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A STUDY OF BLOOD PRESSURE AND SINUS ARRHYTHMIA AS MEASURES OF MENTAL LOAD IN A VISUAL INSPECTION TASK

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A STUDY OF BLOOD PRESSURE AND SINUS ARRHYTHMIA AS MEASURES OF MENTAL LOAD IN A VISUAL INSPECTION TASK

CHAPTER I

INTRODUCTION

Statement of the Problem

In this age of lunar landings and outer space explorations, mechanization and automation of work has been increasing rapidly. In addition to physical effort (muscular work), many tasks consist of a mental load as well. Automation of work tasks has reduced the muscular work involved in man-machine systems. A significant increase in mental load has often accompanied this reduced muscular effort where the worker is required to monitor many dials, displays, annunciator indicators and other visual and auditory signals. To assure compatability between a worker and his task, it is necessary that the contents of the task, both in terms of physical efforts and mental loads, be evaluated correctly.

In any man-machine system, a reasonably accurate evaluation of the proposed system may be possible if a) experimental work in comparable situations is on record in the scientific literature, or b) a scientifically valid methodology can be used in evaluating the proposed man-machine system. For a task requiring physical effort, it is possible to evaluate the task in terms of metabolic costs. Astrand and Rodalhl [Astrand, 1970:4] have published an excellent book dealing with various factors affecting human physical performance. The metabolic cost of many physical activities has been analyzed by these authors. They state that no major problems are encountered in determining the metabolic costs of physical activities.

Determination of mental load is usually less amenable to quantification than metabolic load in developing data for man-machine systems design. Some theoretical and formal considerations permit a priori scaling of intensity of mental load.[1] But the usual procedure is to limit mental load to an anecdotal account (or a hypothetical consideration) and concentrate quantification procedures on the subject's efficiency of performance or perceptual and motor capacity. Using such performance criteria, it is exceedingly difficult, if not virtually impossible, to relate different types of mental load and scale their level of intensity.

A determination of appropriate measures to evaluate mental load in terms of biological costs, (such as blood pressure or heart rate), will be a very significant contribution to the fields of human factors engineering and experimental psychology. As stated above, the performance of a man-machine system consists of physical as well as mental effort. Evaluation of mental load, in terms of physiological variables (e.g., skin conductance) is likely to permit a measure expressing both types of loads (mental or physical).

It is the purpose of this research to study the effect of mental load on the following two physiological indicators:

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[1]Minnesota Multiphasic Personality Inventory (MMPI) is a widely used measure for scaling intensity of response to stress. One scale of MMPI used to measure anxiety is called Psychasthenia. Another scale of MMPI is used to measure responses to threat, impulses and unpleasant thoughts. This scale is referred to as "hysterial denial."

1. Blood pressure

2. Sinus arrhythmia

Of the two physiological indicators enumerated above, blood pressure is well known and needs no further explanation. Sinus arrhythmia, the other physiological indicator, is a measure of the irregularity of the heart rhythm.

Even under normal physiologic conditions, the heart rate is irregular because the vagal and sympathetic activity that influences the sino-atrial node is subject to phasic alterations. The heart rate accelerates on inspiration and slows on expiration. This is called physiologic sinus arrhythmia. However, during exercise, anxiety states and mental load, the sino-atrial node is released from its normal vagal inhibition and the irregularity of the instantaneous heart rate, is reduced. It is this sinus arrhythmia (due to vagal inhibition) that will be investigated in this research (and not the physiologic sinus arrhythmia associated with respiration).

In common usage, the distinction between the terms mental load and stress is not clear. Before discussing the mental load caused by a visual inspection task, the term "stress," its causes and effects will be described. This will provide a framework for analyzing the effects of mental load (caused by a visual inspection task) on the physiological variables of blood pressure and sinus arrhythmia.

Analysis of Stress--Definition, Causes, Effects

In the Oxford dictionary, one of the definitions of stress is given as follows:

"The overpowering pressure of some adverse force or influence."

However, the word "stress" is one with which the layman and professional alike are familiar. It forms a regular part of our vocabulary and has perhaps as many different implications as the people who use it. As such its meaning is clouded by multiple usages and referents. It is a word which connotes a complex and exciting area of problems in many diverse fields. In spite of the universal use of this word, there is very little coherence in the theory and agreed-upon conventions concerning terminology. The very definitions of the subject matter of stress are contradictory. In the absence of a uniform definition of the word "stress," it becomes imperative that it be adequately described with precise terms in relation to the purpose for which it is employed.

It seems convenient to use the word stress as a generic term for the whole area of problems that include the stimuli producing stress reactions, the reactions themselves, and the intervening processes. Thus, the field of stress will encompass psychological, physiological and sociological phenomena and their respective concepts. Stress, in this context, is a collective term for an area of study. It defines a large, complex, amorphous, interdisciplinary area of interest and study. A few of the different types of stress would be sociological, psychological and physiological. These types refer to the effects of stress--regardless of the initial source of the reaction.

Definitions of Stress

Any kind of physiologic activity (locomotion, respiration, etc.) produces some stress in the organism. Thus complete freedom from stress never occurs in living beings, and hence stress is not necessarily a pathologic phenomenon.

For purposes of scientific analysis or evaluation, stress is considered as a reaction by a living creature to hostile conditions in its immediate environment [Levi, 1967:48]. The word environment, in the context of this definition, is used to include both internal physiological and psychological factors as well as the commonly understood external factors.[1]

Neither the literal meaning of the word stress, nor the scientific definition described above, are adequate to encompass the very extensive areas included in the field of stress research. Stress research as a distinct field of inquiry has had an independent existence for only twenty years, and much work in other fields, such as physiology of emotion, fatigue, lie-detection, anger, frustration and fear, is closely associated with stress research.

Selye was among the first to assemble a unified catalog of the neuroendocrine consequences of physical and perceptual overload, reactions to demanding but anomalous stimuli and the homeostatic processes that accompany somatic diseases. According to Selye [Selye, 1950:67],

> . . . stress is the common denominator in the organism's response to a variety of influences such as nervous stimuli, trauma, intoxicants, etc., . . .

This stereotyped response to external influences (trauma, intoxicants, etc.) includes the secretion of certain hormones as adrenocorticotrophic hormone (ACTH), corticostreoids, epinepherine and norepinepherine.

Selye describes [Selye, 1950:67] the process of reaction to these influences as a triphasic reaction to external or internal factors. The somatic processes induced by these stress producing influences are

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[1]Some examples are heat, noise, vibration and adverse lighting.

referred to collectively as the "general adaptation syndrome" [Selye, 1950:67], abbreviated as GAS.

The term GAS includes three stages of an organism's response to stressors.[1]

The initial and swiftest reaction against stressors is initiated by the parasympathetic and the sympathetic parts of the autonomic nervous system. These attempt to adjust the various somatic processes to meet the stressors. This is the first phase of the organism's response to stressors and is defined by Selye [Selye, 1950:67] as the "alarm reaction" which can occur locally or in a general response by the entire organism. This phase of the response to a stressor exhibits features of obvious survival value and relevance to the immediate stressor. The local adaptation syndrome involves short-term homeostatic regulation of the immediate physiological consequences of any physical changes, while the alarm reaction may include mechanisms such as increased heart rate, adrenal flow and pilomotor responses.

The second stage (called stage of resistence) of reaction to stressors may include an increased production of epinepherine by the adrenal glands, stimulated via the sympathetic nervous system. This incresed production of epinepherine couples with impulses from the hypothalamus, brings the pituitary and its hormones into the battle against stressors. These hormones, in turn, influence other glands and thereby regulate the somatic defenses and adaptation. The most important hormone is the ACTH of the pituitary.

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[1]Selye defines [Selye, 1950:67] stressors as the external or internal stimuli which cause stress in the organism.

If the stressor persists beyond the second stage, the body's defenses give way and the adjustment to changes resulting from the stressor is also lost. This is referred to as the "stage of exhaustion" [Selye, 1950:67]. The stressors again inflict the same damage on the organism as during the phase of "alarm reaction." Somatic defenses are no longer able to sustain the process of adjustment. In this stage, the completely overloaded neuroendocrine systems are not capable of responding to new environmental conditions at all.

The triphasic reaction described above has been widely accepted as the basic response mechanism to noxious stressors.

The psychological process that intervenes between the stress stimulus (stressor) and response, as well as between stimulus and response conditions, may be called "threat" [Lazarus, 1966:46]. Threat may be considered as an intervening variable in this phenomenon.

The process activated to mitigate or eliminate threat is termed as the "coping process" [Lazarus, 1966:46]. This coping process is the general term for activity that intervenes between threat and the observed reaction.

At present, any working definition of stress [Lazarus, 1966:46] must identify the external and internal forces or stimulus conditions of stress reactions and the intervening structures and processes that determine when and in what form the stress reactions will occur. According to Lazarus [Lazarus, 1966:46], the three central issues in a study of this phenomenon (referred to as stress) are as follows:

1. What are the conditions and processes that determine when stress reactions will be produced and when they will not?

2. What happens when a stimulus is reacted to as stressful?
3. What are the patterns of reaction that define the presence of stress?

Applying the above three criteria to this research, the investigation can be divided into three parts as follows:

1. Conditions and processes which will cause stress reactions to be produced by performance of a visual inspection task
2. Response of the physiological variables (blood pressure and sinus arrhythmia) to a visual inspection task.
3. Patterns of reactions (of blood pressure and sinus arrhythmia) which will determine the presence of stress.

In the remaining discussion, the word stress will be used to define an organism's response to external or internal stressors.

Causes of Stress

Stress can be induced by a variety of situations or factors. It has often been observed that a set of circumstances or factors, inducing stress at a certain time, may not be stress producing at another time or in another person. It was stated earlier that stress is caused by external or internal factors which appear hostile to a living being. These factors may be classified into three distinct classes, a) environmental stressors, b) psychological stressors and c) physical stressors.

The environmental stress factors are those mechanical and physiological conditions which affect the biological functions. A detailed description of this can be found in Berkhout's paper [Berkhout, 1969:7]. The salient points of his paper will be reviewed in this section. Human performance is degraded if certain limits are exceeded (as discussed below).

The environmental stress factors include the following:[1]

1. Kinetic stressors--linear and angular accelerations, Coriolis conditions and sustained high gravity and zero gravity fields
2. Vibration and acoustic noise--destructive vibration and vibration-induced anxiety
3. Thermal stressors--heat and cold
4. Variations of atmospheric pressure and composition--aerospace conditions and submarine conditions
5. Chemical stressors--airborne chemicals and ingested chemicals
6. Radiation stressors--ionizing radiation, ultraviolet, infrared and radio waves and visible light
7. Magnetic fields
8. Deprivation of sustenance
9. Physical work overload

Psychological factors affect physiological and perceptual processes. These factors are distinct from environmental factors in that they do not operate on specific sensory or physiological systems in a known way. They often seem to depend on the individual for their stressful effect. The psychological factors which are most often encountered in analyzing the performance of man-machine systems are as follows:

1. Monotony
2. Job and task anomalies

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[1]Abridged from K. B. DeGreene's handbook [DeGreene, 1970:16].

3. Disruptions of circadian periodicity
4. Genuine danger

For mental load, the impulses are transmitted from the cerebral cortex to the hypothalamus. The hypothalamus regulates the autonomic nervous system and the pituitary. The increased production of epinepherine, as a result of the increased sympathetic stimulation, also activates the pituitary. This produces an adjustment of the body's processes.

Basically, all hostile or noxious stressors have two factors in common. One is frustration, in which the external situation prevents or makes it difficult to achieve the goal towards which an ongoing activity is directed. The second factor is trauma, in which the situation provides stimuli which are intense enough to disrupt the performance of ongoing activities. These stimuli can be classified as shown below:

1. Disruption of physiological homeostasis
2. Physically painful or unpleasant stimuli
3. Real, contrived or anticipatory failures
4. Distractions, razzing and time pressures and constraints
5. Social conflict and related pressures or procedures

None of the above classifications are mutually exclusive.

Effects of Stress

Various indices of measurement of responses to stress have been employed. These measurements have been physiological as well as psychological. For purposes of classification, these measurements can be grouped into four classes.

1. Reports of disturbed effects--anger, anxiety, depression, guilt and fear

2. Motor behavioral reactions--tremor, increased muscle tension, speech disturbances and facial expressions
3. Changes in adequacy of cognitive functioning--perception, thought, judgment, problem-solving, perceptual and motor skills and social adaptation.
4. Physiological change (the most widely used measure of stress indexing)--which includes the reactions of both the autonomic nervous system and of the adrenal glands which secrete various hormones under stress. The reactions of the autonomic nervous system are those which are reflected in the end-organ activity of the heart, e.g., respiratory organs and sweat glands. Some typical measures pertaining to the autonomic nervous system are, galvanic skin response (GSR), systolic and diastolic blood pressure, heart rate, respiration rate and amplitude, skin temperature, blood volume, change in pupillary size and saliva output.

The measurement of one or more of the autonomic nervous system indications depends upon the stressors employed to create the stressful situation. Thus, it cannot be stated that a given measure is more meaningful than another. The choice of an appropriate measure of the autonomic nervous system indicator, for stress measurement, will depend upon the nature of the stressor. However, for perceptual tasks, there are preferred measures of responses to stress from the point of view of selecting the best indication of the presence of psychological and physiological stressors. Horvath's review [Horvath, 1959:32] as shown in Table 1-1, describes an extensive work, covering a wide range of functional abilities,

TABLE 1-1.—Several stress indicators and conditions for which they have proven effective quantifiers of human responses

Stress Indicator Variables	Appropriate Stress Conditions	Correlated Predictors
Reaction time	Chemical stresses, drugs	Scaled anxiety
Vigilance	Overlong task duration	Personality factors
Visual flicker-fusion-frequency	Food deprivation; combat fatigue; genuine danger	None reported
Perception of ambiguous figures, distorted forms	Verbal harassment; false accusations; intense noise	None reported
Hand steadiness	Distracting sounds; bizarre sights	Social adjustment
Motor matching	Intense noise	None reported
Pursuit tracking	Extreme temperatures; sleep deprivation	Cold pressor response
Speed tapping	Anoxia; muscle fatigue	None reported
Problem solving; coding tests; word association	Random punishment; false criticism	Personality factors; scaled anxiety

including perceptual tasks such as flicker-fusion frequency, perceptual rigidity, resolution of ambiguous figures and several other measures of a subject's ability to resolve distorted, contradictory or reversible forms. Horvath's review is an outstanding survey of the types of abilities for which indirect stress measures are available.

The direct measures of stress reactions are those in which the primary neuroendocrine system[1] and other biological functions are monitored and their values expressed as a function of time or external stimulus conditions. Direct measurement of stress reactions typically involves three interrelated systems, a) circulatory, b) endocrine and c) neural. These three systems constitute the primary homeostatic mechanisms in stress reactions.

Circulatory parameters include heart rate, blood pressure, pulse volume, local skin temperature and vascular constriction.

Endocrine activity may be studied by analyzing biochemical constituents of the blood and urine, the chemical activity of the gastrointestinal tract in vivo and by measuring the physical volume of certain glands in vitro.

The neural activity may be evaluated by measuring those phenomena under direct nervous control, such as skin resistence, skin potential charges, pupillary contraction and the electroencephalogram.[2]

It is virtually impossible to relate any given stressor to a specific index of autonomic activity because individual response is specific

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[1]Primary neuroendocrine system includes endocrine glands such as pituitary, thyroid, pancreas and gastrointestinal mucosa.

[2]Measures the bioelectric potentials generated directly by the nervous system itself.

in certain portions of the autonomic nervous system. Studies have shown that [Notterman, 1959:60] an identical stressor produced an increase in blood pressure for one subject while another subject responded by a decrease in blood pressure. The same phenomenon has been observed with measures such as skin conductance and heart rate.

However, some measures of autonomic activity have found a general acceptance as reliable measures of certain specific stimuli, subject to variability between individuals. These are as follows:

Response to stressors[1]	Preferred Measure of autonomic nervous system's activity
Alertness or excitement	Blocks alpha rhythms in EEG[2]
Emotional state	Change in pupillary size[3]
Anxiety	Palmar sweating[4]
Unpleasant Experiences	GSR (electrical conductivity of the skin), blood pressure and heart rate[5]

Purpose and Scope of Investigation

The primary purpose of this research, as indicated in the preceding discussion, is to study the effect of mental load on blood pressure and sinus arrhythmia. As is often the case with many research problems, there were secondary purposes which grew out of the overall research plan.

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[1] These are not mutually exclusive.

[2] [Welford, 1960:74]

[3] [Lader, 1967:45]

[4] [Levi, 1961:49]

[5] [Speisman, 1961:69]

The following specific purposes were set forth for this research.

1. To determine the effect of inspection of alphabetic, numeric and geometric characters, types of errors,[1] total number of errors and length of inspection task on the physiological measures of blood pressure and sinus arrhythmia for a visual inspection task.
2. To determine the effect of inspection of alphabetic, numeric and geometric characters, types of errors, total number of errors and length of inspection task on the physiological measures of blood pressure and sinus arrhythmia for a simultaneous visual inspection task and an auditory task.

Review of Previous Research

It was stated in the early part of this chapter that stress may be caused by many different factors that result in physiological responses. The concept of the psychological stressor and human reaction to it first came into prominence towards the end of World War I. The effects on some individuals of the experiences of trench warfare opened the eyes of medical men and psychologists to the fact that behind perception and learning, human beings possess emotions, motives, urges and impulses which demand attention from researchers in the area of human biology.

It is only in recent years that psychologists have begun to investigate the possibility of measurement of mental load in a similar manner that physiologists have studied physical work load. Very elaborate and detailed experiments have been conducted by psychologists in studying

[1]The character(s) to be identified in the visual task is (are) called error(s).

human behavior and measuring mental capacity. In all these studies, degradation of performance, or a similar subjective scaling index, was used as a measure of reaction to stress.

On the other hand, physiological variables such as blood pressure, skin conductance, heart rate, etc. have been investigated while conducting experiments related to psychological stressors [Wenger, 1962:76]. In all these studies, response to stress was by anger, anxiety, threat and similar emotional responses.

Stress and Blood Pressure

There have been numerous observations [Goldberg, 1966:24] linking a change in blood pressure level to a change in emotional status.

Mefferd and Wieland [Wieland, 1966:77] conducted an experiment in which stress was produced by exposing subjects to reduced barometric pressure, equivalent to that of 15,000 feet altitude. They observed a marked change in systolic as well as diastolic blood pressure.

Kollar, Slater, Palmer, Docter and Mandell studied the effects produced by sleep deprivation [Kollar, et al., 1966:42]. Subjects went without sleep for 120 hours, at the end of which they performed perceptual and pattern recognition tasks. Subjective scales of indices (Rorschach and Holtzman Inkblot test, Minnesota Multiphase Personality Inventory and Clyde Mood Scale) were used to evaluate psychological reactions. However, no significant change was noted in blood pressure levels (systolic as well as diastolic).

Wittkower [Wittkower, 1970:79] has made a very detailed survey of case histories in the field of Psychosomatic Medicine. He noted a close relationship between change in blood pressure and emotional status of human beings. He observed that in persons with normal blood pressure levels,[1] a change in emotional status produces a change, mainly in systolic blood pressure. In the course of combined medical and psychiatric clinical studies, he found repeated instances where the level of blood pressure was higher at times of tension or life adjustments (in the social environment) and lower during periods of relaxation. Wittkower attributes this change in blood pressure to vascular mechanism reaction patterns. These vascular reactions are often evoked [Wittkower, 1970:79] in association with psychologic stress in subjects with normal blood pressure.

Nodine and Moyer [Nodine, 1968:59] have also noted the effect of psychodynamic factors on the regulation of blood pressure. They surmised that psychological stressors act as a cofactor, in conjunction with the vascular mechanism, in influencing the level of blood pressure. On the strength of various psychosomatic medicine clinical studies, they too discovered adequate evidence to indicate that emotional stimuli "can and do cause changes in blood pressure and other physiological and biochemical functions of the body." They noted that even relatively mild mental activity, in the form of mental arithmetic, may induce rather marked changes in various physiological and biological parameters.

As early as 1927, [Goldberg, 1966:24] it was reported that blood pressure was raised in subjects with anxiety states caused by fear. Goldberg also stated that this rise in blood pressure was labile. Brod et al., [Brod, 1959:11] showed that the blood pressure did return to a

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[1]110/70 mmHg at 20 years of age to 140/90 mmHg at sixty-five years of age [King, 1969:41].

pre-stimulus level in subjects with normal blood pressure. Malamo and Shagass [Malamo, 1951:51] conducted a study in 1951 to note the change in blood pressure as a result of a series of stressor tests. They reported that in normal subjects, blood pressure levels are a very reliable measure of psychological as well as physiological stress.

Stress and Sinus Arrhythmia

The heart rate of a normal healthy subject at rest is irregular. Heart rate patterns during rest can show a momentary irregularity up to 10 or 15 beats per minute, generally referred to as sinus and respiratory arrhythmia.

Recent investigations (since 1963) have shown that mental load, such as that implied in the performance of a simple binary choice task (in which muscular work was virtually nil), can diminish sinus arrhythmia.

In 1963, Kalsbeek [Kalsbeek, 1963:38] published a paper linking diminished irregularity of heart rate (sinus arrhythmia) to mental load. He suggested that mental load resulted in a suppression of sinus arrhythmia and the extent of this suppression might be used as a measure of the mental load.

In 1965, Koster [Koster, 1965:43] analyzed the feasibility of measuring perceptual loads. One of the methods he studied was that relating sinus arrhythmia to perceptual loads. He observed that a subject at rest shows a pronounced irregularity in his heart rate. If he executes a perceptual task, this irregularity decreases, but the mean heart rate remains approximately constant. This decrease can be treated as a measure of the work load. But he concluded that the method is based on empirical findings. Contrary to physiological load, neither the mechanism nor the factors that affect the mechanism are known. In a very sweeping conclusion (in 1964), he states, "As long as we have only a vague notion of perception and even less of perceptual load, the answer to the measurement of perceptual load is not yet available."

In another paper, Kalsbeek [Kalsbeek, 1967:39] noted that increasing perceptual load (by increasing the number of binary choices per minute) diminishes the irregularity of the rest pattern but without affecting the level of heart rate. The subject's blood pressure showed a slight increase--possibly due to the physical effort required in performing the experimental task. He suggested that the next step towards application in industry will only be possible with the help of work study experts, systematically studying which aspects of an industrial task are affecting the irregularity of the heart rate pattern. He, however, was of the opinion that acceptable work load based on the scored suppression of sinus arrhythmia is not yet conclusive.

Kevin Cahill [Cahill, 1969:12] studied the suppression of heart rate irregularity and mental load. He performed experiments in which the subject performed arithmetic additions under time constraints. He obtained a definite relationship between the heart rate variability and mental load caused by performing (mentally) arithmetic addition problems. But he could not distinguish between effects of tested stress levels. He was of the opinion that a longer test period and a wider differential in mental load levels might lead to a difference in sinus arrhythmia scores.

This chapter has been written to explain the purpose of this research and to review previous research which is pertinent to this investigation.

The equipment and measurements used for this investigation are described in Chapter II. Chapter III is a description of the experimental design and procedure. Results and their interpretations are presented in Chapter IV. Chapter V is devoted to the presentation of conclusions of the study and recommendations for further research.

CHAPTER II

EQUIPMENT AND MEASUREMENTS

A visual inspection task and an auxiliary auditory task were investigated in this research. The visual inspection task consisted of identifying alphabetic, numeric and geometric errors. Photographic slides were prepared from matrices (5x5 and 7x7) whose elements were alphabetic, numeric and geometric characters. Forty slides were inspected during a single trial of the visual task.

In the performance of the auditory task, the subjects responded to tones (220 cycles and 1000 cycles) from a sound track. The two tones were pre-recorded on magnetic recording tape. The sequence of the two tones was randomized. Upon hearing the tones, the subjects operated an associated push button.

During the performance of the experimental task, continuous measurements were made of the instantaneous heart rate of the subjects. Blood pressure was also measured at intervals of one minute. By using appropriate transducers (described in the following section), both the blood pressure and the instantaneous heart rate were recorded on a four channel recorder.

The equipment used for the performance of the experimental task and recording the physiological variables (blood pressure and instantaneous heart rate) is listed as follows:

1. A four channel recorder with appropriate accessories to measure and record blood pressure and instantaneous heart rate
2. A slide projector and screen
3. Slides designed to simulate a visual inspection task
4. A tape recorder
5. An electric timer

Equipment for Measuring the Dependent Variables

Recording of the Physiological Variables

A recorder, Model PMP-4A manufactured by Narco Bio-Systems, Inc. was used to record blood pressure, instantaneous heart rate and the subject's response to auditory signals.

The main frame of the recorder consisted of a basic housing for the four recording channels, spaces for accessory plug-in modules and provided electrical power distribution, control and monitoring circuitry.

By utilizing an appropriate transducer and amplifier in the form of a plug-in unit, a physiological variable can be measured as an electric potential, and thus proportional to the physiological variable. The transducers used to measure blood pressure and instantaneous heart rate are described in the following sections.

In addition to the four recording channels, there was a time and event channel. The time and event pen deflected in the negative direction for recording of time signals by means of electric pulses. The time and event pen deflected in the positive direction when actuated by the panel-mounted "event-marker" switch or an external marker switch. By a

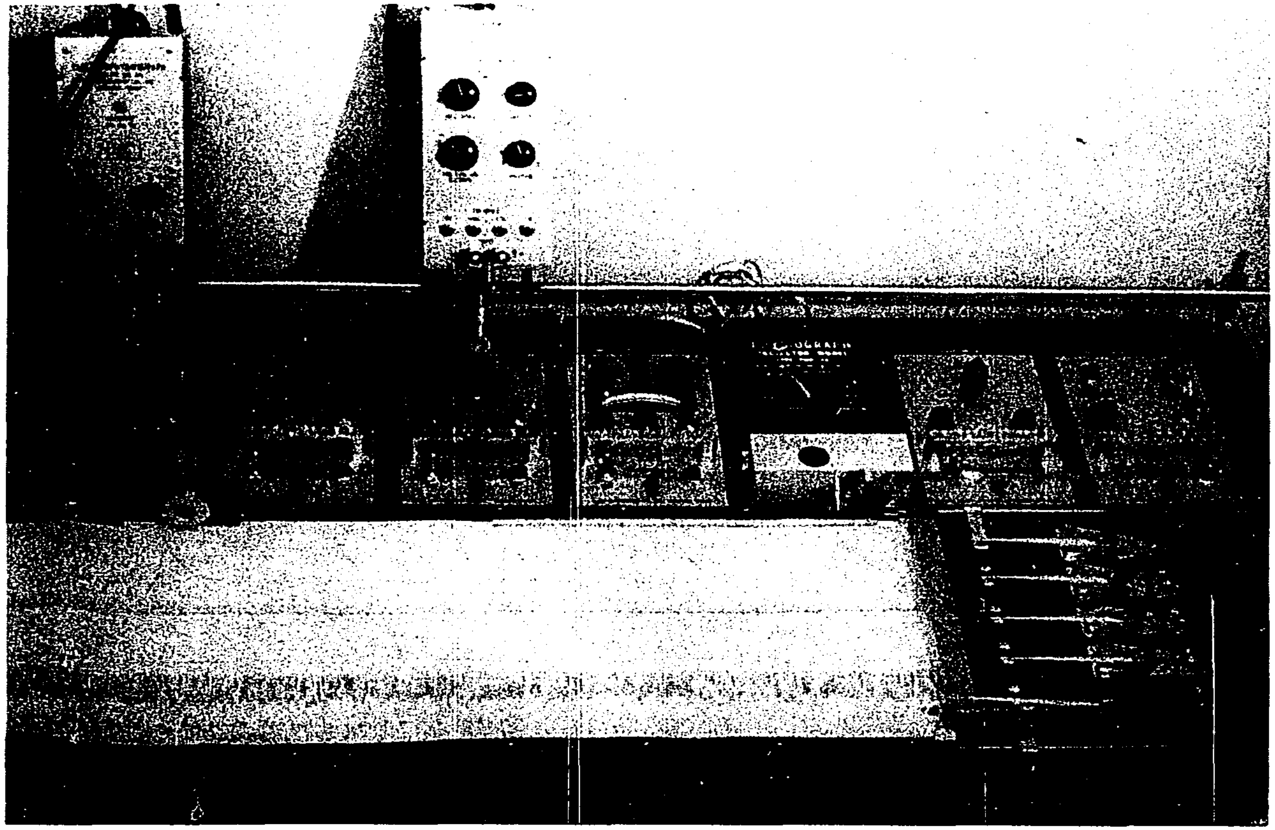

Fig. B-1.--Four channel recorder (and accessories) of physiological variables

Fig. B-2.—View of a subject and the recorder of physiological variables

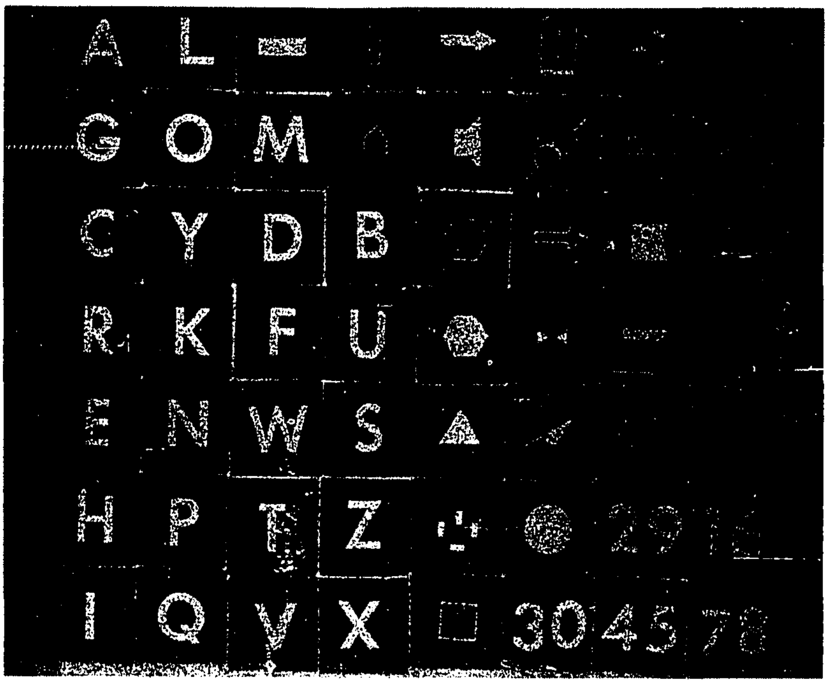

Fig. B-3.—Alphabetic, Geometric and representative Numeric elements used for inspection task

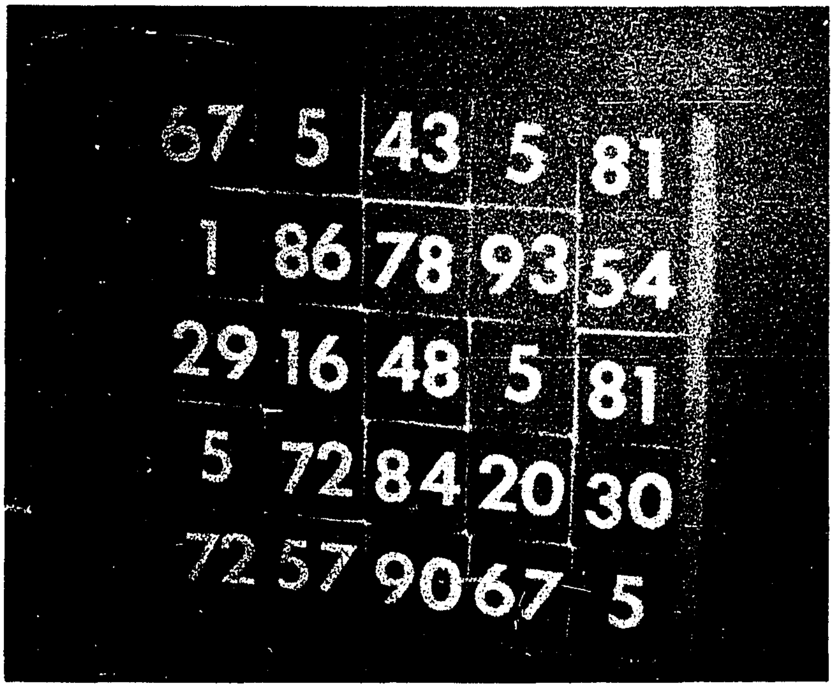

Fig. B-4.--Typical 5x5 size slide of numerical elements

Fig. B-5.--Typical 7x7 size slide of numerical elements suitable change in the electric circuit of this "event-marker," the pen can be deflected in either direction (positive or negative) by means of electric pulses from externally operated switches.

Recording of Blood Pressure

A wrap-around cuff of 12 cms. width, which had a built-in microphone, was used. The microphone was located on the distal edge of the cuff and was placed over the brachial artery. The microphone was used to detect the Korotkoff sounds for identifying both systolic and diastolic blood pressures. The plug from the cuff was connected to the microphone input jack on the electrosphygmograph. The cuff was wrapped around the left arm of the subject.

The electrosphygmograph was used for recording systolic and diastolic blood pressures. The electrosphygmograph is a combination transducer/preamplifier for recording blood pressure. It combines a pressure transducer and a preamplifier to produce single channel recordings of occluding cuff pressure and superimposed Korotkoff sounds. The wrap-around cuff was connected to an automatic cycling cuff pump for automatic blood pressure measurements. The electrosphygmograph had separate input connections and sensitivity controls for pressure and sound measurements. A 100 mmHg internal calibration was provided, in the electrosphygmograph, for calibrating blood pressure recordings.

The automatic cycling cuff pump was an accessory plug-in module and was installed in the accessory compartment of the recorder. It was designed to operate in conjunction with the electrosphygmograph. It could be set for repeated cycles of one-half minute, one minute or two minute intervals for the continuous monitoring of blood pressure. It had pressure-sensitive cut-off switches for limiting the upper pressure of cuff inflation, and for preventing reinflation of a cuff until the cuff pressure had dropped below 20 mmHg. These enabled maintenance of proper circulation in the arm.

Recording of Instantaneous Heart Rate

A preamplifier and an accessory plug-in module were used to record the instantaneous heart rate. The preamplifier was a high-gain, differential, capacitor coupled unit with sufficient voltage gain and frequency selectivity to record all ranges of bioelectric potentials. The preamplifier was designed to accept EKG inputs.

The accessory plug-in module used was the cardiotach, and was installed in the amplifier compartment of the recorder. The cardiotach is capable of graphically displaying beat-to-beat intervals (instantaneous rate) or average intervals from 20 to over 600 beats per minute.

The cardiotach was used in conjunction with an electrocardiograph channel on the recorder to graphically present the time intervals between consecutive heart beats (instantaneous heart rate). The cardiotach was triggered from the monitor jack on the EKG channel output of the preamplifier. The input trigger circuit was tuned to operate most efficiently from the frequency components present in the R-wave of the electrocardiogram--thus eliminating false triggering by other components of the EKG waveform. The cardiotach recorded beat-to-beat (R-R) time intervals on a linear time scale. The interval calibrator provided timing pulses every .02 minute corresponding to the rate of 50 beats per minute.

Equipment Necessary for Defining and Maintaining Independent Variables of the Experimental Task

Slide Projector

The slide projector used was Model Number 850, manufactured by Eastman Kodak Company. The slide projector was equipped with an "automatic focus" device. Thus it was necessary to focus only the first slide and remaining slides would be focused automatically. An electronic timing circuit was used to project each slide for a fixed time period (eight seconds or twelve seconds, depending on length of task). Prior to each session, the performance of the electronic timing circuit was verified by comparison with an electric timer.

Slides for Visual Inspection Task

Figure B-3 shows all the alphabetic and geometric characters used for preparing the different slides used for the visual inspection task. Figure B-3 shows the form of the digits zero through nine. A complete list of all numbers used for the numerical inspection task is shown in Appendix A.

Figure B-4 is an illustration of a typical, numerical slide for the shorter (eight seconds per slide) visual task.

Figure B-5 is a picture of a typical, numerical slide for the longer (twelve seconds per slide) visual task. Approximately 450 slides (150 each for alphabetic, numeric and geometric) were prepared for this research.

Audio Signals

Two distinct audio signals (220 cycles and 1000 cycles frequency) were recorded in random sequence on magnetic tapes. Each audio signal had a time duration of one second. The time interval, between any two successive signals, varied from two seconds to six seconds, selected at random. Eighty auditory signals were used for the shorter length task duration, while 120 auditory signals were used for the longer length task--an average of 15 auditory signals per minute for each task.

The "time and event-marker" recording channel on the recorder was used to record the response of subjects to auditory signals. The recording pen for this channel was deflected in the positive direction for the correct response to the 1000 cycles frequency signal, and was deflected in the negative direction for the correct response to the other (220 cycles frequency) signal. These deflections were caused by the operation of two push buttons in the hands of the subject, which provided the necessary electric pulses for the deflections of the "event-marker" pen.

Measurement of Blood Pressure

Blood pressure can be measured by direct or indirect methods. Direct measurement of blood pressure can be made by inserting a cannula into an artery and connecting it with a strain gauge manometer and recorder. This method of measuring blood pressure is called direct arterial cannulation. The direct method of measuring blood pressure is limited to experimental animals since it involves a certain amount of operative procedure.

For practical reasons, three indirect methods of measuring blood pressure have been developed. These are:

1. The palpatory method
2. The oscillatory method
3. The auscultatory method

All the three methods employ the inflatable armband and some form of pressure indicating device. This assembly is called sphygmomanometer.

The palpatory method depends upon the ability to detect the appearance of a feeble peripheral pulse as the pressure in the occluding cuff is decreased. The technique used is to palpate the radial artery or to employ a peripheral pulse detector.

The oscillatory method employs as its criteria the size of the pulsations imparted by the artery under it. When the cuff pressure is above systolic, the oscillations in pressure are minimal. As the pressure is reduced, the oscillations become larger. The pressure at which this occurs is said to be systolic blood pressure. As the cuff pressure is lowered further, the oscillations become larger and then smaller. The pressure at which the oscillations diminish rapidly is taken as an index of diastolic blood pressure. However, because the transitional points are unclear and variable, the oscillatory method does not provide an accurate measurement of blood pressure [Hoff, 1967:31] and is seldom used today.

The auscultatory method also uses a pressure cuff, but depends upon an entirely different principle than that which underlies the oscillatory and palpatory methods. The criterion for establishing systolic and diastolic pressures is the appearance and disappearance of the Korotkoff sounds. In addition to the pressure cuff, a stethescope or sound pick-up is required to detect the Korotkoff sounds.

The procedure for measuring blood pressure, by the auscultatory method, consists of inflating an arm cuff to a pressure much in excess of suspected systolic pressure. The bell of a stethescope (or a microphone), for detection of Korotkoff sounds, is placed over the brachial artery at the level of the elbow distal to the cuff. The pressure in the cuff is then slowly reduced. As it passes systolic pressure, blood spurts through the brachial artery causing turbulent flow with a sudden expansion and collapse of the arterial wall with each beat. These two factors, along with others, combine to produce sharp tapping sounds which are known as the Korotkoff sounds. When the cuff pressure is near diastolic, the arterial flow is less turbulent and the sounds become muffled and faint. When the cuff pressure is reduced further, the sounds disappear entirely. The pressure at the disappearance of these sounds is taken as diastolic pressure.

Of the three methods described above, the auscultatory method is the most commonly used today. It has been accepted [King, 1969:41] as the indirect method which is most in agreement with direct cannulation measurements.

For this reason, the auscultatory method of measuring blood pressure was used in this experiment.

Measurement of Instantaneous Heart Rate

In Chapter I, the use of sinus arrhythmia in the measurement of mental load was discussed in detail. It was shown that sinus arrhythmia is a reasonable measure for evaluating mental loads in tasks involving little physical activity. Investigators have suggested that sinus arrhythmia is an excellent measure for evaluating mental and perceptual loads.

The normal heart rhythm is not regular. The irregularity of the heart rhythm is called sinus arrhythmia. This arrhythmia is present in the activity of the pace-maker of the heart, the sino-atrial node and is caused by influences from outside the heart. Sinus arrhythmia is suppressed, in combination with an increase of heart frequency during physical load, but not with an increase of heart frequency during mental load [Kalsbeek, 1965:37].

In this experiment, no physical work was required, other than the use of push buttons for response to the audio signals. Thus no change in heart rate was expected. The suppression of irregularity in the heart rhythm, i.e., decrease in sinus arrhythmia, was then due principally to the mental load of the task performed. Thus, it was necessary that the computation of sinus arrhythmia be totally independent of the average heart rate.

Ettema [Kalsbeek, 1964:36] describes four methods of calculating sinus arrhythmia. The four methods are:

1. The "crossing" method
2. The curvimetric method
3. Absolute differences between successive heart beats, measured in terms of the heart rate
4. "Tolerance limits" method

All the four methods described above introduce errors in the calculation of sinus arrhythmia because they use modulus differences between successive heart beats expressed in beats per minute.

Kalsbeek [Kalsbeek, 1967:39] describes a way of calculating sinus arrhythmia in which the effect of heart frequency is absent. Essentially, this method is based on calculating the standard deviation from the instantaneous heart rate. A sample calculation of sinus arrhythmia is carried out as follows.

A continuous interval of 60 heart beats is chosen at the beginning of the experimental task. This is divided into 10 groups of six successive heart beats. In each group of six successive heart beats, the difference between the highest and the lowest values is measured in miliseconds. (This difference R is called the "range" in statistics.) For the ten groups, ten values of range will be obtained. An average value of range is obtained and the standard deviation is computed by multiplication of this average value of range and an appropriate constant, obtained from statistical tables [Neville, 1968:58].

For small samples (15 or less) use of the range is an efficient way to compute the standard deviation. Neville and Kennedy [Neville, 1968:58] state that range is an efficient statistic when dealing with small samples. They state, ". . . a standard deviation estimate obtained from average range R is more accurate when the samples are many and small, rather than few and large."

The use of average range in calculating standard deviation is based on the assumption that the sample data has a normal distribution. This assumption was checked, and found to be valid by plotting samples of data (random samples of instantaneous heart rate) on normal-probability paper. [An additional check was made by calculating the standard deviation of twenty random samples by a) using average range and b) using a statistical method of computing the square root of the arithmetic mean of the squares of the deviations of each value from the arithmetic mean. Values of standard deviations obtained from both the above methods were very nearly the same.] Thus it was decided to use average range in calculating the standard deviation of the instantaneous heart rate.

In this experiment, 10 samples of size 6 were used to calculate the mean range and (from it) the standard deviation.

The equipment and measurements described in this chapter were utilized in the experimental protocol which is discussed in the following chapter.

CHAPTER III

EXPERIMENTAL DESIGN

This chapter is a discussion of the variables, subjects, experimental design and experimental routine employed in this investigation.

Experimental Task

In this study, the experimental tasks used (to create mental load), consisted of a) a visual inspection task and b) an auditory signal response task.

The visual inspection task comprised the identification of a) alphameric errors, b) numeric errors and c) geometric errors. In each of these three categories, subjects were required to identify one, three or five errors.[1] Two fixed levels were used for total number of errors in the visual inspection task a) 64 errors and b) 136 errors.

Two visual inspection tasks were used. In the first, errors were to be identified in the elements of a 5x5 matrix. Each matrix was inspected for eight seconds. In the second visual task, errors were to be identified from the elements of a 7x7 matrix. Each matrix was inspected for twelve seconds. A total of 40 matrices were inspected in each of the two visual tasks. The subjects verbalized the number of errors detected in each matrix.

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[1] Referred to as "types of errors." See Appendix C

The auditory signals response task consisted of the pressing of appropriate push buttons in response to auditory signals. Two different auditory signals were presented in a random sequence and the subjects responded by operating one of the two push buttons,[1] corresponding to the auditory signal presented.

Discussion of the Variables

The dependent variables measured were instantaneous heart rate, systolic blood pressure and diastolic blood pressure. Instantaneous heart rate was used to calculate sinus arrhythmia.

The independent variables used were subject, length of task, kind of visual task, types of errors, type of task and total number of errors.

Subjects

Four male students, three undergraduates and one graduate (all between ages 20 and 23), served as subjects during this experiment. Each subject was paid for time spent on this research at the appropriate student assistant rate.

The four subjects were chosen from approximately eleven candidates, using the following criteria:

1. Normal vision--20/20 without corrective lenses
2. Availability to follow the experimental schedule

Each candidate received an explanation of the work task and the requirement regarding being in the building 15 minutes prior to an

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[1]Subjects were instructed to make only one response for each auditory signal. Rectification or correction of erroneous responses (to auditory signals) was not permitted.

experimental session. The candidates were tested for identification of geometrical errors. Four were chosen who could follow the experimental schedule. Three subjects did not smoke, while the fourth subject smoked less than four cigarettes every day. One subject (non-smoker) was an ROTC cadet and physically active, while the other three subjects did not engage in any regular physical activity or training programs.

After selection of the subjects, individual training sessions were held for all four subjects. The purpose of these training sessions was to familiarize the subjects with the equipment being used and performance of the experimental task. The experimental sessions for this research were begun two days after the completion of the training sessions.

Length of Task

Two tasks of different time durations were used. The first task consisted of inspecting the elements of a 5x5 matrix. Each matrix was exhibited for eight seconds, and forty matrices were shown for the entire task. The second task consisted of inspecting the elements of a 7x7 matrix. Each matrix was exhibited for twelve seconds, and forty matrices were shown for the entire task. The time intervals of eight seconds (first task) and twelve seconds (second task) were chosen as a result of a pilot study[1] that was conducted while the research problem was being formulated.

Kalsbeek [Kalsbeek, 1964:36] and Leopold [Leopold, 1962:66] have performed investigations relating sinus arrhythmia to visual and perceptual loads. Based on their experimental studies, they have recommended

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[1]See Appendix B for results of this pilot study

that the task duration should not be less than five minutes (due to the time-lag in the response of the heart rate), if sinus arrhythmia is used as a measure of mental load.

The duration of the first task was five minutes and twenty seconds. The duration of the second task was eight minutes. This task was 50 percent longer than the first task but consisted of almost twice (one less than twice, to be exact) as many elements as the first task. This task was chosen as a result of the following question:

> By virtually doubling the elements to be inspected while increasing the time for task performance by only 50 per cent, would the physiological measures of mental load (blood pressure and sinus arrhythmia) exhibit a corresponding change?

It was necessary to determine a quantifiable relationship between the time allowed for inspection of elements and the physiological measures of mental load, if affirmative answers to the above question were to be obtained during this research.

Kind of Visual Task

The visual task was chosen at three levels.

1. Inspection of alphabetic elements
2. Inspection of numeric elements
3. Inspection of geometric elements

In an industrial task, one is often expected to sort different items either by their numeric code, or by their alphameric code or by their shapes. Many inspection jobs involve identification of numbers, letters of the alphabet, or different shaped patterns.[1] In many automated processes, the malfunction of component elements is exhibited by previously coded numbers, alphameric characters or different shape patterns. It would be a reasonable conclusion, if one were to state that many visual inspection tasks involve some form of identification of either numbers, letters of alphabets or some geometrical shapes or configurations. Hence, it was felt that these three levels would be representative of actual inspection tasks.

Types of Errors

Three levels were chosen for this independent variable. The first level consisted of identifying only one letter of the alphabet, or one number, or one geometrical shape for any given trial.

The second level consisted of identifying from one to three different letters of the alphabet, or from one to three different numbers, or from one to three different geometrical shapes.

The third level consisted of identifying from one to five different letters of the alphabet, or from one to five different numbers, or from one to five different geometrical shapes.

The selection of one, three and five errors was based on increasing levels of stress. This would be analogus to the inspection of one, three or five types of defects in an industrial situation.

The increase in types of errors between the first and the second levels, and between the second and the third levels was selected as the

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[1]Some examples are numeric coding on cartons, alphameric/numeric classification codes on machine parts, different geometric shapes to designate various types of products or components of an assembled machine.

same (two) so that if types of errors were found to have a significant effect on the dependent variables, an appropriate statistical analysis could be made. This statistical analysis would enable the determination of the analytical relationship between the types of errors and the dependent variables.

Type of Task

Two types of task were selected. The first task consisted of only visual inspection, while the second task consisted of visual inspection and responses to auditory signals.

Stress can be produced by simultaneous loading of two or more sensory channels of a subject. This is based on the theory that a person's information processing capacity is necessarily single-channeled [Adams, 1962:2]. A simultaneous input of two or more sensory stimuli results in the "time-sharing" of the single-channel information processing capabilities of a subject. The capacity of the processing system is limited, and so the information processing mechanism cannot attend to two or more stimuli simultaneously. It is not certain as to where in the path (sensory input--response selection--response performance) of the processing this limited capacity mechanism is to be found. Some hypotheses place it on the secondary side and others on the response side [Smith, 1967:68]. But, this limited information processing capability manifests itself as increased mental load, and very often results in deteriorated performance of the task.

In industrial work situations, alarms or similar emergency conditions are often exhibited by alarm bells, sharp buzzer tones, shrill whistling noises and similar auditory signals. Hence it was decided to select a secondary auditory task while the visual task was being performed. Two auditory signals having a frequency of 220 and 1000 cycles respectively, were recorded in random sequence on a magnetic recording tape. The signals were of one second duration, and the time interval between two successive signals was also selected at random. This would correspond to an inspection alarm in an actual industrial situation.

The purpose of this secondary auditory task was to determine if a significant increase in stress can be determined as compared to the performance of a visual task alone.

Total Number of Errors

Total number of errors were selected at two levels. The first level consisted of 64 errors while the second level consisted of 136 errors, in the visual task.

Forty matrices were inspected during each visual task. The number of errors in each matrix varied from none to five. For 64 errors in the visual task, the errors were distributed[1] as follows, among individual matrices.

Number of Errors	Number of Matrices	Percentage of Matrices	Total Errors
0	16	40	0
1	8	20	8
2	4	10	8
3	4	10	12
4	4	10	16
5	4	10	20
Total	40	100	64

[1]Corresponds to inspection tasks where a majority of the inspected items are acceptable.

For 136 errors in the visual task, the number of errors per matrix varied from none to five. But, the number of matrices having none through five errors was reversed[1] from the earlier level. Thus, the errors were distributed as follows, among individual matrices.

Number of Errors	Number of Matrices	Percentage of Matrices	Total Errors
0	4	10	0
1	4	10	4
2	4	10	8
3	4	10	12
4	8	20	32
5	16	40	80
Total	40	100	136

The two levels of the total number of errors were selected to determine if two similar inspection tasks could cause a different level of stress, if the total number of errors were different.

Experimental Design

The experiment was designed to determine the effect of each of the independent variables on the dependent variables. A six factor factorial design, with two replications, was used. This experimental design is outlined in Appendix C. The model for this experimental design is as follows:

$$X_{abcdefg} = \mu + S_a + L_b + SL_{ab} + K_c + SK_{ac} + LK_{bc} + G_d + SG_{ad} + LG_{bd} + KG_{cd} + T_e + ST_{ae} + LT_{be} + KT_{ce} + GT_{de} + M_f + SM_{af} + LM_{bf} + KM_{cf} + GM_{df} + TM_{ef} + \text{(all third, fourth and fifth order interactions)} + \epsilon_{g(abcdef)}$$

[1]Corresponds to inspection tasks where a majority of the inspected items are not acceptable.

Where:

$X_{abcdefg}$ = dependent variable observed for a^{th}, b^{th}, c^{th}, d^{th}, e^{th}, f^{th}, and g^{th} levels of their respective treatments

μ = common effect for the whole experiment

S_a = effect due to subjects

a = 1, 2, 3, 4

L_b = effect due to length of task

b = 1, 2

K_c = effect due to kind of visual task

c = 1, 2, 3

G_d = effect due to types of errors

d = 1, 2, 3

T_e = effect due to type of task

e = 1, 2

M_f = effect due to total number of errors

f = 1, 2

$\epsilon_{g(abcdef)}$ = effect due to replication (random error)

g = 1, 2 for all a, b, c, d, e and f

There are a total of 576 possible combinations when all levels of the six factors and two replications are considered. Each combination is referred to as a trial. The order of each trial was randomized, using a table of random numbers.

The dependent variables used in the analysis of results were:

1. Increase in systolic blood pressure between rest and work
2. Increase in diastolic blood pressure between rest and work

3. Decrease in sinus arrhythmia between rest and work

The absolute values of the dependent variables were not used for the following reasons.

First, it is the reduction in sinus arrhythmia which is affected by mental load. In other words, the use of sinus arrhythmia as a measure of stress is based on measuring the difference in sinus arrhythmia between rest and work. This makes it necessary to use the difference between rest and work for systolic and diastolic blood pressure if they are to be compared with the reduction in sinus arrhythmia.

Second, the experimental tasks used involved virtually no physical work. Thus there was reason to believe that the dependent physiological variables (blood pressure and sinus arrhythmia) would return rapidly to the levels existing prior to the work session, at the termination of the experimental tasks. This assumption was checked and found to be valid, during the conduct of the experiment.

Third, unless the subject's blood pressure and instantaneous heart rate were within his normal values[1] no experimental tasks were performed. This is discussed in the latter part of this chapter.

Thus, it was for these reasons that the dependent variables used were a) increase in blood pressure and b) reduction in sinus arrhythmia.

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[1]Blood pressure and instantaneous heart rate (of all subjects) were measured at three different times, prior to the experiment. During these three sessions, the subjects remained seated and no reading material was provided. After the subjects were seated for ten minutes, blood pressure was measured and also every five minutes thereafter, while the instantaneous heart rate was recorded continuously. Each session was thirty minutes long. An average value for blood pressure and sinus arrhythmia was calculated for each of these three sessions. These three average values were considered as normal values for the subjects.

Experimental Routine

The selection of four subjects for this research was discussed in the earlier part of this chapter (under the discussion of variables). This selection process served as an adequate illustration (for the subjects) of the way the experimental task was to be carried out. After selection of the four subjects, an individual session was held for each subject in which a) the purpose of the experiment was explained, b) how the experiment would be conducted, c) manner of responding to auditory signals, d) schedule he would be expected to maintain during the experiment, e) to answer any questions the subject might have regarding experimental procedure and f) let the subject perform a trial session with six sample matrices.

All subjects were instructed not to appear for a session if they were tired or ill. They were also instructed not to drink coffee or any type of cola beverages, at least three hours before the experiment. They were not allowed to perform the experiment on the days when they had taken aspirin, stimulant or depressive drugs of any kind. The subject who smoked, refrained from smoking on the days of his experiments.

Upon arrival for each session, the subject was seated. The shirt was raised and the chest area, where electrodes[1] would be placed, was scrubbed with alcohol. A ground electrode was placed on the sternum. Two electrodes were placed on the left side, approximately over the fifth rib, about three inches apart. These two electrodes were used for the bipolar potential sensing of the heart beat. All the three electrodes were attached to the subject by means of two-sided adhesive washers. A

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[1]Surface electrodes, and Electrode paste, part number 96-600-85, manufactured by Narco Bio-Systems, Inc.

suitable electrolyte paste was employed to ensure proper electrical contact. The blood pressure cuff was wrapped around the arm with the microphone placed over the brachial artery.

The subject was given two push buttons (one in each hand) for his response to the audio signals when the experimental task consisted of both auditory and visual stimuli. The subject was then provided reading material of his choice from among several popular magazines. The heading of a data sheet was completed, and the rest period was started.

The slide projector was then set up and a sample matrix slide was focused on the projector screen. No further focusing was needed during the entire session as the projector was equipped with an auto-focus device. An electronic timing circuit was used to exhibit slides for the required time duration (eight seconds and twelve seconds per slide, depending on length of task). The setting of the time scale of the electronic circuit was verified with an electric timer[1] prior to the beginning of a session and at the completion of each session. It took approximately six minutes to set up the slide projector, projector screen and verify the timing of the electronic circuit.

The subject's blood pressure and instantaneous heart rate were observed on the recorder for three minutes. If these appeared to be different from his normal values (described earlier) the session was terminated at this point. If the blood pressure and instantaneous heart rate appeared to be within the subject's normal values, the reading material was laid aside and the task was begun. At the end of the task, the subject was requested to remain seated. During a five minute recovery period the

[1]Accuracy of the electric timer was 0.01 seconds.

recording of blood pressure and the instantaneous heart rate were continued.

The experiment was performed in a quiet, air-conditioned room where the temperature was maintained between 68 and 74 degrees Fahrenheit. Illumination of 75 foot candles was provided by two lamp, fluorescent fixtures of size 1x4 feet. No glare was directed at the subject from these fixtures.

All experimental sessions were held between 6:30 P.M. and 9:30 P.M. on weekdays and between 9 A.M. and 5 P.M. on Saturdays and Sundays. The trials were completed between February 10, 1970 and May 6, 1970.

In the following chapter the results and their interpretation are discussed.

CHAPTER IV

RESULTS AND INTERPRETATIONS

The main objective of this research was to determine the effect of mental load (caused by a visual inspection task), on blood pressure and sinus arrhythmia.

In this study, the experimental tasks used (to create mental load), were a) a visual inspection task and b) an auditory task. The results and their interpretations will be discussed in this chapter.

The primary statistical model used in the analysis of the data in this experiment was the analysis of variance.

The significant effects were determined by using an IBM 360/50 computer, utilizing an analysis of variance program. This program (BMDO2V) was developed at the Health Sciences Computing Facility, UCLA and was revised in May, 1968, for use on an IBM 360/50 computer.

The error term consisted of the replications factor and all interactions involving replications. The F-statistic was computed in accordance with the table for the six factor design presented in Appendix C.

Analysis of Variance

Each of the dependent variables (systolic blood pressure, diastolic blood pressure and sinus arrhythmia) will be considered in this section. A summary of the significant affects for all three variables is shown in

Table 4-1 for comparison purposes. The risk of committing a type I error was set at $\alpha = 0.05$.

In accordance with the usual format for interpretation of results obtained, the discussion would have been subdivided into three major sections, each covering the effect of a specific independent variable on the three dependent variables (systolic blood pressure, diastolic blood pressure and sinus arrhythmia). However, to follow this format would have resulted in a lack of continuity, since the effects obtained for blood pressure and sinus arrhythmia are similar, and could logically be discussed in the same context.

In the following sections, significant main effects are discussed first, followed by significant interactions. To permit the joint comparison of the effect of a particular independent variable upon blood pressure, as well as sinus arrhythmia, the means for both the dependent variables have been plotted in the Figures D-2 through D-9. Thus by comparison of responses for blood pressure and sinus arrhythmia, the possibility of using sinus arrhythmia as a measure of mental load can be evaluated. The following discussion of results has been organized to incorporate a joint discussion of blood pressure and sinus arrhythmia, noting significant relationships between these two variables.

Each subject made less than 1 percent error during the inspection of a) alphabetic elements, b) numeric elements and c) geometric elements. In responding to the two auditory signals, each subject made the correct responses to 99.5 percent of the auditory signals.

Before proceeding with the discussion of results, a) the effect of mental load on blood pressure and b) a hypothesis for reduction of sinus

TABLE 4-1.--Summary of significance of effects.

SOURCE OF VARIATION	LEVEL OF SIGNIFICANCE OF EFFECTS		
	INCREASE IN BLOOD PRESSURE		DECREASE IN SINUS ARRHYTHMIA
	SYSTOLIC	DIASTOLIC	
Subjects, S_a	.05	NS	.01
Kind of task, K_c	NS	NS	.01
Types of errors, G_d	.01	.01	NS
Total number of errors, M_f	NS	.05	NS
Length of task, L_b	NS	NS	NS
Type of task, T_e	NS	NS	NS
SG_{ad}	NS	NS	.01
LT_{be}	NS	NS	.05
LM_{bf}	.05	NS	NS
KG_{cd}	NS	NS	.05
SLK_{abc}	NS	NS	.05
SLM_{abf}	NS	NS	.01
SKG_{acd}	.01	NS	NS
SKM_{acf}	NS	NS	.01
SGT_{ade}	.05	NS	NS
LKT_{bce}	NS	NS	.05
LGT_{bde}	NS	NS	.05
KGM_{cdf}	NS	NS	.05
KTM_{cef}	NS	NS	.05
$SLGM_{abdf}$	NS	NS	.01

arrhythmia during performance of a mental load task, will be described. This will provide a background for interpreting the results obtained.

Results of the analysis of variance for the main effects and statistically significant interactions are shown in Table 4-2 (increase in systolic blood pressure), Table 4-3 (increase in diastolic blood pressure) and Table 4-4 (reduction in sinus arrhythmia).

Mental Load and Blood Pressure

As described in Chapter I, blood pressure is influenced by the following factors:

1. Cardiac output
2. Peripheral resistance to blood flow
3. Capacity of closed vascular path
4. Elasticity of blood vessels
5. Blood volume
6. Viscosity of the blood

In healthy human beings, factors three through six do not vary during mental tasks [King, 1969:41]. King and Showers [King, 1969:41] state that peripheral resistance to blood flow is influenced by impulses from the vasomotor centers in the medulla oblongata. The vasomotor centers are affected by impulses from the higher centers, so that emotional stress may cause constriction of the arterioles, resulting in an increase of blood pressure. The arterioles constitute the chief factor [King, 1969:41] in determining resistance to blood flow.

Thus it can be concluded that stimulation of the sensory nerves of the vasomotor center cause vasomotor reflexes which result in a change in the caliber of the blood vessels. This effects a change in blood

TABLE 4-2.--Analysis of variance table (partial): increase in systolic blood pressure

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	"F" Ratio	Level of Significance
Main Effects					
Subjects, S_a	3	94.73	31.58	2.851	.05
Length of task, L_b	1	0.04	0.04	0.005	NS
Kind of Visual task, K_c	2	38.52	19.26	2.149	NS
Types of errors, G_d	2	102.81	51.40	23.25	.01
Type of task, T_e	1	3.8	3.8	0.629	NS
Total number of errors, M_f	1	4.24	4.24	0.622	NS
Significant Interactions					
LM_{bf}	1	115.38	115.38	15.60	.05
SKG_{acd}	12	308.90	25.74	2.32	.01
SGT_{ade}	6	11.00	1.83	2.30	.05
Error e_n	288	3189.67	11.08		

TABLE 4-3.--Analysis of variance table (partial): increase in diastolic blood pressure

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	"F" Ratio	Level of Significance
Main Effects					
Subjects, S_a	3	3.35	1.12	0.1446	NS
Length of task, L_b	1	29.6	29.6	3.106	NS
Kind of Visual task, K_c	2	8.98	4.49	0.726	NS
Types of errors, G_d	2	90.27	45.135	16.25	.01
Type of task, T_e	1	0.16	0.16	0.048	NS
Total number of errors, M_f	1	26.52	26.52	25.87	.05
Error e_n	288	2227.39	7.73		

TABLE 4-4.—Analysis of variance table (partial): reduction in sinus arrhythmia

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	"F" Ratio	Level of Significance
Main Effects					
Subjects, S_a	3	260.20	86.73	8.343	.01
Length of task, L_b	1	0.76	0.76	0.005	NS
Kind of Visual Task, K_c	2	229.82	114.91	15.917	.01
Types of errors, G_d	2	381.6	190.8	4.09	NS
Type of task, T_e	1	114.54	114.54	6.38	NS
Total number of errors, M_f	1	16.16	16.16	0.748	NS
Significant Interactions					
SG_{ad}	6	280.00	46.67	4.49	.01
LT_{be}	1	135.51	135.51	11.565	.05
KG_{cd}	4	228.04	57.01	3.962	.05
SLK_{abc}	6	157.09	26.18	2.518	.05
SLM_{abf}	6	174.67	58.22	5.60	.01
SKM_{acf}	6	221.168	36.86	3.546	.01
LKT_{bcf}	2	82.28	41.14	5.754	.05
LGT_{bde}	2	153.45	76.73	9.130	.05
KGM_{cdf}	4	158.08	39.52	4.365	.05
KTM_{cef}	2	161.20	80.60	5.568	.05
$SLGM_{abdf}$	6	182.34	30.39	2.923	.01
Error e_n	288	2994.15	10.396		

pressure. This change in blood pressure is generally an increase if the stimulus is in the form of mental stress or excitement; if the stimulus is disagreeable or a shocking experience, it usually causes a decrease in blood pressure [King, 1969:41].

There have been numerous incidental observations to the effect that the level of blood pressure varies with emotional status. Wittkower [Wittkower, 1970:79][1] determined that the level of blood pressure is higher at times of stress and lower during periods of relaxation, whether spontaneous or induced.

Sinus Arrhythmia and Mental Load

At present, there is no known explanation for the reduction of sinus arrhythmia during performance of mental tasks. Based on physiological control of the heart and the effects of visual stimuli, a hypothesis (for reduction of sinus arrhythmia by mental load) will be proposed in the following discussion (see Figure D-1).

The heart is innervated by a) vagus nerves which belong to the parasympathetic (craniosacral) division of the autonomic nervous system and b) the accelerator nerves which are postganglionic fibers of the sympathetic (thoracolumbar) division of the autonomic nervous system. The influence of the vagus nerve is to inhibit the heart rate, while the accelerator nerves increase the heart rate. The cardiac control center (located in the reticular formation) controls the activities of both the vagus nerves and the accelerator nerves, thereby maintaining the normal heart rate. If a person is exercising, or performing physical activities,

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[1] Similar conclusions have been published by Malamo and Shagass [Malamo, 1952:50], and Heslam, Shagass, Malamo [Malamo, 1951:51].

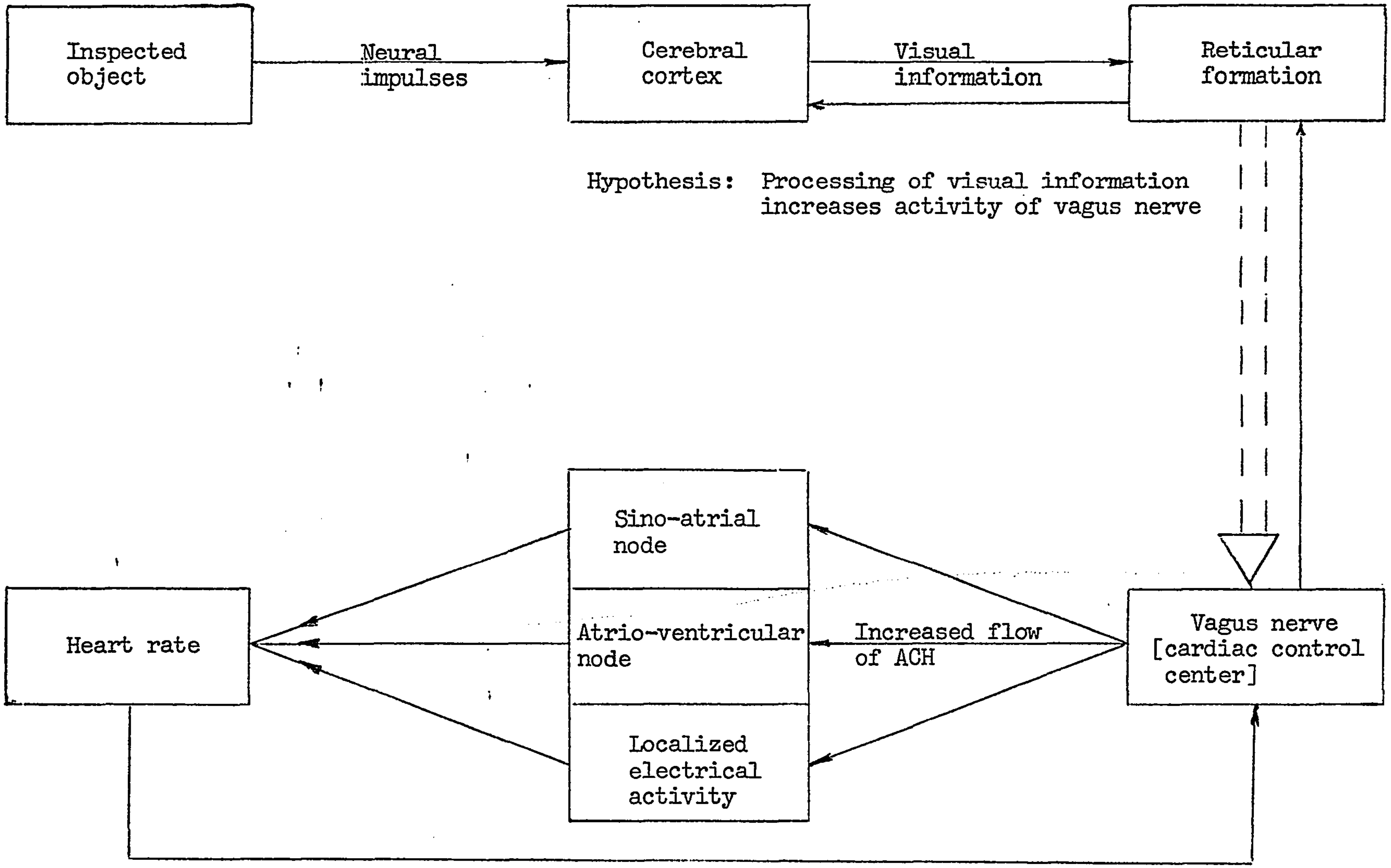

Fig. D-1.--Hypothesized heart rate control diagram the accelerator nerves cause the heart rate to increase accordingly.

The irregularity of the heart rate may be a result of; a) alterations in the rate of electrical discharge of the sino-atrial node (controlled by vagus nerves), b) interference with the conduction of the electrical impulses from the pace-maker (sino-atrial node) of the heart, c) independently functioning secondary pace-makers of the heart (e.g., atrio-ventricular node) which have a lower rhythmicity than the sino-atrial node and d) some combination of the above. [Cardiac muscle has the property of inherent rhythmicity.]

During the performance of a visual inspection task, neural impulses from the optic nerve travel to the cerebral cortex. These neural impulses are processed in the reticular formation, because the reticular formation receives stimuli from the cerebral cortex, as well as the thalamocortical projection fibers (called thalamic afferents). At this stage, the visual information is processed and evaluated and the mechanism of response (if response is required) is initiated. Thus, when the subject detects an error in the object inspected, the reticular formation processes this error and initiates the response required. Thus the mental load is caused only when the visual information is being processed and evaluated for possible responses.

If the processing of the visual information in the reticular formation increases the activity of the vagus nerve (controlled by the cardiac control center in the reticular formation), the reduction of sinus arrhythmia can be explained. The hypothesis proposed is that the mental load causes an increase in activity of the vagus nerve, as a result of processing the visual information in the reticular formation.

The vagus nerve liberates acetylcholine (ACH) at the nerve endings in the cardiac region. This acetylcholine acts on the cells of the atrial muscle fibers and the sino-atrial node. In other words, as long as the vagus nerve continues its discharge of acetylcholine, no increase in heart rate can take place.

The liberation of acetylcholine also has an influence on the atrio-ventricular node. The atrio-ventricular nodel fibers are sensitive to the action of acetylcholine and the action potential of the atrio-ventricular node is diminished. Acetylcholine also diminishes the action-potential of localized (or spontaneous) activity in the fibers of the cardiac muscle. As a result, the electrical discharges from the sino-atrial node are not interferred (or hindered) by localized activity in the cardiac region. This enables the sino-atrial node to maintain its rhythmicity of electrical discharges and thus reduce irregularity of the instantaneous heart rate.

Summarizing the above, the mental load (caused by processing of the visual information), conveying impulses to increase the activity of the vagus nerve (in the cardiac control center), causes an increase in the flow of acetylcholine. This results in the suppression of localized electrical activity (in the cardiac region) and allows the sino-atrial node to control the heart rate without electrical interference. Thus the irregularity of the heart rate is diminished, without affecting the mean heart rate.

Significant Main Effects

Subjects

The plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus subjects is shown in Figure D-2. Duncan's multiple range test [Hicks, 1964:30] was performed on the mean values for increase in systolic blood pressure and reduction in sinus arrhythmia score. There is no significant difference between a) subjects 1 and 2 and b) subjects 3 and 4, for both dependent variables.

Wittkower [Wittkower, 1970:79] states, "Psychological stress leads to vascular mechanism reaction patterns which cause an increase in blood pressure level of some, but not all, subjects." Vascular mechanism reaction patterns are similar (though not identical) for all persons. Thus it could be expected that the four subjects might not exhibit identical increases in systolic blood pressure due to mental load.

In Figure D-2 (as well as Figures D-3 through D-9) it is seen that reduction in sinus arrhythmia has a greater magnitude than increase in blood pressure for the same level of the independent variable. However, the maximum variation in responses (during experimentation) for these dependent variables[1] should be taken into consideration while comparing changes in sinus arrhythmia and blood pressure.

Kind of Visual Task

Figure D-3 shows a plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus kind of visual task.

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[1] 7 mmHg for diastolic blood pressure; 12 mmHg for systolic blood pressure; 18 milliseconds for sinus arrhythmia

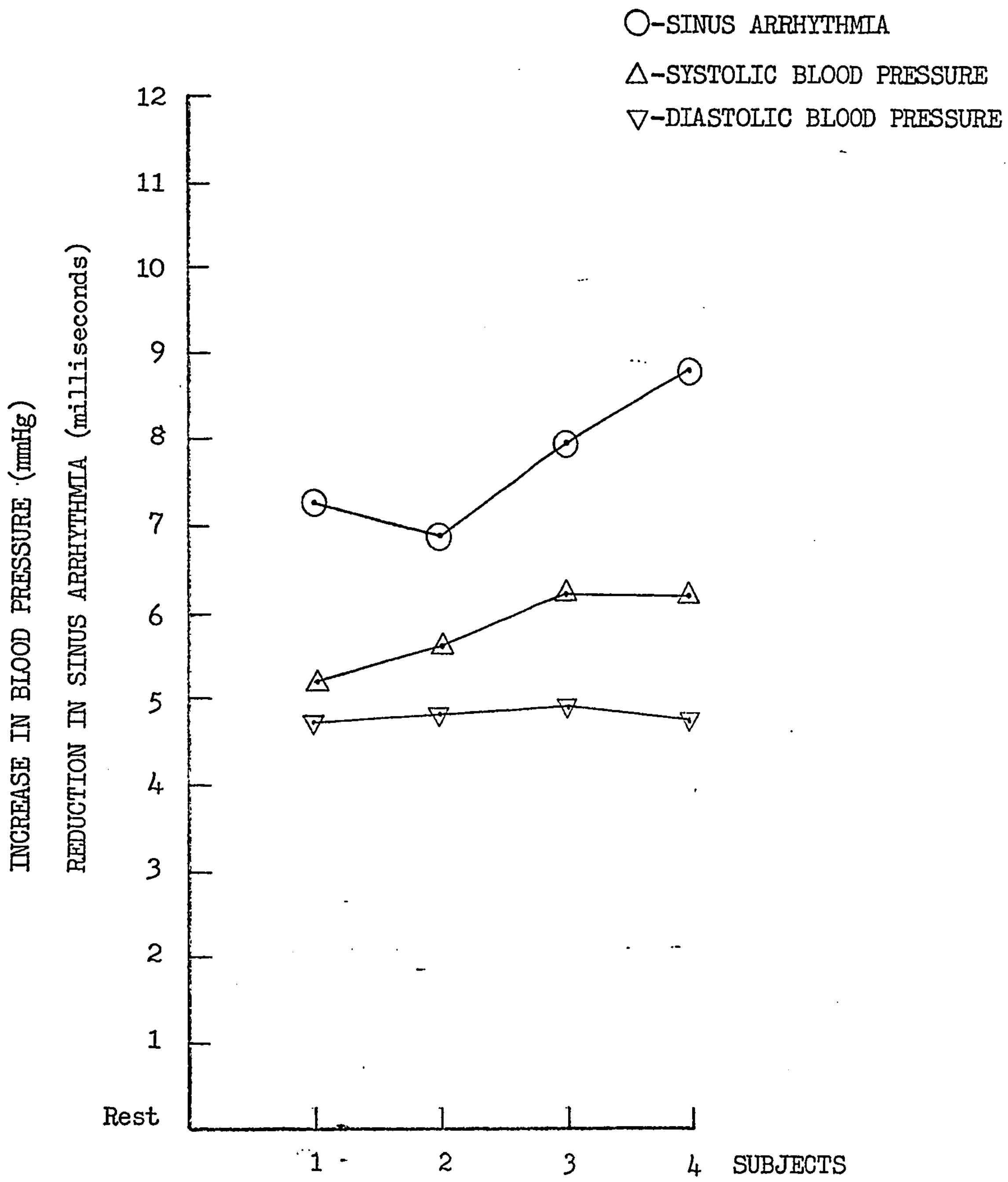

Fig. D-2.--Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus subjects

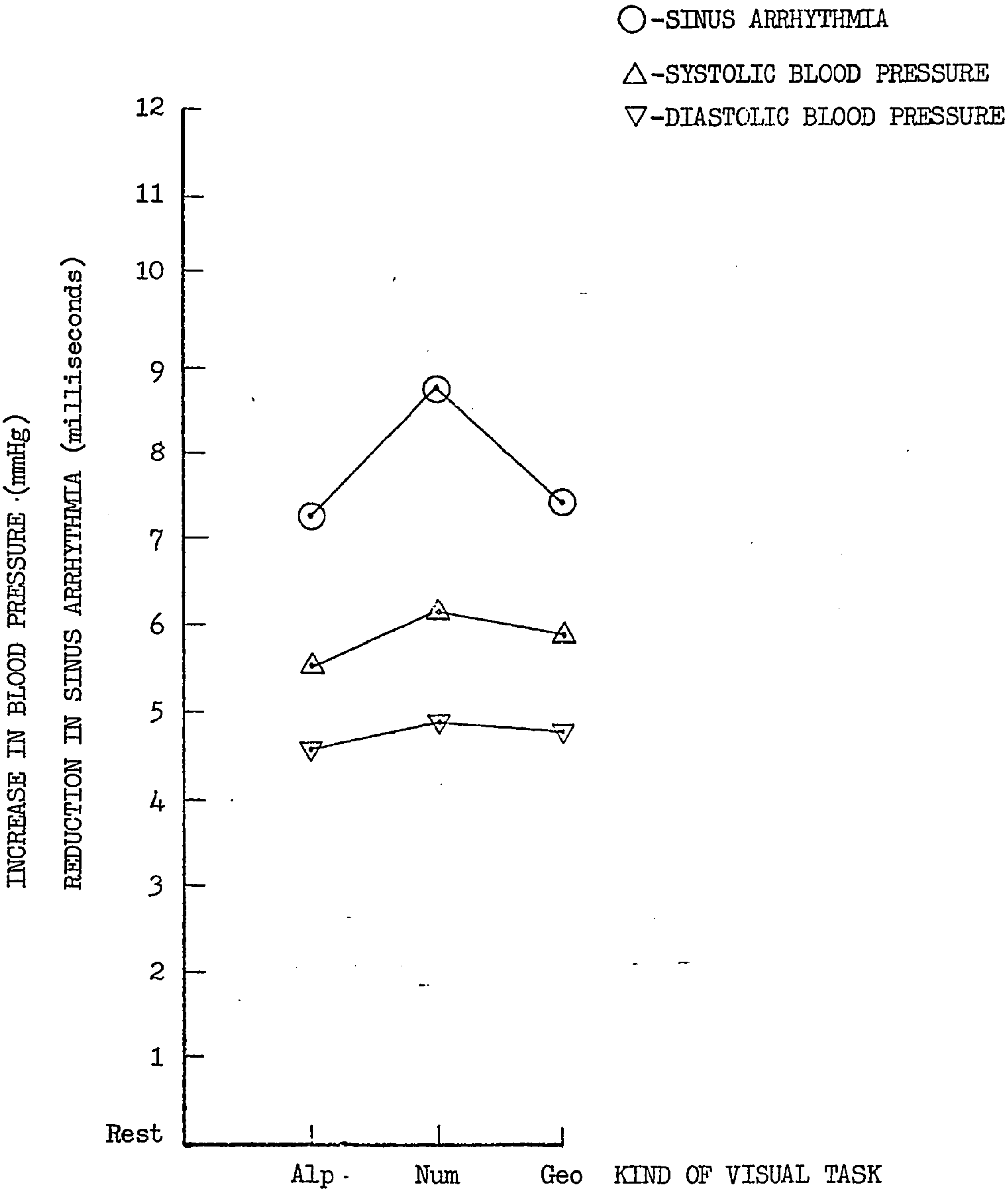

Fig. D-3.—Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus kind of visual task

The three levels of the kind of visual task correspond to alphabetic errors, numeric errors and geometric errors. It can be observed that numeric errors resulted in the highest change in both dependent variables, while alphabetic errors caused the least change in the two dependent variables. This is a very noteworthy phenomenon. It suggests that greater mental load results from identifying numbers than from identifying alphabetic characters.

The intensity of mental load (during visual inspection), as scaled by subjects and their physiological responses (blood pressure and sinus arrhythmia), is shown in Table 4-5. It is observed that the subjective scaling is identical to the ranking of mental load measured by reduction in sinus arrhythmia. But, the ranking of mental load, measured by increase in blood pressure, is not similar to the subjective scaling of mental load. Thus, it can be concluded that reduction in sinus arrhythmia is a more sensitive measure of mental load (in a visual inspection task) than increase in blood pressure.

Thus a difference in the three types of inspection tasks (alphabetic, numeric and geometric) resulted in a different mental load, as measured by an increase in blood pressure and a reduction in sinus arrhythmia. It appears reasonable to believe that alphabetic and geometric codes used in industries result in lower mental load than numeric codes. If a task requires a considerable amount of identification of codes, reduction in sinus arrhythmia can be employed to scale the intensity of mental load caused by the different types of codes.

Types of Errors

Figure D-4 is a plot of means for a) increase in blood pressure

TABLE 4-5.--Intensity of mental load, as ranked by subjects and their physiological responses

	Subject 1				Subject 2				Subject 3				Subject 4			
Kind of Visual Task	SS	SBP	DBP	SA	SS	SBP	DBP	SA	SS	SBP	DBP	SA	SS	SBP	DBP	SA
Alphabetic errors	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1
Numeric errors	3	3	3	3	3	3	2	3	3	3	3	3	3	3	2	3
Geometric errors	2	2	2	2	2	2	3	1	2	2	2	2	2	2	3	2
Types of errors																
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	2	2	2	2	1	3	2	3	2	2	2	2	2	2	2	2
5	3	3	2	3	2	2	3	2	3	3	3	3	3	3	3	3

REMARKS:

SS = Ranked by subject

SBP = Systolic blood pressure

DBP = Diastolic blood pressure

SA = Sinus arrhythmia

1: Represents low intensity of mental load

3: Represents high intensity of mental load

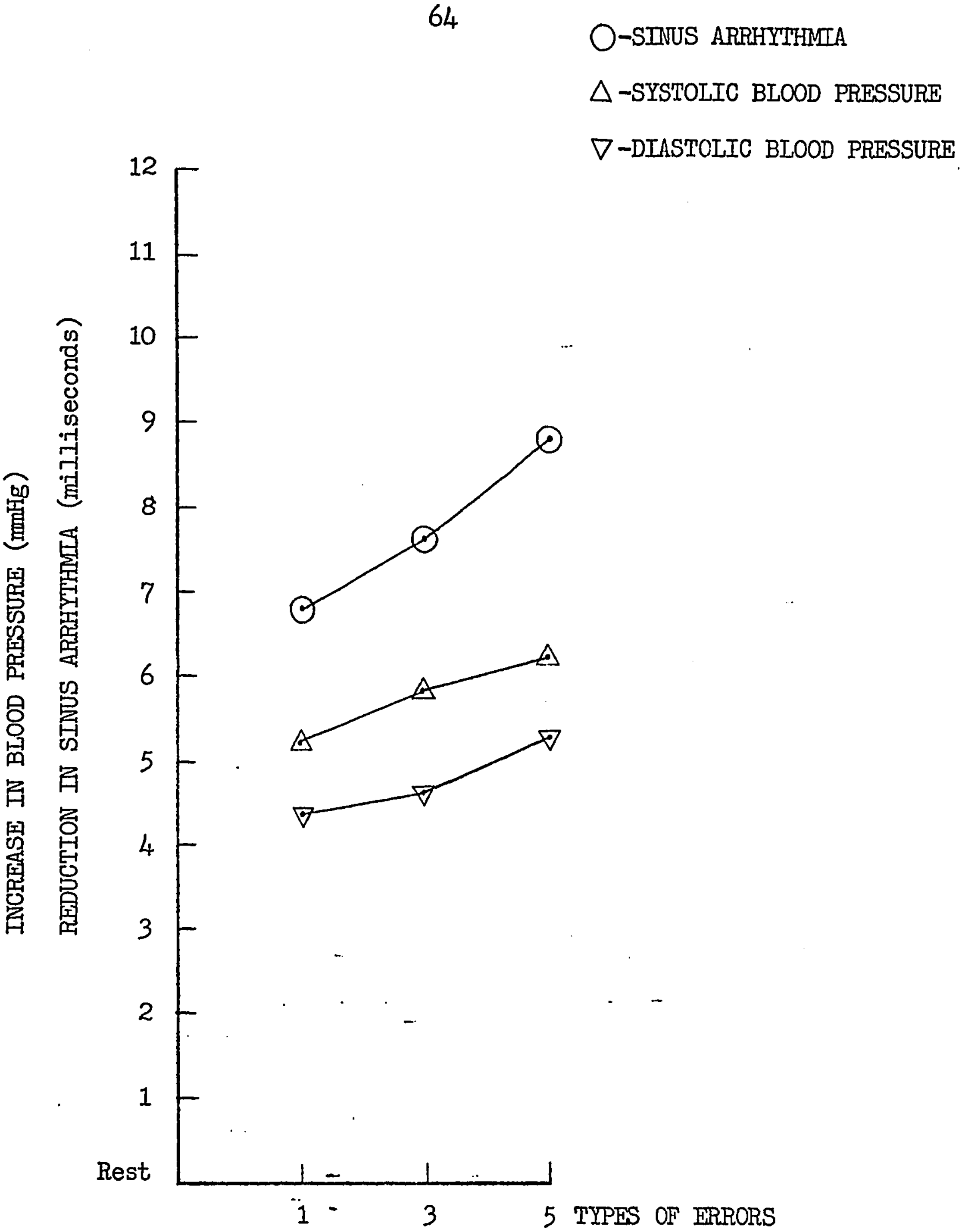

Fig. D-4.--Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus types of errors and b) reduction in sinus arrhythmia, versus types of errors. Three levels were used for this independent variable. The first level corresponds to inspection of the smallest types of errors (1 alphabetic, or 1 numeric, or 1 geometric error). It is seen that all three dependent variables show the smallest effect for the first level of the types of errors.

The second level corresponds to the intermediate types of errors (3 alphabetic, or 3 numeric, or 3 geometric errors) in the visual inspection task. As can be expected, the change in dependent variables is larger for this level than for level one. It is reasonable to expect that an increase in types of errors (from 1 to 3) will cause an increase in the response of the dependent variables.

The third level corresponds to the largest types of errors (5 alphabetic, or 5 numeric, or 5 geometric errors) in the visual inspection task. The change in the response of the dependent variables is also the greatest for this level.

By using principles of information theory [Attneave, 1959:5], the input information[1] (measured in bits) for each of the three levels of types of errors were determined. For 1, 3 and 5 types of errors, the input information is 509 bits, 664 bits and 736 bits respectively. It can be noted from the graph that an increase in input information caused an increase in the three dependent variables.

Total Number of Errors

Figure D-5 shows a plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus total number of errors.

[1]See Appendix D

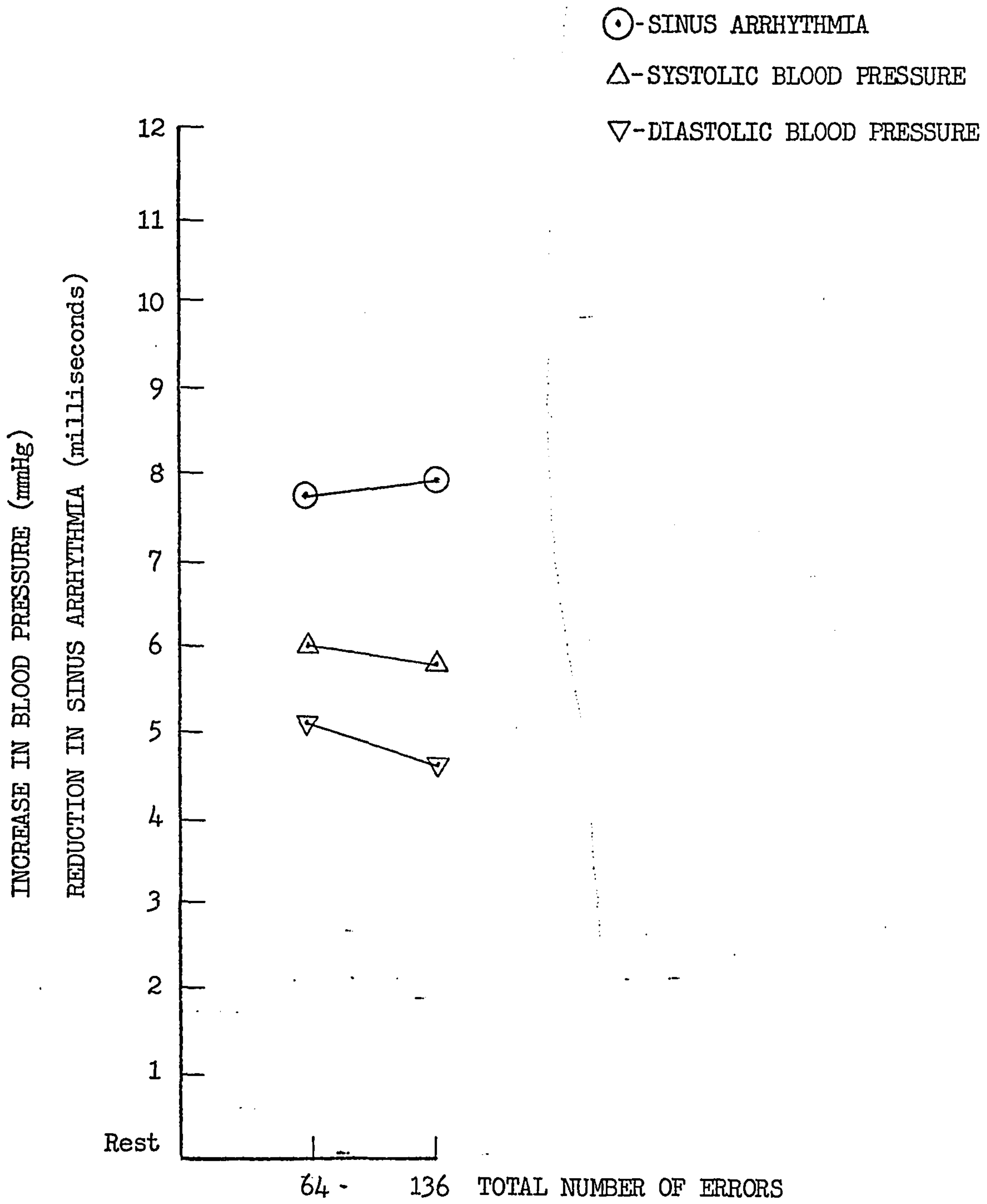

Fig. D-5.--Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus total number of errors

No significant difference was observed between the means for sinus arrhythmia, or between the means for systolic blood pressure.

The first level corresponds to detection of 136 errors[1] (for one visual task consisting of 40 individual inspections) while the second level corresponds to the detection of 64 errors[2] in the same visual inspection task. No logical or satisfactory explanation can be given for the different pattern of response by reduction in sinus arrhythmia (as compared to systolic blood pressure and diastolic blood pressure). It can be attributed to chance variation.

It is observed that the smaller total number of errors (64 errors) resulted in a greater change in blood pressure (both systolic blood pressure as well as diastolic blood pressure) while the greater total number of errors (136 errors) resulted in a smaller change in systolic blood pressure, as well as diastolic blood pressure. This apparently puzzling result can be explained as described below.

All subjects were interviewed individually at the completion of the entire experiment. They were questioned about their mode of inspecting individual slides for detection of errors.[3] Their replies offered one probable explanation as to why the smaller number of errors (64 errors) resulted in a greater change in blood pressure, while a greater total number of errors (136 errors) resulted in a smaller change in blood pressure. All of the four subjects stated that during inspection of individual slides, they scanned a slide more than once, if they detected

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[1]642 bits of input information

[2]377 bits of input information

[3]These interviews were held after completion of all experiments, but before data was analyzed.

less than three errors. [But during tasks of greater time intervals for viewing slides (7x7 matrix, 12 seconds per slide), they always had enough time to view the entire slide at a slower pace (as compared to 5x5 matrix, 8 seconds per slide) and thus avoid repeated scanning of the same slide.] When the total number of errors was 136, only 30 percent of the slides had less than three errors. Thus probably the subjects did not scan the slides more than once for 70 percent of the slides. However, when the total number of errors was 64, 70 percent of the slides had less than three errors. It is reasonable to assume that 70 percent of the slides (5x5 matrix) were scanned more than once by the subjects. This resulted in a higher mental load for the smaller total number of errors. [It is shown in a subsequent section of this chapter that this was not the case for 7x7 matrix.]

Type of Task and Length of Task

The two remaining main effects, namely, a secondary auditory task (performed simultaneously with the visual inspection task), and length of task (5.33 minutes for 5x5 matrix inspection task, 8 minutes for 7x7 matrix inspection task) did not have a statistically significant effect on any of the three dependent variables.

Significant Interactions

Statistically significant interactions will be discussed in this section. First the significant first order interactions will be discussed. Second and third order significant interactions will be considered at the end of this section.

Subject x Types of Errors Interaction

Figure D-6 is a plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus subject x type of errors interaction. With the exception of subject 2, the pattern of responses in inspecting for increasing types of errors, was a continuing reduction in sinus arrhythmia. This is expected for increased mental load caused by inspection for increasing types of errors.

The response of different subjects varies within this pattern, indicating either higher level of mental load, or basic differences in sinus arrhythmia for different subjects.

With the exception of subject 2, the changes in blood pressure (both systolic and diastolic) exhibit a pattern which is similar to the pattern of reduction in sinus arrhythmia. However reduction in sinus arrhythmia is a more sensitive measure[1] than change in blood pressure for measuring the effects of this interaction.

Length of Task x Type of Task Interaction

The plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus length of task x type of task interaction is shown in Figure D-7.

For the shorter length task (5.33 minutes) it is seen that greater change in the dependent variables is caused by a combined visual inspection and auditory task as compared to the visual inspection task alone. However, for the longer length task (8.00 minutes) there is almost no difference in the response of the dependent variables, between the two

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[1]See Table 4-5

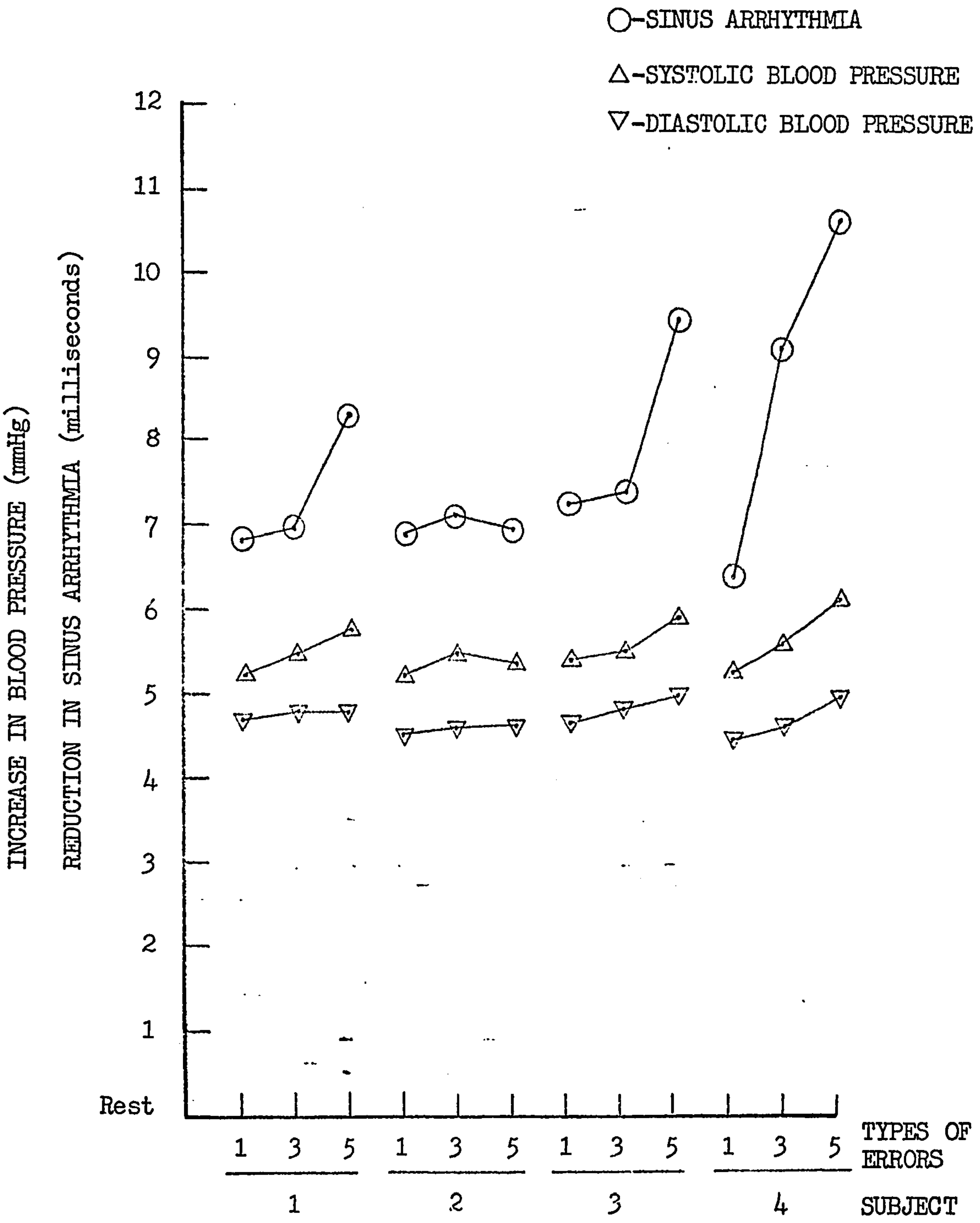

Fig. D-6.--Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus types of errors x subject interaction

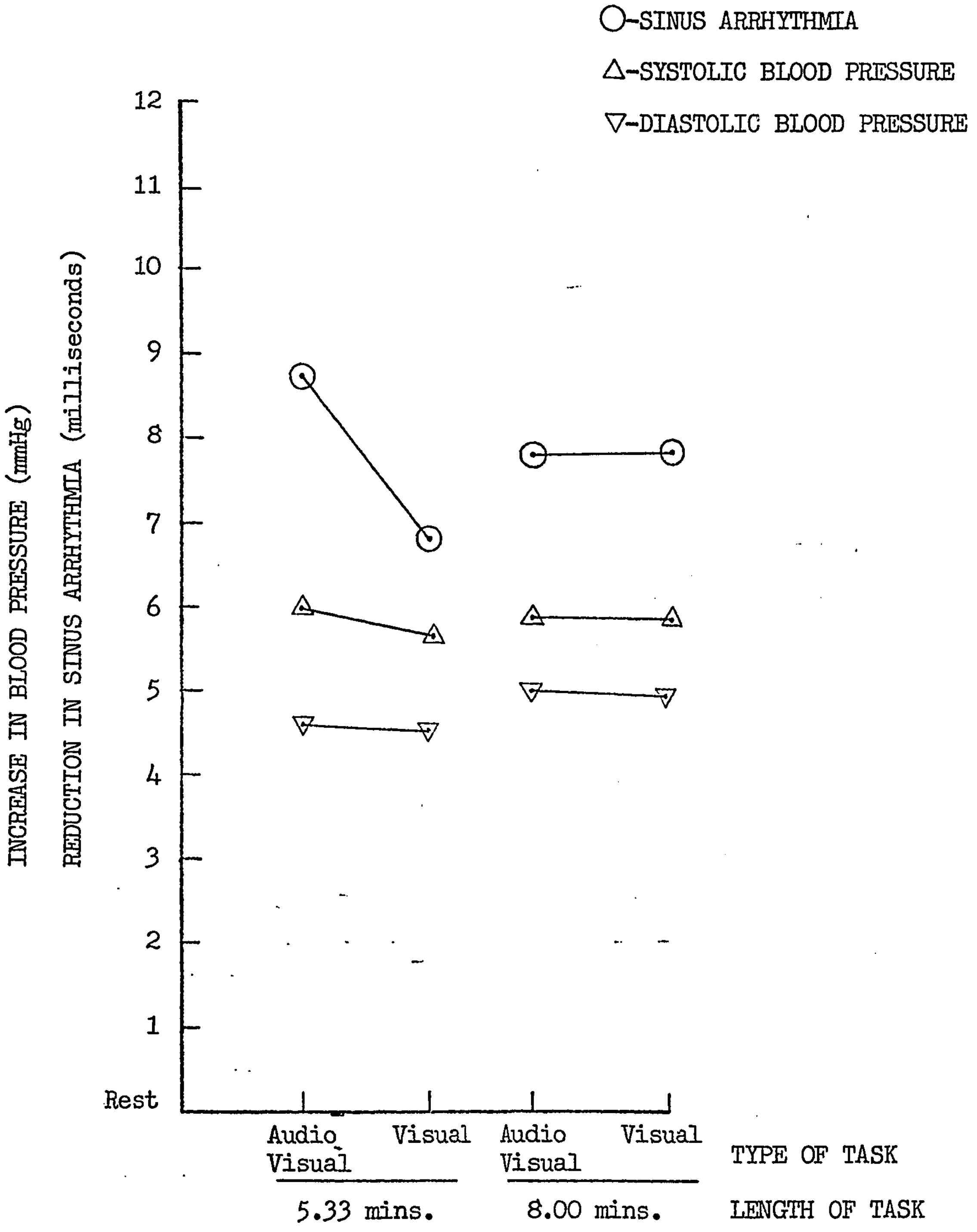

Fig. D-7.—Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus length of task x type of task interaction types of task.

This is indeed a very interesting interaction, and uncovers some interesting results which were not apparent from the analysis of variance computations.

First it is seen that the increase in blood pressure during performance of the visual inspection task is almost the same as the increase in blood pressure during combined performance of the visual inspection task and auditory task. This is true for the shorter length task (5.33 minutes) as well as the longer length task (8.00 minutes).

However, for the shorter length task (5.33 minutes), the reduction in sinus arrhythmia is greater for a combined visual inspection task and auditory task as compared to visual inspection task alone. This suggests that for the shorter length task (5.33 minutes) if increase in blood pressure is used as a measure of mental load, the visual inspection task and the combined visual inspection task and auditory task cause almost the same mental load. But the mental load for the combined visual inspection task and the auditory task is greater than the mental load for the visual task alone, if reduction in sinus arrhythmia is used as a measure of mental load. Thus, for the shorter length task, reduction in sinus arrhythmia is a more sensitive measure of mental load caused by the two types of tasks, than increase in blood pressure.

Considering the longer length task (8.00 minutes), there is very little difference in the response of the dependent variables (blood pressure and sinus arrhythmia) for performance of both types of tasks (visual inspection task and combined visual inspection task and auditory task). A likely explanation for this is the increased time for performance of the inspection task. It is believed that this increased time[1] permitted the subjects to perform the additional auditory task without imposing a corresponding mental load.

This supports the contention of the subjects that the smaller length task (5.33 minutes) was more difficult to perform than the longer length task (8.00 minutes), as discussed in the preceding section.

This viewpoint of the subjects is in contrast to what might have been expected. During the shorter inspection task (5.33 minutes) 25 elements had to be inspected in eight seconds (3.13 elements per second), while 49 elements had to be inspected in twelve seconds (4.08 elements per second) for the longer inspection task (8.00 minutes). This would imply that the mental load may be lower during inspection of a greater number of items in a relatively short time duration, than the mental load of inspecting fewer items during the same period of time. It also implies that the mental load is not related to the average time per inspected object. This may be the reason why inspectors work much faster than the expected times based on the results of classical studies of times taken for discrimination and choice [Thomas, 1962:70].

The apparent increase in mental load during the shorter inspection task (5.33 minutes) as compared to the longer inspection task (8.00 minutes) can be explained in terms of the mode of inspection and the process of perception. It appears that the subjects inspected the individual elements as errors or non-errors, rather than identifying each individual element and then deciding as to whether it was an error or

[1]The increased time for inspection was confirmed by the subjects (see page 67).

otherwise. With this mode of inspection, the measure of inspected elements per unit time does not necessarily reflect the intensity of mental load. Inspection (under these circumstances) is analogus to locating a deformed object (e.g., a blot) from a cluster of similar looking objects (bolts), by scanning them for characteristics which would make the object (bolt) deformed. Presence (or absence) of such characteristics are inspected, and not the characteristics which would make the inspected item an acceptable one (non-errors) in the visual inspection task. The explanation for this mode of inspection does agree with the process of perception discussed below.

It is believed that there is a great reduction in the amount of visual information which is separately processed [Fogel, 1967:22]. In cases where a visual display presents an excessive amount of data, the observer accepts only an abstraction of the display, by selecting those features which represent groups of data. The observer notes the texture rather than the individual and minor details. This process of perception is characterized by classification which best codes the visual display. The resulting perception captures a comparatively small amount of information, but maintains the essential characteristics or meanings by selectively eliminating most of the reduncancy [Fogel, 1967:22]. There result parameters such as texture, form, symmetry and many others.[1] Thus objects tend to be seen as grouped when they are similar in shape, or close together or continue along a line [Welford, 1970:75]. This was also observed by Thierman [Thierman, 1968:71]. He stated that familiarity

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[1]Fogel [Fogel, 1967:22] states that a major portion of data reduction occurs in the retina and optical nerve.

with objects inspected enables the visual data to be comprehended as a unitary whole.

Welford [Welford, 1970:75] suggests that the process of perceptual selection is designed to secure economy of decision, reducing the number of units of data dealt with. In this process, integration operates to ensure that maximum data are analyzed in the minimum terms, commonly by fitting some overall scheme and then dealing separately with discrepant details. At the same time, the mechanism of selection seems to select the degree of specificity of the unit and details are in line with the needs of the situation--perceptual analysis proceeds only so far as required.

Thus it is seen that a visual inspection task of relatively short time duration results in a greater mental load than a visual inspection task for a longer period of time. Addition of an auxiliary task (auditory task in this research) results in an increased mental load for the shorter visual inspection task, but does not cause any significant increase in mental load for the longer visual inspection task.

In data processing centers, manufacturing of printed circuit boards for electronic industries, manufacturing of telephone relays and accessories, visual inspection is of considerable importance. To determine the mental load involved in these inspection tasks, it is suggested that sinus arrhythmia is a better measure than blood pressure. Also, if these tasks are moderately-paced, the increase in mental load caused by an auxiliary task may be detected more readily by sinus arrhythmia, than by an increase in blood pressure.

Length of Task x Total Number of Errors Interaction

The plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus length of task x total number of errors interaction is shown in Figure D-8. The reduction in sinus arrhythmia does not show significantly different values for the different means of this interaction. Although length of task was not a significant main effect, its interaction with total number of errors is statistically significant for increase in systolic blood pressure. It is not possible to state anything definite about the significance of this interaction. It is suggested that future research be conducted to investigate further into the reasons of this interaction.

Types of Errors x Kind of Visual Task Interaction

Figure D-9 is a plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia versus types of errors x kind of visual task interaction. For the independent variable of kind of task, levels 1, 2 and 3 correspond to inspection of alphabetic errors, numeric errors and geometric errors, respectively. The three levels of types of errors correspond to inspection of one, three or five types of errors.

It is seen that numeric errors cause more mental load than geometric errors or alphabetic errors, for all types of errors. The effect of kind of visual task was described during discussion of main effects and will not be repeated in this section.

For levels 3 and 5 of types of errors, it is seen that alphabetic errors caused less mental load than geometric or numeric errors. However for level 1, geometric errors caused less mental load than alphabetic or numeric errors. This indicates that during visual inspection tasks,

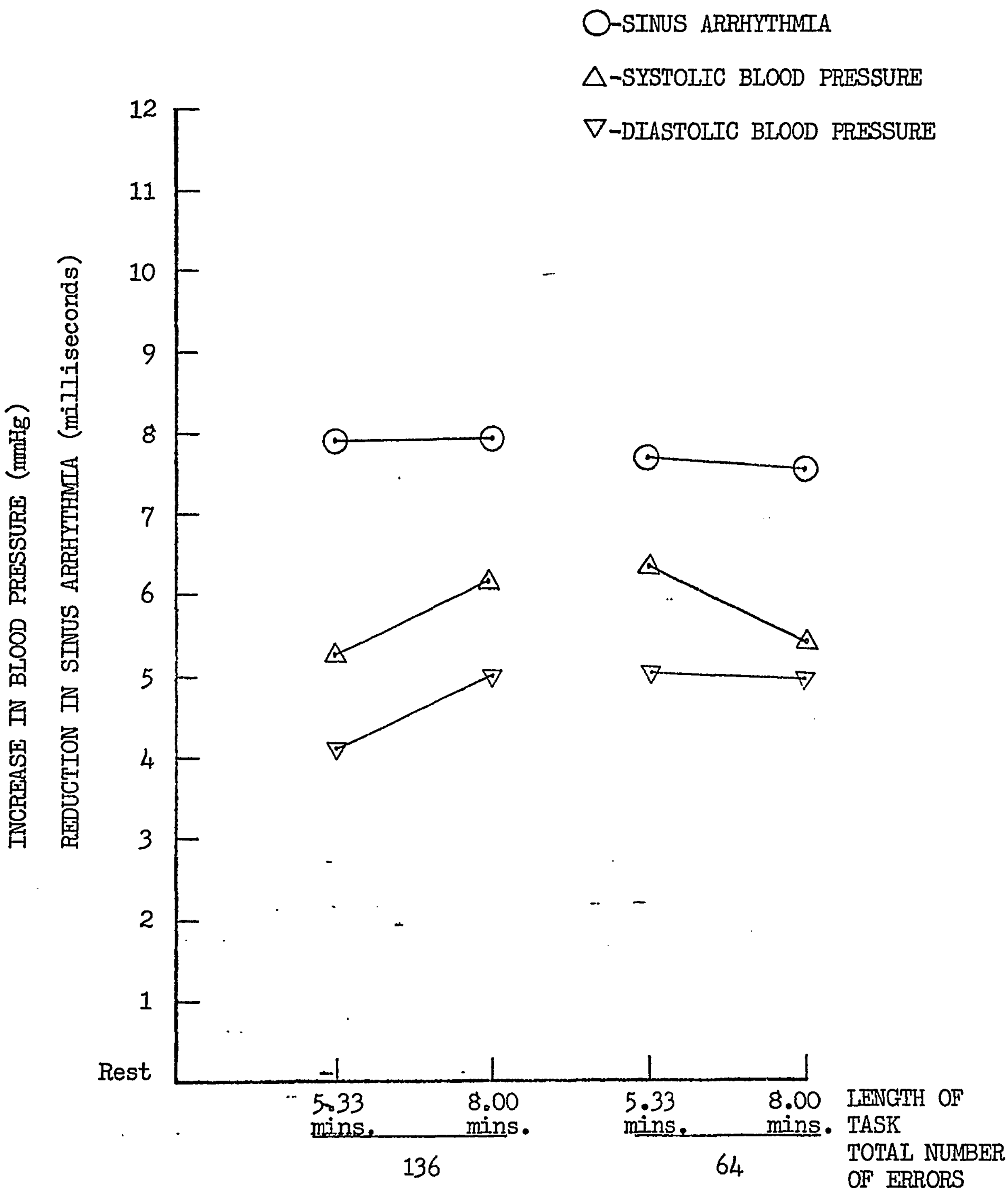

Fig. D-8.—Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus length of task x total number of errors interaction

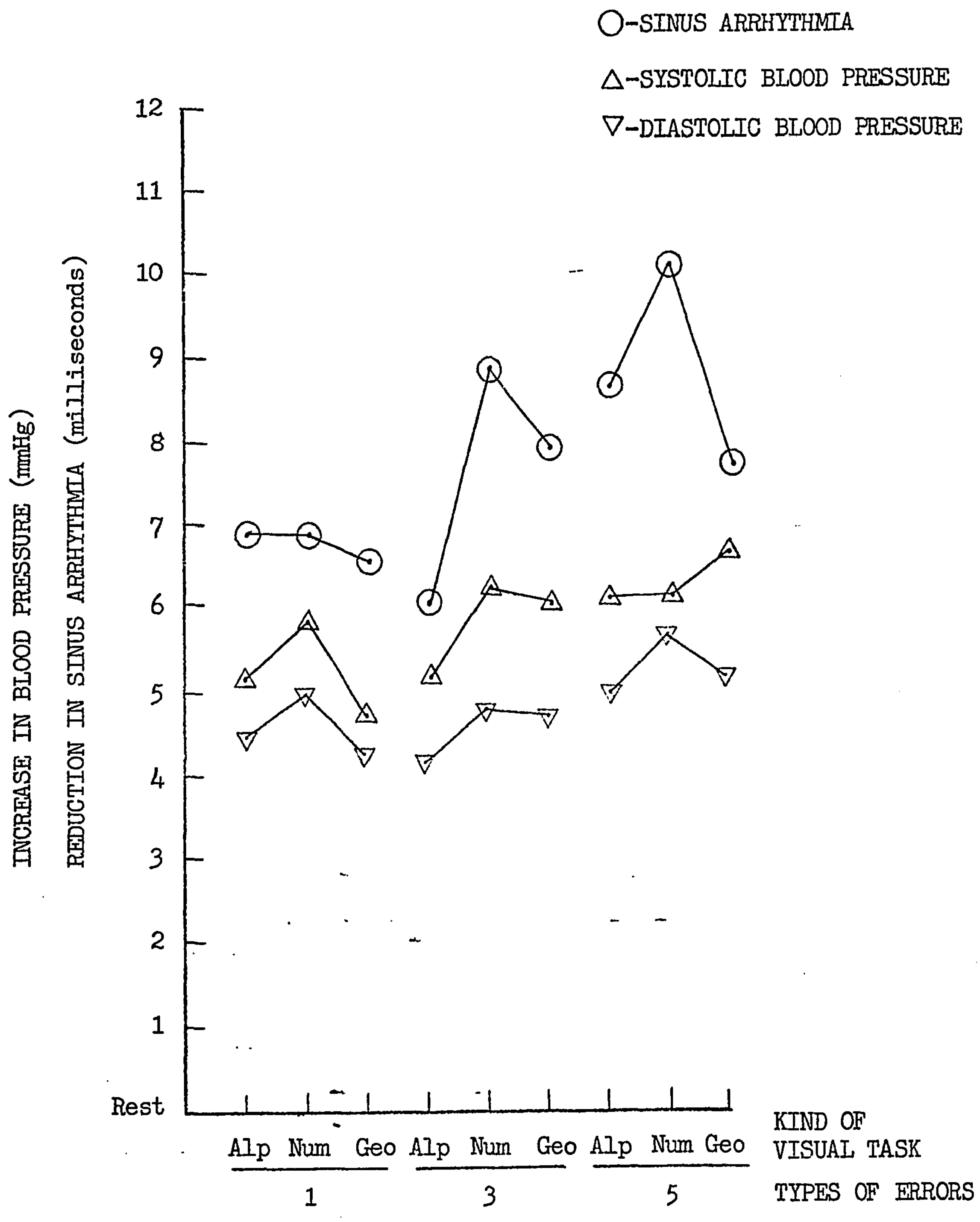

Fig. D-9.—Plot of means for a) increase in blood pressure and b) reduction in sinus arrhythmia, versus types of errors x kind of visual task interaction the mental load does not increase linearly with respect to the types of errors. The increase in mental load is the result of type of error as well as the error being alphabetic, numeric or geometric.

The change in blood pressure for inspection of five geometric errors does not agree with the pattern exhibited by the remaining means. This may be attributed to chance variation.

The importance of detecting alphabetic, numeric and geometric errors in typical industrial situations was discussed earlier in this chapter and will not be repeated here. It is again pointed out that reduction in sinus arrhythmia is a more sensitive measure of mental load (caused by a visual inspection task) than blood pressure.

Second and Third Order Interactions

A review of Table 4-1 indicates that a number of second and third order interactions were significant. More than half of these significant interactions can be attributed to the affects of subjects in the interactions. These significant interactions are listed below.

a) Subject x Length of task x Types of errors interaction

b) Subject x Length of task x Total number of errors interaction

c) Length of task x Types of errors x Type of task interaction

d) Length of task x Kind of visual task x Type of task interaction

e) Subject x Kind of visual task x Type of errors interaction

f) Subject x Kind of visual task x Total number of errors interaction

g) Kind of visual task x Type of errors x Total number of errors interaction

h) Kind of visual task x Type of task x Total number of errors interaction

i) Subject x Type of errors x Type of errors x Type of task interaction

j) Subject x Length of task x Type of errors x Total number of errors interaction

A plot of these interactions reveals that the pattern of response between subjects differs for the dependent variables measured. Differences between subjects are often found in experiments of this nature, so this result was not unexpected. It is apparent that a possible explanation of these different patterns of response would be complex in nature, because each interaction exhibits a response pattern not easily explained as a consequence of the experimental conditions. A sufficient explanation of these second and third order interactions involving subjects must be deferred until more is known about the mechanisms of sinus arrhythmia and/or blood pressure. As a consequence, the application of these research results to an inspection task for measuring mental load (in a visual inspection task) levels of individual subjects must be restricted until further research has been accomplished. However, the dependent variables (sinus arrhythmia and blood pressure) have been shown to be sensitive to different mental load levels in this simulated inspection task when the effects of subjects are normalized.[1]

The remaining second order interactions were examined by plotting the means for the interactions. No consistent patterns could be observed from the plots of the means for these interactions. No satisfactory explanation is possible for these higher order interactions.

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[1]Using the average response of the four subjects

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This chapter consists of conclusions drawn from this study, recommendations for further research and a summary of this investigation.

Conclusions

When this investigation was undertaken, the relation between sinus arrhythmia and mental load in a visual task (consisting of inspection of alphabetic, numeric and geometric errors), was not at all certain. All investigations, pertaining to sinus arrhythmia, had been related to tasks of a binary choice nature, mental arithmetic, reading from books, or reciting of typical words or phrases in a language study. This is the first known study in which sinus arrhythmia has been used as a measure of mental load in the performance of a visual inspection task.

The overall conclusion can be drawn that sinus arrhythmia is a more sensitive physiological response measure of mental load in a visual inspection task, than either increase in systolic blood pressure or increase in diastolic blood pressure. It can be further concluded that increase in systolic blood pressure is a more sensitive physiological measure than increase in diastolic blood pressure. These conclusions are, as should be emphasized, based on the conditions of this experiment where a static visual inspection task was used.

There was a significant difference between the subjects, as measured by the reduction of sinus arrhythmia, during the performance of inspection tasks. Moreover, many significant second and third order interactions had subjects as one factor of interaction. This leads to the conclusion that further understanding of the mechanism influencing sinus arrhythmia is necessary before it (sinus arrhythmia) could be adopted as a measure of mental load. Subjects are specific in their autonomic responses to mental load, and this further complicates the uniform use of sinus arrhythmia in measuring the responses (to mental load) of specific individuals. For applications of the use of sinus arrhythmia, in evaluating the level of mental load for individual subjects, reduction of sinus arrhythmia does appear to be a more sensitive measure than change in blood pressure.[1]

During visual inspection of typical displays (like signs, charts, markings, printed circuit boards, various forms of printed or written materials), it can be concluded that inspection for alphabetic elements causes less mental load than inspection for geometric elements used in the task. Also, inspection of numerical elements causes greater mental load than either alphabetic or geometric elements. For controls and information displays, or for alarm indications, less mental load will result if alphabetic coded signals (or indications) are employed. This is particularly important for automatic process equipments, control and co-ordination centers of electric power utilities and graphic presentation of information.

It can also be concluded that mental load does not increase linearly with an increase in the types of errors in an inspection task. Thus, an increase in types of errors from one to three may result in a greater

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[1]For tasks that involve negligible physical activity.

increase in mental load, as compared to the increase in mental load when the types of errors are increased from three to five. Also, the increase in mental load, due to an increase in types of errors, is greater for alphabetic errors than for geometric errors used in this study.

Finally, it can be concluded that the mental load is not significantly influenced by the total number of errors or the length of an inspection task.

As a result of the conclusions stated above, it has been confirmed again that the intensity of mental load[1] caused by a visual inspection task, is determined by a) the person performing the inspection task and b) the nature of the inspection task. The factors which are related to the inspection task, and influence the response of the physiological variables,[1] are types of errors and inspection for alphabetic, numeric or geometric elements. In this research, the length of inspection task and an auxiliary auditory task, did not have a significant effect upon increase in blood pressure (systolic or diastolic) or reduction in sinus arrhythmia.

Recommendations for Further Research

Several recommendations pertaining to future research will be discussed in this section.

First it is suggested that a dynamic inspection task, similar to objects moving on a conveyor belt, be used in any future study. The reason for this suggestion is that such a task will be more representative

[1]As measured by a) reduction in sinus arrhythmia and b) increase in blood pressure (systolic and diastolic).

of an actual industrial situation.

Second, it is suggested that future studies investigate the effect of inspection for combined alphabetic-numeric, or numeric-geometric, errors in a visual inspection task. Some significant interactions, observed in this study, suggest that intensity of mental load may differ considerably for a combination of various types of alphabetic, numeric and geometric errors.

Only one and two digit numerals were used in this study. It will be worthwhile to investigate the effect of three and four digit numerals. One important application of such a study would be the manner in which telephone numbers, bank account numbers, credit card numbers, etc. are used.

It is suggested that an auditory signals task be investigated as an independent (or primary) task. In this study, it was concluded that an auxiliary auditory signals task does not increase the response of physiological variables during performance of a primary visual inspection task. It would be extremely interesting to study what kind of a response in physiological variables might be obtained during performance of a primary auditory task and a secondary visual task.

Finally, this is the first study in which reduction in sinus arrhythmia was used as a measure of mental load in a visual inspection task. There are countless applications in innumerable industries where visual inspection is involved in one form or another. It is impossible to enumerate all possible implications of this study to an infinite number of visual inspection tasks. This study has demonstrated that sinus arrhythmia can be used as a measure of mental load in a visual inspection task. By utilizing defferent modes of inspection (in future studies), the application of this relationship in industrial or other situations is limited only by one's own imagination.

Summary

This investigation was conducted to determine the use of sinus arrhythmia as a measure of mental load in a visual inspection task. Further, the effects of subject, alphabetic, numeric or geometric errors, types of errors, auxiliary auditory task and total number of errors, upon increase in systolic blood pressure, increase in diastolic blood pressure and reduction in sinus arrhythmia, were determined for a visual inspection task. The significant conclusions drawn from this investigation are enumerated below:

1. Reduction in sinus arrhythmia can be used as a measure of mental load in a visual inspection task.
2. Reduction in sinus arrhythmia is the most sensitive physiological measure of the three used, followed by increase in systolic blood pressure and then increase in diastolic blood pressure.
3. Increase in systolic blood pressure is significantly affected by subjects and types of errors.
4. Increase in diastolic blood pressure is significantly affected by types of errors and total number of errors.
5. Reduction in sinus arrhythmia is significantly affected by subjects and inspection for alphabetic, numeric or geometric errors.

APPENDIX A

LIST OF NUMBERS USED IN THE INSPECTION TASK

The following numbers (selected at random) were used in the inspection task:

1	38	72
5	43	75
14	45	78
16	48	81
19	50	84
20	54	86
29	57	90
30	60	91
34	62	93
36	67	

APPENDIX B

PILOT STUDY TO DETERMINE INSPECTION TIME

Eight male students (four graduates and four undergraduates) participated in a pilot study used to determine the average time for inspection of slides. Twenty alphabetic slides (5x5 matrix) were used for the inspection task and the subjects inspected the slides for three types of errors. The time required by each subject for the inspection of each slide was measured. The average time required by the subjects is as shown below:

Subject	Inspection time (seconds/slide)
1	8.4
2	9.3
3	9.1
4	8.2
5	8.0
6	7.9
7	8.2
8	8.3

The average time of inspection (for all subjects) is 8.4 seconds per slide.

APPENDIX C

EXPERIMENTAL DESIGN FOR SIX FACTORS

FACTOR	IDENTIFICATION	LEVEL	TYPE EFFECT
Subject	S	1 2 3 4	Random
Length of task	L	5.33 mins 8.00 mins	Fixed
Kind of visual task	K	Alphabetic Numeric Geometric shapes	Fixed
Types of errors	G	1 3 5	Fixed
Type of task	T	Visual & Auditory Visual only	Fixed
Total number of errors	M	64 136	Fixed
Replications	R	1 2	Random

APPENDIX D

DETERMINATION OF INPUT INFORMATION

Input information (measured in bits) was determined by use of the equation [Attneave, 1959:5],

$$H = p1 \log_2 \frac{1}{p1} + p2 \log_2 \frac{1}{p2}$$

H = information in bits for each inspected element

p1 = probability of error

p2 = probability of no error

The following is a sample calculation for the determination of input information (measured in bits) for 64 errors in the shorter length (5.33 minutes) task.

Number of inspected elements = 25 x 40 = 1000 (40 slides, 25 elements per slide)

Number of errors = 64

$$\therefore p1 = 64/1000$$

$$\text{and } p2 = 936/1000$$

$$\therefore H = \left[\frac{64}{1000} \log_2 \frac{1000}{64} + \frac{936}{1000} \log_2 \frac{1000}{936} \right]$$

∴ Total input information = (number of inspected elements) x (H)

= (1000) x (H)

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