detailed descriptions of errors are available and the discussion offered in the preceding subsection cannot be significantly supplemented.

b. Similarity of Signals: Reid and Holland (1954), using geometrical figures to study the effect of stimulus similarity, found that similarity among the stimuli in a complex task decreased the proficiency with which the test was performed. This decrement could be reduced, however, by either patterning the responses of one task component or decreasing the rate at which the responses had to be made. Thus it appears that when the subject has to spend time making a difficult discrimination, the rate at which he can accurately respond, decreases. This seems in agreement with a previously made point of the dynamic nature of processing, i. e. that if a subject required to maintain a given response output (must spend central processing time by making difficult discriminations) there is less time available for him to spend processing the response and his flexibility and accuracy of action is impaired.

c. Overlap of Signals: Poulton (1956), studying overlapping signals in an auditory task value subjects answered calls, required subjects to write down a three-figure number if it were preceded by his call sign; he found that more errors were made when two numbers were synchronized than when a number was masked by a name, and that more errors occurred when the numbers from both competing calls had to be recorded than when it was necessary to note only one of the numbers. This seems to be another example of the discriminator problem previously discussed as does the study by Mackworth and Mackworth (1955) who found a linear relationship between errors of omission and overlap of signals.

SUMMARY

This chapter has presented a review of task induced stress, which was defined as an effect induced by shifts in task demands in the direction of making the task more closely approach (or surpass) the limitations of human capacity. The approach to the problem was based upon the assumption (1) that human beings can be considered as limited capacity information channels, (2) that these limitations can be roughly approximated in terms of task variable measures, (3) that the human channel performs certain necessary operations upon input data to produce a response, and (4) the operations combine to form a dynamic restriction on channel capacity. The greater the time and effort spent on processing operations, the lower the channel capacity.

It was seen that experimental data on the whole are consistent with this approach. Stress occurs primarily as a function of speed or load demands. The nature of each of these stresses was discussed in detail and it was seen that it is possible to reduce stress by reducing perceptual demands, translation demands, and effector demands. A number of specific factors were discussed under each of these headings.

There appear to be numerous ways in which stress can be reduced, primarily by raising channel capacity. Many of these take advantage of certain approximation procedures used by humans when they are faced with high speed and high load tasks. Institution of these ideas depends upon the flexibility of the human operator and his ability to shift his behavior in times of overload or near overload. The potential for such behavioral shifts is clearly better for load stress than speed stress.

SECTION V

CONTROL OF STRESS

GENERAL TECHNIQUES: BEHAVIORAL ADAPTATION

Recent research in the area of task induced stress has intensified interest in the problem of determining factors which will modify reactions to a given stress situation.

That adaptive learning which occurs with experience independently of specific training procedures is often referred to as adaptation.

Analysis of performance by numerous subjects on the USAAF Psychomotor Skill Battery led Deese and Lazarus (1952) to conclude that adaptation to stress occurred during the psychomotor testing sessions. The authors tested several groups of airmen, submitting them to the following experimental conditions: (a) control group, 40 subjects, simply told to do the best they could and urged to continually try to improve their performance; (b) experimental group I, 40 subjects, told that failure on the test would have serious consequences in relation to their future Air Force careers; (c) experimental group II, 80 subjects, an added threat of failure induced through false norms introduced early in the learning process; (d) experimental group III, treated exactly as group II, except that the false norms were introduced late in learning; and (e) experimental group IV, who experienced equipment failure. The authors found that when the mean times on-target for all the groups were compared, the controls were markedly superior to all other groups in the early trials, but as learning progressed the difference disappeared. In relation to this phenomenon the authors stated, "... the psychometric stress is effective in impairing performance for only a short period of time. Apparently there is a gradual adaptation to this stress." The goal of stress control in situations where performance decrement due to "stress" is more severe and long lasting has been to speed up the adaptation process in order to eliminate, or at least alleviate, any performance decrement inherent in the particular stress-producing task situation.

SELECTION TECHNIQUES

One obvious approach to stress modification lies in establishing performance criteria for a specific stress situation, and then selecting only individuals who are able to meet these criteria. World War II gave great impetus to studies of this nature for the practical purpose of "beefing up" military selection techniques. Haggard (1949) discussed the various aspects involved in the stress of submarine warfare and made the following statement about selection: "If a completely adequate description of the submarine situation were available, it should be possible to deduce the essential characteristics of men who would adjust as submariners with minimal emotional stress. That is to say, men should be selected for submarine duty whose objective qualifications, potentialities for adaptation, conscious and unconscious needs, motivational patterns, and identifications are optimally satisfied by the demands and satisfactions provided by life aboard a submarine."

More recently Sells (1961) reported that only minor changes have been made in the psychological and physiological requirements for initial air crew selection since World War II. He underlined the continuing need for research in this area by referencing Mosely (1957) who said, "It is apparent from the accident data that we do not have at present adequate objective measurements of the task imposed

upon the pilot in high performance aircraft." It would seem that we dare not ignore the necessity for seeking answers to such important questions. To do so, as we stand at the threshold of space, would display a careless disregard for the successful planning, initiation, and conclusion of future space flights. Sells was referring to the stresses imposed by jet and rocket aircraft which include reduced barometric pressures, temperature alterations, accelerations, disorientation, anxiety and fatigue when he said, "An obvious method of reducing the effects of these stresses is to select pilots and other crewmen who have superior tolerances. However, superior tolerances to simple stresses may be overcome by synergic action of multiple stresses. Hence in spite of arguments concerning differences in tolerance acquired by the use of personal protective equipment, the physical standards must be high enough to insure some resistance to the hazards of unexpected events and resultant unprotected states."

Research in the area of crew selection for space travel is clearly in its embryonic stages. Flickinger (1959) has rather clearly outlined the research that has been done and that is being continued on such topics as crew performance and stress tolerance. In his discussion of the psychophysiological stresses involved in space flight he outlined some of the aspects of the future work to be done in these areas in the following statement:

"Work at both the basic and applied levels of this problem will be considerably augmented to provide a more complete understanding of bodily mechanisms in response to stress from the cellular level on up through regulatory systems to the complete functioning organism. With more fundamental knowledge of cellular biology and regulatory systems inter-relationships, particularly as concerns brain mechanisms, we stand an excellent chance not only of identifying the premium man for the premium job but also of producing more premium men through natural and artificial adaptation techniques. On the applied end, a crew selection and conditioning unit will be established in an area where there is a high population increment of pilots who are required to perform premium tasks."

The foregoing was not included to imply that problems of psychological stress as related to task performance are inherent only in tasks encountered in space vehicles. The problems of task induced stress of the speed and load variety have been with us for a long time in such unglamorous tasks as performance on a production line (Conrad, 1951). Perhaps as researchers we should be grateful to the advent of the space age, for it has thrust into sharp focus all the problems related to task induced stress.

But despite the long history of man's concern with such problems, remarkably few results of demonstrable value have been achieved. True, there are many suggestions present in the relationships discovered between various laboratory tasks and miscellaneous measures of anxiety, physiological reactivity, etc. However, as we have indicated in our prior discussion, the correlations are small, and many of the results appear to have applicability only on a task specific basis.

PHARMACOLOGICAL TECHNIQUES

The study of drugs, particularly tranquilizing agents, has accounted for a large portion of the research in the area of stress control.

J. G. Miller (1960) has been very active in research of this nature. He reported an experiment which examined the effects of drugs in three types of stress situations: (a) experimentally induced; (b) illness induced (headache); and (c) drug induced. In the experimentally induced stress condition, the stress apparatus consisted of a box in which sparks as threats of shock, actual shocks, blasts of air, and loud noises could be presented. The subjects experienced the stress conditions while taking various pencil-and-paper tests. In one study neither 800 mg. of meprobamate nor 400 or 800 mg. of emylcamate altered performance on the tests. Producing stress by drugs would therefore appear to be difficult, at least for moderate dosages of the drugs mentioned above.

A study reported by McGuire and Leary (1958) investigated stress tolerance in 10 healthy male subjects, both in the normal state and under therapeutic doses of tranquilizers. The experimenters were concerned about the effects of these drugs on pilots, who it appeared were using them somewhat indiscriminately. The experiment performed by the authors was designed to assess the effects of drugs on pilot-related tasks. The subjects serving in the experiment were given a complete physical examination after which they were exposed to a series of five stresses. Following this, they were given therapeutic doses of promazine hydrochloride, meprobamate, or placebo. Some subjects eventually received all three. Testing began after the subjects had been placed on a particular drug from three to five days. The drug was continued throughout testing. No more than two tests a day were performed on a given individual, and these were separated by long time intervals to keep a subject's "stress" response to a particular test from influencing his responses on others.

The authors examined the effects of the drug conditions on performance in the following "stress" situations: (1) valsalva overshoot - subject forcefully expires into a tube connected to a 500 cc flask, which is attached to a mercury manometer. The apparatus is designed to insure against closing the glottis as a mode of maintaining elevated pressure by forcing the pressure to extend down into the lungs. When the intrapulmonic pressure is released, the systolic blood pressure "overshoot" is determined; (2) continuous positive pressure breathing, 30 mm. Hg. pressure, 100% oxygen at 25,000 feet in the altitude chamber; (3) tilt table - the subject is tilted to 65° and remains there for twenty minutes. Blood pressure and pulse are recorded every two minutes; (4) Harvard Step Test - a five minute period of stepping onto and down from a platform 20 inches high at the rate of 30 steps per minute; and (5) combined stress test, a combination of the stresses to which high performance aircraft pilots might be exposed (exact nature of the test classified). The authors found that tranquilizers reduced stress tolerance when the latter is defined in terms of such indices of physiological adaptability. The limitation was not as severe with meprobamate as it was with promazine hydrochloride. As the degree of stress increased, it was determined that the limitation of adaptation became marked with both groups of tranquilizers. High doses yielded more severe limitations. The authors concluded that the drug-induced limitation occurs regardless of whether or not the subject is under chronic medication. It was their opinion that pilots using such drugs should be removed from flying status during the periods of medication. However, it should be emphasized that the stresses studied were strictly physiological in nature and may bear little relation to psychological stress.

Uhr (1960), pp. 610-633) provided a comprehensive review of research investigating the effects of various drugs on psychomotor and perceptual performance. He reported that most of the experiments consistently show that ordinary doses of such tranquilizers as chlorpromazine and reserpine impair performance at speeded, simple perceptual, or coordinated psychomotor tasks. He made the following statement in relation to the effects of drugs on performance under stress (p. 616):

"Several tranquilizers (especially meprobamate and chlorpromazine) rather consistently improve performance under stress and apparently by lowering anxiety level, definitely affect motivation level. There is also some indication that this tranquilizing effect is felt subjectively and can be observed to have autonomic influences, but it does not lead to improved performance." [in the normal situation]. "This absence of facilitation of behavior could well be caused by counteracting behavioral toxic-effects or the absence of disruptive anxiety in normal subjects who work at simple straight-forward tasks. But, when tests are chosen because they are sensitive to and disrupted by anxiety, or when high anxiety levels are induced by laboratory stressors, performance tends to be improved by tranquilizers."

This statement should serve to indicate the chaotic state of this area of psychological stress research. As long as drug effects are described in such terms as tranquilization, sedation, and stimulation, it will be impossible to establish generalizations about drugs in relation to performance on different tasks. However, numerous efforts are being made to establish the dimensions of drug effects (c.f. Cattell, 1960, Eysenck, 1960, Uhr & Miller, 1960). It will remain, then, to interrelate these to task dimensions.

TRAINING TECHNIQUES

The groundwork for developing the ability to cope with such impulses as anxiety and fear is laid early in childhood. There is some evidence that adults can gain control by being gradually exposed to stress-producing situations. According to Haggard (1949) an individual can become progressively adapted to stress situations and thereby develop an ability to function optimally in stressful situations. Haggard further stated, "Realistic training under realistic conditions of stress is a necessary procedure if many individuals are not to become psychiatric casualties when confronted by actual dangers. In fact, one observer believes that 'shell shock' is nothing but insufficient training."

Military training programs constitute one of the prime responsibilities of any military service. The transformation of the raw recruit into an "operationally ready" military man has been a military problem since time immemorial. However, the complexity of present-day weapons has considerably increased the need for formal technical instruction. To cope with this problem weapon simulators have been developed to provide the necessary "realistic" procedural training with its attendant transfer to the actual task.

Fortunately, the development of simulators has greatly increased our capability for task analysis. According to Seale (1960), "We may define task analysis as that portion of the total systems analysis effort which defines systematically and in as much detail as possible at any given time, the stimulus inputs to the operator, the response outputs of the operator, and the operational environment

in which he works." The task analysis approach has tremendous merit in providing knowledge about the aspects of a task that may or may not produce stress. However, the focus of task analysis needs to be broadened to include not only the stimulus inputs to the operator, but also the operator's ability to store this input information and process it into useful responses to a particular task situation. Essentially this means applying what is presently known about human information processing to task analysis. From data of this nature it should be possible to determine whether improved selection techniques, training techniques, task modification or a combination of all three, will best serve to increase performance level on a particular task.

The chaotic condition of the literature related to psychological stress does not provide a clear thread of cohesive evidence or results that could be grouped into an article entitled "How to Train Individuals to Perform in Situations of Task Induced Stress." In effect there is no real empirical basis for developing such training principles. Since this is the case, an attractive alternative exists in a statement by Gustafson, Honsberger, and Michelson (1960): "...It is, therefore, quite possible to exploit existing training technology and to do a highly competent and successful job within the limitations imposed by the state of the art, provided only that the training analyst is not unduly hindered by concern that his procedures be impregnable to attack on scientific grounds. A pure applier concerns himself first with developing a training program that has high probability of success, and only secondarily with whether he really understands what he is doing. We can consider optimizing the program through research only after a successful program has been established. The pure technician uses experience, expert opinion, and even brute force to overcome the obstacles in his path; and the training problems that cannot be solved in this manner turn out to be surprisingly few and far between."

This strictly applied approach becomes less attractive when it is realized that it also implies strict validation studies. Direct empirical validation is generally difficult due to the lack of criterion data. Even so intensive an effort as that of OSS Assessment Staff (1948) to develop selection and training techniques for performance under stress was unable to produce any proven results. For a discussion of the criterion problems encountered, see Lazarus et.al. (1952), Pp. 24-25.

It would appear, then, that one must rely on generalizations from laboratory or other non-operational situations for the prediction of operational performance. This implies a considerably deepened understanding of the nature of stress, both of its causal elements in the task situation and of its consequences in task performance. It also implies that it is possible to compare meaningfully different tasks unless one is willing to run a study for each new task that develops.

SECTION VI

SUMMARY, CONCLUSIONS, AND RESEARCH IMPLICATIONS

In the preceding section, an attempt has been made to provide increased understanding, at least on the intuitive level, of the nature of psychological stress. The purpose of this effort was to bring into a sharper focus the major factors that contribute to determining how much stress is produced and how this stress will be reflected in performance.

Section I, the introduction, was primarily a statement of the problem and outline of the report's coverage. In Section II, a broad overview of stress research was presented in an effort to define the field (in the sense of the methods and contents of studies bearing the "stress" label). The topic of Section III was individual differences in reactions to stressful situations--i. e., the emphasis was upon predictor devices such as might be applicable for personnel selection. Coverage was primarily devoted to physiological indices and personality scales, inventories, etc.

Section IV was an attempt to focus upon a particular type of stress phenomenon: that of "task induced" stress. An attempt was made to show its relationship to psychological stress in general, and to review the relevant stimulus and response parameters. Section V represented an effort to cover what is known, in the way of direct implications from published data, about the control of stress.

Now, there is a need to summarize the implications of the vast body of research that has been barely touched upon. There is need for an attempt to derive hypotheses for stress control that extend beyond the rather scanty body of direct implications discussed in Section V. To these ends, a rough conceptual model--qualitative but with provisions for quantification--will be derived, and its implications for stress control discussed. Provisions for testing and quantifying the model have been presented by Hurst (1961).

A CONCEPTUALIZATION OF STRESS

Based upon the research discussed primarily in Section IV, it appears that task parameters set limits upon human processing ability through their influence upon the following factors:

1. Perceptual demands (speed and complexity)
2. Coding requirements
3. Needs for decoding or translation
4. Storage demands
5. Effector requirements
6. Stimulus-response compatibility
7. Informational requirements of response: extent to which it must preserve

the stimulus information. (This factor is particularly important since it sets limits on the types of strategies--filtering, perceptual anticipation, etc.--which can be adopted by experienced subjects.)

The human data-processing channel has a rate limit which may be defined in terms of $f(t)$, where t is the time taken to process a single stimulus symbol under given conditions.

Let \bar{t} = mean processing time, and

$f(t)$ = frequency distribution of processing times

Limiting values for these functions are set by (1) the informational content of the symbols, and (2) the method of coding implicit in the stimuli. Within these limits, considerable variation in $f(t)$ can occur. This variation can be largely attributed to four factors, which are not independent: (1) normal, or steady-state variation, produced by threshold variations, ambient noise condition, etc., (2) changes in coding by the subject, (3) changes in perceptual strategy adopted by the subject, and (4) general effects of experience, which may influence coding and perceptual strategies as well as having other effects more difficult to classify.

By defining the symbols/sec given in the input as $\frac{1}{a}$, "a" becomes the inter-stimulus interval and \bar{a} the mean time interval between successive stimulus presentations. Thus, the joint function $f(t-a)$ defines the degree to which channel capacity is being approximated. Chapter IV included a discussion of human behavior as a function of the mean and variance of the value, $(t-a)$. The net effect upon performance can now be partially defined in terms of overload, "O": the effect produced by having channel capacity approximated and surpassed. Note that "O" refers simply to overload, not to either "stress" or "stress effect upon performance." There is need to introduce a second term which takes the emotionality component into account and to combine this term with "O" to define net stress effect upon performance. By taking this approach it is possible to offer a formulation of the stress concept which promises to lead to measurable overt behavior consequences.

Let "V" be an index of the emotional component of stress effect. This construct has been developed to take into account the emotional aspects of the various types of psychological stress that have been so widely investigated in the experiments cited in preceding chapters. Consider some of the various "stresses" that have been described: failure stress, frustration stress, ego-threat stress, distraction stress, and speed/load (pacing) stress. It would seem that all of these phenomena, including the emotional component of "task induced" or speed/load stress, can be defined in terms of the utility notion of the economists as adapted by decision-making theorists (cf. Davidson, Suppes and Siegel, 1957). What appears to be the common, critical element in these situations is how much variation in utility is expected, by the subject, as a result of the situation outcome, and of how uncertain he feels about this outcome. Thus, "failure" or "frustration" stresses would owe their principal affect to the fact that he foresees the possibility of a large (downward) swing in utility, but is uncertain about whether or to what extent it will occur. (Certainty of failure would be expected to induce apathy rather than stress.)

The effect of increasing ego-involvement would be similarly interpreted, since this increases the utility swing contingent on one's ability to perform at his level of aspiration. The effects of various distractors (noise, etc.), as well as those of pacing and other increases in task demands, can be expressed in terms of the performance decrements they produce--which lead to a greater uncertainty of success. (It is probable that the emotional effect of this anticipation is such as to further impair performance, thus resulting in a greater affective disturbance, which causes more impairment, etc., until the decrement is such that outcome uncertainty begins to decrease--i. e., failure becomes relatively certain. At this stage V should begin to decrease, thus, tending to resist further performance decrements.

If the foregoing conceptualization be correct, it should be possible to summarize the effects on the emotional component in terms of how much of a utility swing is anticipated as likely to occur; or, more precisely, as how much of a swing is anticipated as how likely. This relationship can be expressed in an equation such as the following (developed in more detail in Hurst, 1961):

$$(1) \quad V = \sum_{i=1}^n (K_i P_i - E)^2 = \sum_{i=1}^n K_i^2 P_i - E^2$$

- where
- V = expected variance in outcome utilities
 - K_i = incentive (utility) of the i^{th} outcome
 - P_i = subjective probability of the i^{th} outcome
 - E = expected utility value of task outcome
 - (E = $\sum_{i=1}^n K_i P_i$)

To interpret the above, consider a task with N possible outcomes forming a mutually exclusive and exhaustive set. Each outcome could be considered a score interval, as 0-10, 10-20, etc. Attached to each possible outcome, i , is an incentive value K_i ¹. Now the stress effect on the subject should depend on two considerations:

¹Note: In the general case, the value K_i refers to the difference in utility between that attending the i^{th} outcome and that of the present state. The illustration has treated only the case of positive increments in utility, but the model is intended to cover also the case of negative increments. There is some evidence (Atthowe and Siegel, 1961) that the anticipation of negative changes is attended by more stress than that of positive changes, even when the amount of increment and the degree of uncertainty are held constant. If this is verified, the expression can probably be adjusted with an appropriate constant.

(1) How much money (or other unit of utility) swings on the outcome?

(2) How much uncertainty exists as to which way the swing will be?

The greater the possible swing, the greater the expected stress. However, the stress effect should approach zero as the outcome uncertainty approaches zero, regardless of the size of the swing. Equation (1),

$$V = \sum_{i=1}^n K_i^2 P_i - E^2$$

considers both factors. It is an expression for the variance of outcome utilities in a hypothetical series of repetitions of the given situation. Note that the expression involves subjective probabilities. Thus, the variance, V , is real only in the sense that it represents what variance a given subject would predict for the outcomes of a series of identical trials. It is not implied that the subject goes through any such computation, but rather that he behaves as if he had done so.

It is hypothesized that stress is a monotonically increasing function of V .

It is now possible to express the total effect of task-induced stress upon observed performance. Denote this net effect as " ΔP ." It is clear from the foregoing discussions that

$$(2) \quad \Delta P = g(O) + h(V)$$

where g and h refer to functions whose precise nature are not at present known.

Recalling that O is a function of the distribution of $(t-a)$,

$$(3) \quad O \sim f(t-a),$$

we also know that V will be influenced by $f(t-a)$, since this determines the subjective probabilities of successes (P_i terms) for the events in Equation (1). Thus the distribution, $f(t-a)$, has a two-fold effect on performance: a direct effect through overload, not influenced by outcome utilities,

$$O \sim f(t-a)$$

and another effect through the emotional component which does depend on outcome utilities,

$$(4) \quad V \sim [j(U), f(t-a)]$$

.. Substituting these two expressions in Equation (2), one obtains

$$(5) \quad \Delta P = g [f(t-a)] + h [j(U), f(t-a)]$$

or more simply

$$(6) \quad \Delta P = g'(t-a) + h' [U, (t-a)]$$

which expresses the functional relationship between input arrival distributions, service time distributions, and outcome utilities.

The qualitative relationship between "V", "O", and task parameters can be clarified by providing a block diagram which shows the type of concepts hypothesized. Figure 6 shows such a diagram. The terms used are as follows:

- f (a) = the distribution of arrival times of the stimuli;
- f (t) = the distribution of service times
- C = "complexity": those aspects of the stimulus situation which define the task difficulty (c. f. , information in bits/symbol, type of information coding implicit in stimuli, etc.)
- Cd = method of coding adopted by subject
- Ex = the effects of past experience
- St = the strategy adopted by the subject
- O = the actual overload, i. e. , (t-a)
- O' = the perceived overload which is a function of O, instructions, level of aspiration, etc.
- U = the payoff differential, which defines, in units of utility, the difference between successful and unsuccessful performance.
- V = the expected utility variance, as defined above.
- ΔP = change in performance , designated by percentage of information transmitted.

Some particular implications stemming from the block diagram should be discussed. The first is that if the payoff swing, U, associated with different

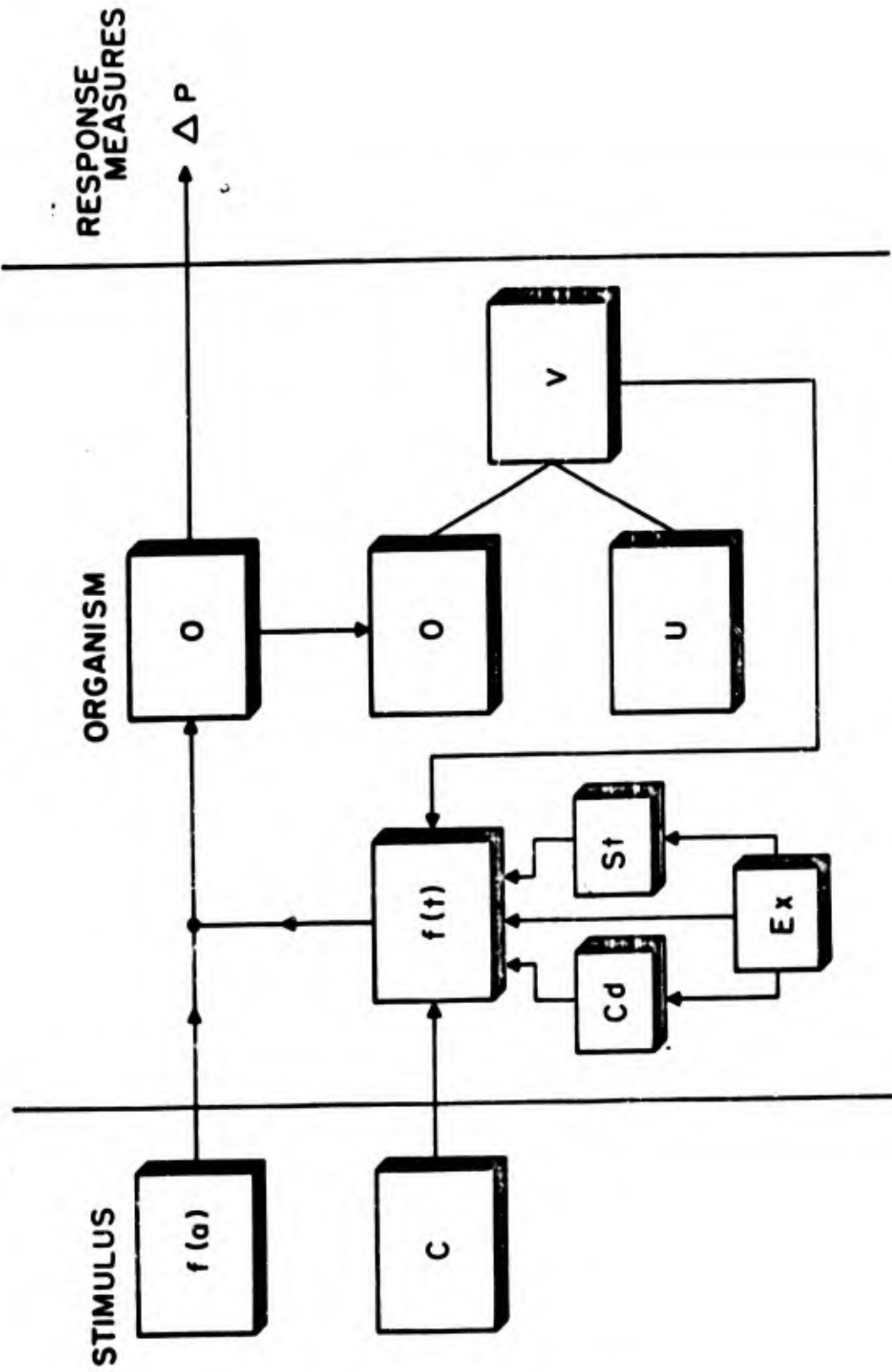


Fig.6 Block Diagram Of Stress Conceptualization

performance outcomes is comparatively low, then the "O" component will define, to a large extent, the performance outcome. However, if U is increased, this increases V. This affects t (t) and will thus affect O and O'. However, when O is sufficiently great as to make satisfactory performance nearly impossible, V becomes low. This produces a favorable effect on f (t), with a consequent decrease in O, thus resisting further performance decrements. This feedback relationship is an interesting one and is explained further below.

The second point brought out by the figure is that perceived overload, O', does not necessarily equal overload, O, which is defined in terms of f (t-a). For the present, however, it appears reasonable to assume a monotonic relationship between O and O'. If this is the case in preliminary studies, concern can be focused on O. When individual differences are to be focussed upon, it will be necessary to determine differences in the transform between O and O'.

IMPLICATIONS FOR STRESS CONTROL AND FOR FURTHER RESEARCH

A cursory inspection of the model indicates that ΔP is ultimately a function of utility variation and f (t-a). The first implication is that performance decrement can be reduced in magnitude by preventing excessive overload, which can be effected through increasing \bar{a} or decreasing \bar{t} . This implication is such obvious common-sense as scarcely to justify the need for a model. The methods of effecting these changes are less obvious. They would include operation-sequencing procedures to increase the mean and reduce the variance of a, the inter-stimulus interval. They would also include any means by which operators were encouraged to adopt filtering and/or coding procedures such as might reduce the mean and variance of t, the stimulus processing time. The problems involved here are highly complex, and there would seem to be no way to answer them short of a large amount of "rawly empirical" research.

Concerning the emotional aspects (control of "V"), the implications from the model are less obvious. Some degree of stress is present, by definition, in the highly motivated subject. The question is not one of how to eliminate stress, but rather of determining its optimum values for particular tasks and discovering how to attain such values.

The first phase of the problem--determining optima--presupposes some quantitative measurement of "stress." Tentatively, the most promising avenue for achieving this would seem to be through the use of physiological indices. Dimensionalization of these indices, as suggested in Chapter II, should permit defining "stress" in a manner both operational and conceptually meaningful. The physiological index, or dimension, should exhibit of monotonically increasing relationship with "V" as defined above.

The second phase of the problem--manipulating the value of "V"--is less directly approachable, but should be much better understood soon after the measurement problem has been solved. Ability to measure the emotional component in this semi-direct manner should provide a tool of inestimable worth in the validation of training and selection procedures.

One promising avenue is through manipulation of the relationship between O and O'. This would result in a given value of O being associated with a reduced value of O', which would be associated with a lowered V. Such an effect could be implemented through the "adaptation" process defined in the preceding chapter.

Intuitively, it would seem that the operator would adapt emotionally as well as perceptually, through practice under overload conditions, to the overload phenomenon. Thus, a particular high input rate might still exceed channel capacity, but the operator would no longer perceive this state of affairs as so disastrous.

A second approach is through manipulating the utility function, by teaching the operator to view the outcome on a long-term basis instead of short-term. For example, the operator of a PPI performing a "tracking" duty would be trained that it is not catastrophic to miss an opportunity to update the position of a particular target, so long as his over-all performance, in terms of updatings/minute, remains at a satisfactory level. This would prevent the occurrence of the familiar situation where the operator, in attempting to attend to every pip on each antenna rotation, falls progressively farther and farther behind the sweep and, in a state of greater or lesser panic, makes his updatings on images of progressively fading quality.

This type of training could be classified under the heading of "the teaching of filtering strategies," but willingness to adopt such strategies is related to the basic question of utility variation. The facts (Davidson, Suppes and Siegel, 1957; Hurst and Siegel, 1956) indicate that subjects do, indeed, perceive utility variation on a short-term basis when confronted with a series of similar trials. Consider, for example, a subject in a gambling situation whose positive utility of winning \$50.00 is equal in magnitude to his negative utility of losing \$40.00. He is confronted with two options as follows:

	Option A	Option B
Event E	Win \$50.00	Win \$2.00
Event not-E	Lose \$42.00	Win \$2.00

If he is convinced that the event, E, has a probability of occurrence of .50, he will surely choose Option B, even though its expected value is only + \$2.00 as opposed to + \$4.00 for Option A. In this manner he will maximize his expected utility with regard to the outcome.

Now suppose that this same subject is confronted with a series involving a very large number of such choices. Regardless of his utility function for various amounts of wins and losses, he will maximize expected utility for the sequence as a whole by choosing in accordance with mathematically expected value. (This conclusion is based on the assumption that, regardless of the shape of his utility function, nearly everyone would rather have more money than less.) Yet the experimental data cited above indicate that it is a very rare subject who, when confronted with a long series of similar options, adopts the "expected-value" strategy.

Such a strategy can be learned, as is evidenced by the behavior of professional gamblers; but since it does not occur naturally, it must be deliberately taught. Training procedures for data-processing operations might well incorporate such teaching, since incorporation of the "long-term" view should not only diminish V but also encourage the use of adaptive filtering strategies.

A third approach is through manipulation of the values of the P_i terms in Equation (1),

$$V = \sum_{i=1}^n K_i^2 P_i - E^2$$

Perceived probability of successful performance is a matter of confidence related to job competence and of temporary emotional state. The former is a matter of training. The latter could probably be modified through use of psychoactive drugs, especially stimulants such as amphetamine which appear to increase feelings of confidence, optimism, etc., without impairing normal-state performance as do tranquilizers. It is difficult at the moment to see how specific training techniques could contribute to favorable values of the P_i 's, aside from the obvious implication that excessive use of reproof in the training situation would increase failure expectancies and should therefore be avoided.

The K_i values are difficult to manipulate. They must be kept at high enough values to provide adequate motivation, but prevented from becoming too high. This necessitates manipulation and empirical study of the reward-punishment aspects of the operational situation, as they actually affect the operator. Physiological as well as performance measures should be compared, and results used in the apportionment of operator responsibilities.

In conclusion, it must be stated that the model, in the absence of a necessary body of experimental data, has few direct implications for training and other methods of stress control. However, the specification of the stress concept, and the development of the indicated measurement techniques, should lead to improved efficiency in the design and conduct of the required empirical studies.

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13. ABSTRACT

The purpose of this report is to review the literature concerning psychological stress. Emphasis is placed upon experimental evidence, with particular emphasis upon task induced stress. An attempt is made to define psychological stress in terms of the published material bearing the "stress" label, and thus provide an overview of the field. In the subsequent detailed coverage, individual-difference material, such as might be used in personnel selection, is treated separately from treatment effects. Task induced stress is treated as a separate topic, with an attempt to draw relationships between this phenomenon and those of psychological stress in general. Implications from the literature for control of stress are presented. In summarizing the findings reviewed, a formulation is presented of the relationships believed to be involved in the phenomenon of task induced stress. The parameters which determine information overload are discussed. A conceptual model is presented concerning the "emotional" component of psychological stress. A relationship is derived between this emotional component and information overload in the production of the performance effects typical of "task induced stress." Implications for control are derived from the foregoing conceptualization, together with suggestions of avenues for future research, much of which remains to be done.

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