INTERBEAT INTERVAL AS AN INDICATOR

OF MENTAL AND THERMAL STRESS

by 5402

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Due primarily to its ease of attainment and its relationship to body functions, the heart rate has been the subject of many investigations. It is well known that physical exercise will cause the heart to beat more regularly along with its higher rate. Recent research suggests that greater regularity of the heart can also result from factors such as heat and mental load.

Modern technology has reduced the amount of physical load that a worker is expected to exert but it has increased dramatically the mental tasks required of almost all employees. Thus the importance of qualifying these mental activities becomes evident. One of the most promising indexes of mental stress is the regularity of the heart beat or the variability of the interbeat interval. This variability of interbeat interval, hereafter termed the "iv," has the distinct advantages of being objective. It may be a more potent index of stress than is presently available. This thesis presents an evaluation of the "iv" as an indication of stress.

LITERATURE REVIEW

Task Stress and Interbeat Variability

The objective measurement of mental or perceptual work load has been evaluated by Kalsbeck and his associates since 1962 (Schouten, Kalsbeck, and Leopold, 1962). A summary of these findings appeared in his 1968 article (Kalsbeck, 1968). It was noted in the 1968 study, that increasing the mental load, a binary choice task, did not increase the heart rate but did diminish the iv.

The original study (1962) was the first of many articles originated by Kalsbeck in the area of mental stress. It gives some background for latter studies and an introduction to the ultimate goal of objectively measuring mental stress.

Schouten, Kalsbeck, and Leopold (1962) used a primary task with five different secondary tasks to determine the degree of mutual impairment. The primary, or first task, consisted of an auido binary response task. The stimulus consisted of a tone of either 2000 Hz or 250 Hz presented randomly by ear at a rate of between 10 and 120 stimuli per minute. The response consisted of pressing a right or left pedal respectively. The secondary tasks utilized the subjects hands and eyes:

1. Applying a washer and nut to a screw
2. Inserting a pin in a hole
3. Solving arithmetical problems and writing the answers
4. Maze tracking
5. Spontaneous writing.

For two subjects the performance in the second task in percent was plotted versus 0, 20, 40, 60, 80, and 100% performance in the first task. Maximum performance, 100%, in the primary, first, task was established as no more than two errors or failures occuring in three minutes. Test duration, the number of subjects, type of pacing, and the results, in other than percentage were not explicity reported.

In general, a decay in secondary task performance was observed as a function of increasing primary task performance. It was concluded that "expressing the effect of perceptual and mental load in terms of steps of decay, as brought to light by our experiments, may be of use in tackling the problem of evaluating perceptual and mental load."

Kalsbeck and his associates have reported on the same studies in many different sources. Because of the similarity of these studies only selected articles are included in this review.

In one study, Kalsbeck and Ettema (1965) attempted to determine if heart rate and regularity were independent and whether irregularity could be used to measure mental load. The mean heart rate for the 85 subjects tested was 75 beats/minute (bpm) with a standard deviation of 9.6 bpm. An earlier method (Kalsbeck and Ettema, 1963) was used to determine a sinus arrhythmia irregularity score (irregularity of heart rhythm). Using this manual scoring method, the score was determined by counting the number of times instantaneous heart rate, plotted by cardiotachometer, crossed control lines. For the 85 subjects the mean irregularity score was 11/minute with a score standard deviation of 8.5/minute. This established a standard or reference point for resting subjects.

This scoring method has been explained in detail by Ettema (Ettema, 1965).

Three different experiments were then run with each using a different set of subjects and each having two levels of stress. Each level of stress and a session duration of three minutes. In the first experiment six subjects performed a visual and binary choice task at two levels, 45 bits/minute and 70 bits/minute. The second experiment had thirty subjects perform audio binary choice tasks at 60 and 80 percent of their individual maximum errorless response rate. These percentages were approximately 72 and 96 bits/minute respectively.[1] The final investigation had 21 Dutch subjects hearing a Spanish test being read twice. The first time was "hearing" only and the second time they "listened" intently to count the times the word "los" was used. These subjects did not speak Spanish.

Table 1 shows a summary of their results. Heart rate and sinus arrhythmia for the tested subjects were expressed as percentages of resting conditions for the initial 85 subjects. Irregularity diminished with load. As noted in the table a Wilcoxon Test (one-tail) was used to determine significance. An inconsistency is evident in the heart rate relations (between rest and condition III) but this is as it was reported.

Kalsbeck and Sykes (1967) reported an investigation of the objective measurement of mental load which utilized both secondary task and sinus arrhythmia score evaluation. Fourteen student subjects were used. The subjects were divided into two groups of seven each. Each group performed two tasks simultaneously. The first task, the primary task, was paced. It consisted of responding with two hand keys to two lights which

Table 1

Kalsbeck and Ettema's Results

Task

	Rest	Visual Binary Choice		Audio Binary Choice		Hearing	Listening
	(R)	45 bits/ min. (I)	70 bits/ min. (II)	72 bits/ min. (III)	96 bits/ min. (IV)	(V)	(VI)
No. of subjects	85	6		30		21	
Heart Rate	100%	106%	106%	104%	106%	101%	102%
Sinus arrhythmia score	100%	47%	15%	60%	45%	86%	51%

Wilcoxon Test

Heart Rate		Sinus Arrhythmia Score		Sinus Arrhythmia Score	
III > R	$p < .025$	I < R	$p < .025$	IV < R	$p < .005$
R > III	$p < .005$	II < R	$p < .025$	IV < III	$p < .005$
IV > III	$p < .005$	II < I	$p < .05$	V < R	$p < .01$
		III < R	$p < .005$	VI < R	$p < .005$
				VI < V	$p < .005$

switched on randomly at fixed times. Before each session each subject's individual maximum response rate was established. The secondary task consisted of responding with two pedals to tones of 2000 and 250 Hz. This task was unpaced and the tones were presented randomly by earphones. In the dual task situation the experimenter increased the rate of lights from 0% (secondary task alone) to 100% of the subject's maximum performance in randomized 10% increments. As reported, the first group of subjects were instructed in the form of a pay-off matrix for secondary task performance. The other group was merely told to answer as many tones as possible without making errors or omissions in the primary task. The first group was thought to be highly motivated whereas the second group was thought to be neutral.

No difference was found on any of the performance measures between the two groups. Irregularity of the heart rate was scored by the method of Kalsbeck and Ettema (1965) and was reported as a percentage of the irregularity score obtained during the preceeding rest period. The highly motivated group remained at a sinus arrhythmia score of about 70%. The neutral group started at a higher level of irregularity (81% of rest), decreased to 64% of rest at approximately 72 bits/minute of primary task performance.[2] The neutral group started with less effort and increased their effort with greater primary task demands as indicated by interbeat variability.

Another method of evaluating the iv has been utilized by other authors. With this second method, successive peaks of an electrocardiogram (EKG) are measured by hand and then transcribed to a data sheet and ultimately computer cards. The calculations of mean interbeat intervals, heart rates, standard deviations, and coefficients of variation are performed by computer. The variability measures are the standard deviation of the intervals and the coefficient of variation.

Cahill (1969) utilizing this second method, found a relationship between the iv and mental stress. Ten subjects were required to solve a differing number of addition problems in one minute. The number of six column (6 x 4) addition problems available in the one minute work session were, in the order they were presented, two, four, six, and six. The fourth session also had an added "distraction stress" of 70 dbA white noise. Criteria used were heart rate, standard deviation of the interbeat interval, coefficient of the variation of the interbeat interval and accuracy. Kalsbeck's method of scoring was not used. Variability of the interbeat interval, the iv, was evaluated by means of the standard deviation and the coefficient of variation. The coefficient of variation was the standard deviation divided by the mean for a particular specified period.

Cahill determined that interbeat variability decreased significantly while solving addition problems ($p < .05$). It was also found that heart rate increased five bpm during stress although this was not tested for significance. No significant affect on variability could be observed by the addition of 70 dbA white noise although Kalsbeck (1968) reported a significant effect for 80 db and 90 db. The coefficient of variation was significantly ($p < .05$) lower during work than rest but no distinction could be drawn among levels of work.

Konz and Cahill (1970) reran a variation of Cahill's experiment to see if interbeat variability changed not only between work and no work but among levels of work at the same task. Twelve male engineering students served as subjects. The subjects, following a balanced and mirrored sequence, added a series of 6 x 4 addition problems during a one minute work session. In order to encourage a variation in mental load three conditions were tested. A bonus of 5 cents was paid for every column added correctly during the condition having the greatest number of problems. In the low condition one problem (ie. six columns) was available, the medium condition had four problems, and the high bonus condition had six problems.

Once again the same results were obtained; the standard deviation and the coefficient of variation were significantly lower ($p < .001$) during work than rest but no distinction could be drawn among levels of work. The earlier conclusion was verified; the interbeat interval of EKG did vary and the variation decreased with the addition of tasks.

Koster (1965) in summarizing his other work (Traverne and Koster, 1966; Koster, 1966), used four methods to measure perceptual load. Three were based on the primary-secondary task principle and one on Kalsbeck's method of scoring sinus arrhythmia. One well-trained subject performed seven tasks. The load of each of the seven tasks was evaluated by each of the four methods and each situation was repeated five times. The four performance measures were reaction, tracking, and tapping as subsidary measuring tasks and sinus arrhythmia scoring as a physiological measure.

Koster found that Kalsbeck's method was "very good" at discriminating between tasks but could not distinguish between work and rest. "Very good" was established as having a "highly significant" but not reported F value. It was noted that the sinus arrhythmia score obtained during some tasks was higher than that measured on the subject at rest. It should be noted that these results are contrary to those reported by Kalsbeck (1968), Cahill (1969), and Konz and Cahill (1970). These authors report significant reductions in variability with the addition of tasks.

Gibby, Gibby, and Townsend (1969) investigated the stability of the rate of change of heart-beat (instantaneous heart rate) from non-stress to stress conditions. The major hypothesis tested was that the rate of change of heart-beat does not shift significantly from non-stress to stress conditions but rather it tends to remain relatively consistent within the individual from one situation to another.

Eighty white male college students who were either science or engineering majors were subjects. All subjects underwent initial mental and physical examinations and it was noted that the subjects could be categorized as being of superior intelligence and presumably free of any significant degree of physical disability, emotional disturbance, and psychosomatic involvement.

On the first day of the study, each subject was required to rest in a reclining position and the EKG was recorded for a 15 minute period. On the following day, at the same time as on the first day, the subjects simultaneously experienced both psychological and physiological stress with the identical heart measurements recorded. Physiological stress was achieved by electric shock and psychological stress was achieved by time-to-completion recognition task.

The Pearson product-moment correlation between rate of change under non-stress and stress conditions was found to be statistically significant ($p < .001$). It was shown that the rate of change of heart beat remained essentially constant and that the person who was "stabile" (minimum rate of change) under non-stress conditions was similarly stabile under conditions of stress and the person who was "labile" (maximum rate of change) under non-stress condition was labile in stress. It was concluded that the rate of change of heart rate is a stable parameter and they implied that the rate of change in heart-beat rate obtained under non-stress conditions may be used to predict performance of the person under stressful conditions. Thus, the degree to which individuals demonstrate interbeat variability differs and this difference between individuals exists in both stress and non-stress conditions.

Meers and Verhagen (1970) investigated sinus arrhythmia and its relation to information transmission and emotional tension. They performed two seperate studies; the first used twenty well informed third and fourth year psychology students as subjects and the second used twenty-six industrial technicians as subjects. In both studies, Kalsbeck's scoring method was utilized.

The first study utilized Kalsbeck's audio binary choice task. The subjects were all volunteers who were well informed about the experiment and its aim of associating supressed sinus arrhythmia with high task rate. The subjects were also familiar with the experimenter. In what the authors termed a "relaxed atmosphere," only 12 of the 20 subjects had a decrease in sinus arrhythmia during maximum paced (mean of 59 bits/minute) and unpaced (mean of 63 bits/minute) test conditions. From rest to maximum load there was a mean decrease of sinus arrhythmia score of 0.4%. This was not significant for p = 0.10 by the Wilcoxon test.

The second study involved industrial technicians taking what they were told was a job determining psychological examination. The authors termed this a "tense atmosphere". Utilizing the same audio binary choice task for 24 of the 26 subjects a decrease of sinus arrhythmia was found during maximal load when compared with resting scores. There was a mean decrease of the arrhythmia of 25.1%. This was significant for p = 0.001 by the Wilcoxon test.

It was concluded that the emotional state of the subject is of great importance and that besides a high rate of information transmission some emotional tension is indispensable to get a degree of sinus arrhythmia suppression.

Interbeat variability has been shown to decrease with mental or task stress. It has been linked with emotional loading and it has been demonstrated that it is a stable measure within individuals under varying stress conditions. Both Kalsbeck's method and the method reported by Cahill and others have been successful in distinguishing mental stress from resting conditions. Kalsbeck's method has been successful in differentiating levels of the same task whereas the second method has failed. The second method has been applied to only relatively mild self paced mental tasks and to some physical stress, namely heat.

Heat Stress and Interbeat Variability

Some work has been done using the iv as a criterion during heat stress. This work has been summarized by Konz and Cahill (1970) and a similar summary appears in Table 2. All investigators used the criteria of the standard deviation or coefficient of variation.

Konz and Nentwich (1969) reported four experiments in hot humid environments with localized cooling of the head. Experiment one used mental work (addition problems) at room temperatures of 99, 103, 107, and 112 F. Experiment two had mental work (number recall) at 107 F. Experiment three had physical work (walking a treadmill) at 100 F. In experiment four, heart rate variability was investigated without localized cooling as an index of stress. The six conditions of experiment four are reported in Table 2. In pilot experiments one, two, and three the same two subjects were utilized.

In experiment one there was significantly ($p < .05$) less stress in the neutral than in the heated environments. Lower stress was associated with lower heart rates, surface temperatures, core temperatures, sweat rates, and greater variability. With the cooling hood there was significantly ($p < .05$) less stress than without the hood; with the hood in the four temperatures, 99 F, 103 F, 107 F, and 112 F the standard deviation was lower than without the hood. Productivity was about 3.6% higher with the hood.

In experiment two the two subjects had 30 seconds to recall a five-by-five numeric matrix that had been presented for 45 seconds. A neutral (76 F) and a heat stress environment (107 F) were used. The subjects followed a work sequence of 15 minutes neutral and 60 minutes heat two full times and completed the test with 15 minutes in the neutral environment. While in the heat environments the subjects alternated wearing the cooling hood for the full hour exposures. No statistical evaluation was

Table 2

Interbeat Variability during Stress

Environmental Temperature	Task	Heart Rate	Std. Dev.(σ)	Coefficient of Variation $\sigma/\bar{x}$ (%)	N subjects x samples/ subject	Reference
76 F	idle	79	.058	7.6	150	Konz & Nentwich
	add	78	.056	7.7		
98 F	sedentary	82	.056	7.7		
	add	94	.042	6.6		
	walk	109	.018	3.3		
76 F	idle	80	.057	7.6		
76 F	anagrams	85	.034	4.8	240	Konz & Gupta
	anagrams	98	.022	3.7		
76 F	idle	--	.079	--	56	Sharma
112 F	walk	--	.020	--		
76 F	idle	77	.067	8.4	36	Aurora
112 F	walk	150	.019	4.2	36	
76 F	idle	80	.049	6.4	280	Cahill
	add	85	.038	5.4		
76 F	idle	79	.063	8.2	372	Konz & Cahill
76 F	file	82	.034	4.6	900	Santamaria

reported but for three of the four hood-no hood comparisons in heat the mean standard deviation of the interbeat interval was lower without the hood. This means that there was greater stress without the hood. For the productivity measure the results were inconclusive.

In experiment three the subjects walked on a level treadmill for twenty minutes and then sat for twenty minutes, walked twenty minutes, etc. Exposures lasted 60 minutes with a subject wearing the hood for the entire exposure. In general the increase in heart rate was approximately 10 beats per minute more without the hood than with the hood. The mean standard deviation of the interbeat interval decreased from about .020 seconds in a neutral environment to about .011 seconds in heat. No differences were established between wearing the hood or being exposed. No statistical analysis was reported.

Experiment four tested ten male undergraduates at: 1) 76 F sitting, 2) 76 F adding, 3) 98 F sitting, 4) 98 F adding, 5) 98 F walking, and 6) 76 F sitting. Neither the heart rate nor the interbeat variability was significantly different during the first three conditions. Heart rate increases from conditions three to four and four to five were significant ($p < .05$). Heart rate during condition six was significantly less than condition five. The mean rates for conditions one through six were 79, 78, 82, 94, 109, and 80 beats per minute, respectively. Similar results were reported for interbeat variability. For conditions one through six the respective mean standard deviations were .058, .060, .056, .042, .018, and .057 seconds. Conditions one, two, and three were not significantly different. The other conditions were significantly different (3<4, 4<5, and 5>6) at the 5% level. It was concluded that more work was needed to make interbeat variability applicable as an analytical tool.

Konz and Gupta (1969) cooled individuals with a water cooled hood in a heat stress environment. Eight subjects were exposed to a 76 F environment (30 minutes) and a 100 F environment (120 minutes) while performance and physiological data were gathered. The subjects were required to perform a mental task, anagrams, in both environments. Without cooling, the standard deviation of the interbeat interval dropped from .035 seconds in 76 F environment to .022 in heat and the coefficients of variation dropped from 5.0% to 3.7%. With cooling the changes were .033 to .029 seconds from 4.6% to 4.3% respectively. It was demonstrated that interbeat variability decreased when heat stress was added to mental work and that the variability decreased less, indicating less heat stress on the subjects, when the subjects were cooled.

Sharma (1970) evaluated an air cooled helmet system. Eight walking subjects were cooled in an environment of 112 F, 60% relative humidity (r.h.). It was found that the standard deviation of the interbeat intervals dropped from .079 to .020 seconds as a subject was exposed to heat. The average standard deviation, without cooling, dropped from .079 seconds in the neutral condition to .020 in the heat stress and from .062 to .021 with cooling. There was significantly ($p < .05$) less drop in the standard deviation during exposure when the subjects were cooled. Presumably, with cooling, the subjects were under less stress. Sweat and body temperatures confirmed this.

Aurora (1970) used air cooling on four subjects in three heat stress environments. All three environments were 100 F Effective Temperature.

In environment one (104 F, 90% r.h.) without cooling the standard deviation of the interbeat intervals dropped from .067 seconds before the experiment to .019 seconds in heat. With cooling the standard deviation dropped from .068 seconds in pretest to .035 in heat. Without cooling the coefficient of variation dropped from 8.4% to 4.2% in heat and with cooling the change was from 8.8% to 5.5% in heat. Environments two and three gave similar results. The standard deviations were tested and there was a significantly ($p < .05$) smaller drop during exposures when the subjects were cooled.

There appears to be general agreement that both heat and task stress reduce interbeat variability. Localized cooling has a favorable result in that the reduction in the iv is less; subjects are under less thermal stress. This is confirmed by sweat rates and body temperatures. Table 3 gives a review of the literature sited. A major consideration during mental task stress appears to be emotional loading and this could explain some differences in the literature.

Scoring Sinus Arrhythmia

Two methods of scoring sinus arrhythmia have already been discussed. Kalsbeck's method used control lines at plus and minus three, six, and nine beats per minute around a predetermined resting heart rate. An irregularity score is determined by assigning one, two, or three points depending upon where the rate lies relative to the control lines about the resting mean; one point is awarded for each deviation from the mean between three and six bpm, 2 points between six and nine bpm, and above 9 bpm 3 points. Thus, for each one-minute period of interest a seperate

Table 3

Summary of the Literature

Reference	Stress	Comment
Kalsbeck and Ettema (1965)	Mental Task	Variability reduced-task levels differentiated
Kalsbeck and Sykes (1967)	Mental Task	Variability reduced with task
Cahill (1969)	Mental Task	Work-rest differentiation only
Koster (1965)	Mental Task	Inconclusive results (only one subject)
Gibby, Gibby, and Townsent (1969)	Mental and Physical	Interbeat variability a stable parameter by subjects
Meers and Verhagen (1970)	Mental Task	Mental (emotional) stress an important variable
Konz and Nentwich (1969)	Thermal	Variability decrease in heat
Sharma (1970)	Thermal	Localized cooling is advantageous
Aurora (1970)	Thermal	Localized cooling is advantageous

score can be obtained by working with the cardiotachogram plot of instantaneous rate and control lines.

The second method was that used by Cahill and others. Using this method the raw data is the EKG rather than the cardiotachogram. Beat intervals are measured by hand from the EKG. Figure 1 shows an example of raw EKG data. These R-to-R peak intervals in millimeters are then used as inputs to a computer analysis. Intermediate steps include the transferral of the intervals from data sheets to computer cards. Outputs used for analysis include the heart rate, standard deviation of the interbeat interval, and the coefficient of variation.

Ettema (1965) discussed other methods presently available for scoring sinus arrhythmia and tested all of them on the same data. The first method tested was Kalsbeck's which has already been discussed at length. The "crossing" method was the next method discussed. Tolerance lines were visualized at three beat/minute intervals, but now independently of the mean. For every minute, the number of times the curve changes three beats was counted. In this way all the 'jumps' in the cardiotachogram corresponding to three beats per minute were counted.

The third method evaluated was the sum of the absolute difference between successive beats in terms of both beat time and frequency.

As explained by Ettama an irregularity index using beat times was obtained by adding all the differences between every two successive beats within a minute.

$$\text{Index} = \sum_{n-1}^{f} |T_n - T_{n-1}|$$

where:

- T time of beats in seconds
- f frequency number of beats in the minute
- f-1 corresponds to the first beat of the following minutes

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Figure 1

Raw EKG Data Showing Intervals

This index, expressed in terms of frequency, becomes:

$$\text{Index} - \sum_{n-1}^{f} \left| \frac{60}{Tn} - \frac{60}{T_{n-1}} \right| .$$

The fourth method discussed was the curvimetric method. This method was discarded as too costly. The length of the cardiotachogram curve needed to be measured for every minute and this length was the index. Ettma noted that the cardiotachogram curve would require a correction for paper speed as only the amplitude portion of the curve corresponded to the differences in frequency between successive heartbeats.

Of the three methods evaluated by Ettema, Kalsbeck's was the most discriminating. Twenty-four persons were tested at a 60 and 40 bits/minute auditory binary choice task and method one, Kalsbeck's method was the only one that gave significantly different values.

It appears from the literature that Kalsbeck's method and the method reported by Cahill and others have achieved the widest usage.

The Physiology of Sinus Arrhythmia

The irregularity of heart rhythm is called sinus arrhythmia. Clynes (1960) felt that the most important pattern attainable from heart irregularity data was respiratory arrhythmia. During inspiration the vagal tone is decreased and this results in an increased heart frequency. Vagal tone refers to the impulses of the vagus nurve which regulates the reactions of the major interior organs. Anrep (1936) found that when vagal tone was very low or very high the influence of respiration on heart rhythm was very small. In contrast, Davies (1966) found that only at very low respiration rates could a clear rise and fall of heart rate be seen.

The relationship of respiration and heart irregularity is indeed complex. Many hypothesis have been put forth but as yet unproven. Dimondi (1969), in a more recent investigation, hypothesized that blood return in the right heart was the stimulus of sinus arrhythmia. Ettema (1965) summarized the present state-of-the-art as follows: "During several conditions sinus arrhythmia is suppressed combined with an increase of heart frequency during mental load (Kalsbeck and Ettema, 1963-'65). This tends to the supposition that suppression of sinus arrhythmia is caused by a change of respiration (Angelone, 1964) and (or) a decrease of vagal tone during physical load and (or) an increase of vagal tone during mental load."

The finding of a relationship between sinus arrhythmia (or iv) and mental stress has generated much interest in determining the physiological justification of this association. Many more current articles will probably be written investigating and hypothesizing as to the causal relationships that are apparently in operation.

PROBLEM

As can be seen from the literature the variability of the interbeat interval, the iv, has been used as a stress index for both mental and physical (thermal) stresses. The purpose of this experiment was to evaluate the iv under both of these conditions and to determine its relative sensitivity. The goal of this experiment was to determine if a mental task could be distinguished from a sedentary situation in both a heated and a neutral condition.

Two levels of mental stress, sedentary and performing anagrams, were evaluated under two levels of thermal stress, heated and neutral. The iv was evaluated by means of the standard deviation and the coefficient of variation. Comparison criteria were heart rate, core temperature, performance during anagrams, and a subjective stress scale during all conditions.

METHOD

Overview

Eight subjects were exposed to two thermal environments, one being "comfortable" or neutral and the other heated. In each of these environments a subject was sedentary for one-half hour and performed anagrams for another half-hour. Thus, each subject was exposed to both a physical (thermal) stress and to a mental or task stress of anagrams.

Experimental Design

The time schedule for each trial is given in Table 4 and the testing schedule is given in Table 5. The sequences were balanced and the testing schedule established under the following criteria:

1. Allow sufficient time between sessions to insure total recovery of the confederate
2. Simplify thermal control of the chamber by having only one environment per day
3. Subject availability.

The subjects were questioned as to their availability for testing. Appropriate times were then established and posted as to the day and time. Subjects then signed this sheet on a first come first serve basis. Following this method only one subject needed to adjust his schedule.

The subjects were tested by twos and a confederate was also tested with each group.

Mental Stress

Half of the time a subject was performing anagrams and the remainder of the time he was resting. This occured in both environments.

Table 4

Time Schedule for Each Trial

Minutes From Beginning	Event
0-15	1. Remove personal clothing
	2. Don standard uniforms
	3. Attach instrumentation
	4. Subjects seated in pretest room
15-30	1. 3 basal recordings (1 every 5 minutes) of EKG and core temperature
	2. Subjects enter the chamber
30-60	1. Test Period 1— See Table 6
	2. 6 recordings of EKG and core temperature
	3. Complete subjective stress form
60-90	1. Test Period 2— See Table 6
	2. 6 Recordings of EKG and core temperature
	3. Complete subjective stress form
	4. Subjects leave chamber
90-105	1. Subjects seated in pretest room
	2. 3 recovery recordings of EKG and core temperature
105-120	1. Remove and clean instrumentation
	2. Subjects dress and depart

Table 5

Schedule of Conditions

Day	Time	Subject Numbers	One Hour Exposure: Condition 1 (1/2 hr.)	One Hour Exposure: Condition 2 (1/2 hr.)
Tue.	9:00 - 11:00 a.m.	1,2,C*	N	NA
	1:00 - 3:00 p.m.**	3,4,C	NA	N
Wed.	9:00 - 11:00 a.m.	5,6,C	H	HA
	1:00 - 3:00 p.m.	7,8,C	HA	H
Thur.	9:00 - 11:00 a.m.	1,2,C	HA	H
	1:00 - 3:00 p.m.	3,4,C	H	HA
Fri.	9:00 - 11:00 a.m.	5,6,C	NA	N
	1:00 - 3:00 p.m.	7,8,C	N	NA

N = 75 F at 60% r.h. = 71.0 E.T.

NA = N plus anagram task

H = 110 F at 50% r.h. = 95.2 E.T.

HA = H plus anagram task

* C = Confederate

** Due to equipment failure this session was rerun the following Monday from 1:00 - 3:00 p.m.

Resting. In this thesis subjects were sedentary, operationally defined as seated and engaged in conversation or magazine reading when they were not performing the task. During a one hour exposure they remained seated and half the time were resting or sedentary and the other half of the time were performing the task.

Task. The subjects were required to sit quietly and solve a self paced number of anagrams (Gupta, 1969) twice, once in heat, and once in a neutral environment. Table 6 shows a sample page of anagrams. Every five minutes the subjects received a new page to solve.

Each problem page had three sets of eight letters. Each letter was selected with a random number table. Each letter in the table was represented in proportion to its frequency of use in the English language. For example, the letter "O" was assigned 8.00% of the random numbers as this is its occurance rate (Gaines, 1956). Restrictions were made in the selection of the groups of eight letters that no letter could occur more than twice and there were at least two but not more than five vowels.

During the five minutes allowed per page the subject formed words from any of the three sets of letters. Only letters from one set were allowed for forming of any specific word. The subjects had the same problem sets simultaneously. Any English word more than two letters long including places, but excluding names and abreviations was allowed. The American College Dictionary served as the standard. The performance measure was acceptable words formed per five minute period.

Table 6

Sample Anagram

T A H T C G G E

N I N B E T E T

C E N I G D O T

Confederate. The purpose of the confederate was to add emotional stress (Meers and Verhaegen, 1970) to the task situation. He was to accomplish this by generating more words than the subjects. Since he was located in the center of an eight foot table, the subjects, located on each end of the table could see him generating words at a greater rate. Figure 2 shows the relative positions of all subjects during test conditions. The confederate is located in the center.

Physical Stress

In this thesis two levels of physical (thermal) stress were utilized, one was a neutral level and the other was a heated level.

Neutral Level. Much thermal research has been performed in the environmental test chamber at the Institute for Environmental Research, Kansas State University. Nevins, Rohles, and Feyerherm (1966) developed an initial comfort range and Rohles (1970) extended this. Rohles determined that for male college age (19-24 yrs.) adults the subjects were comfortable at 75 F and 60% relative humidity (r.h.). This was for one hour exposure of sedentary subjects clothed in uniform garments.

In this thesis subjects were sedentary or performing anagrams and they were clothed in the standard garments described by Rohles (1970). Exposures lasted one hour. The uniform consisted of cotton pants, shirts, socks, and shorts. Figure 3 shows a subject wearing this uniform. Everything except the shorts was furnished. The environment in the neutral (N) or neutral with anagram (NA) conditions was established at 75 F at 60% r.h. (Rohles, 1970) or 71.0 F Effective Temperature (E.T.).

Figure 2

Testing Positions

The Confederate is Located in the Center.

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

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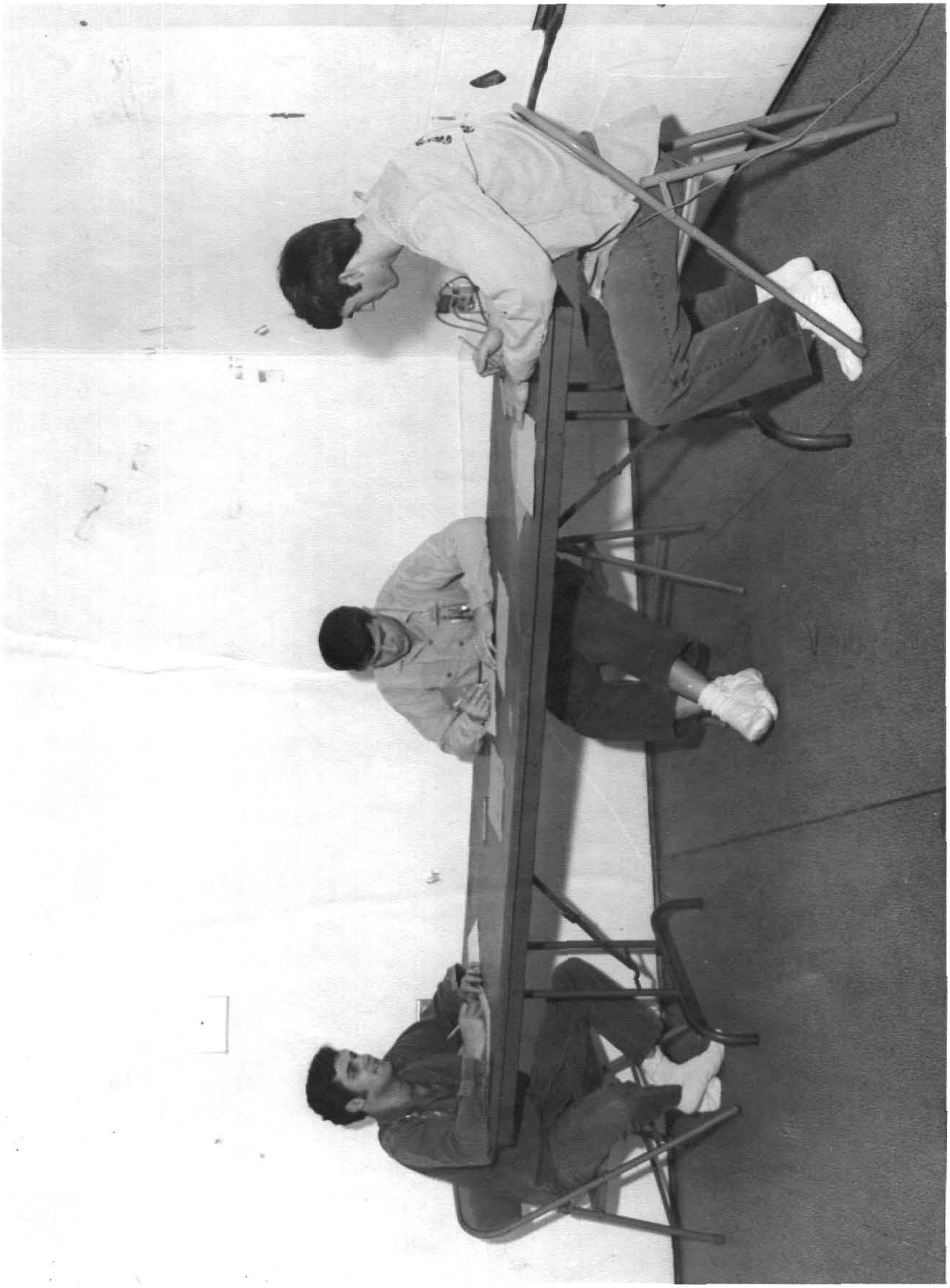


Figure 3

Subject in Standard Uniform

Heated Level. Rohles, Nevins and Springer (1967) established some guidelines under conditions of high thermal stress. Using male subjects clothed in shorts they determined that environments between 86.8 F Effective Temperature (E.T.) and 91.3 F E.T. were thermally nonstressful, those between 92.9 F E.T. and 95.5 F E.T. were transitional and those from 97.0 F E.T. to 100+ F E.T. were stressful. Their criteria was a two degree artificial temperature rise within four hours.

Initially, the environment during the heated (H) and heat with anagram (HA) exposures was established at 110 F and 60% r.h. (98.0 F E.T.) but due to the limitations of the heating equipment 110 F 50% r.h. (95.2 F E.T.) was run. The equipment was unable to both heat and add sufficient moisture to the cold dry winter air.

The sedentary subjects, therefore, were exposed to two environments, heated (95.2 F E.T.) and comfortable or neutral (71.0 F E.T.), for one hour in each. During this hour they were solving anagrams for half the time and conversing or reading magazines for the other half. In any one day subjects were exposed to two one-half hour tasks, reading-conversing and anagrams, in one environment.

Subjects

Prospective subjects answered a newspaper advertisement describing a need for paid subjects in an environmental study. They were given an initial briefing describing the task; only English words, no abbreviations, etc.; and then any questions were answered. They were then presented three pages of anagrams similar to Table 6 and they had five minutes per page to form as many acceptable words as they could. Table 7 gives

Table 7

Preselection Anagram Test

Subject	Word Output	Result
A	15	rejected
B	37	stand-by*
C - 8	38	Accepted
D - 7	40	Accepted
E - 6	44	Accepted
F - 1	51	Accepted
G - 4	56	Accepted
H - 3	59	Accepted
I - 2	59	Accepted
J - 5	59	Accepted
K	68	Stand-by.
L	69	Confederate
M	74	Standy-by
N	107	Standy-by*

* failed pretest physical: rejected.

the total words generated in the 15 minutes by each person who answered the advertisement as well as the previously selected confederate. Subject A was rejected due to the fact that English was not his native language. Subject B was accepted as a standby subject while subjects K, M, and N were accepted as standby confederates.

All eight subjects plus the four standbys and the confederate were then given physical examinations as a safety precaution for the heat exposures. This was a standard examination consisting of a review of medical history, heart rate, blood pressure, and blood count. Subjects B and N failed the physicals and were rejected. All rejected subjects and standbys were paid $1.50 for their trouble.

The selected subjects, all having demonstrated lesser skill than the confederate, were then told they would be paid $10 for two test sessions of two hours each. They were questioned as to their availability for testing and a compromise schedule was worked out. The next day they returned and signed up for a session that fit their schedule. These sign up numbers are given in Table 7. Subjects 1 and 2 signed up for Tuesday and Thursday morning, subjects 3 and 4 signed up for Tuesday and Thursday afternoon, etc. General subject information may be found in Table 8.

Besides the $10 for experiment pay each subject also received one cent for each acceptable word formed during the test sessions. Between this bonus and the presence of the confederate, who was superior on the task, it was hoped to add more mental (emotional) stress to the task.

Measurements

Performance. During the anagram phases of the experiment an intercom buzzer was used to signal the subjects. The first buzz was the signal to

Table 8

Subject Information - Male College Students

Number	Age	Weight	Height	Major	Year
1	20	170	5'10"	General	Fresh.
2	19	137	5' 9"	Geography	Soph.
3	21	185	5'11"	Business	Sr.
4	20	175	5'10"	Business	Jr.
5	19	155	5'10"	History	Soph.
6	21	146	6' 0"	Geology	Soph.
7	23	160	6' 0"	Pre-Med	Sr.
8	19	155	5'11"	General	Soph.
Confederate	23	170	5' 9"	Engineering	Grad.

start the task. Every five minutes thereafter a buzz meant for the subjects to turn the page and continue working. The final buzz meant to stop working and to complete a questionaire. For every five minutes of the half-hour of anagrams the subjects solved a new page for a total of six pages per test. The productivity measure was words formed per five minute period.

Physiological. Both the electrocardiogram (EKG) and the internal (core) temperature of the anal canal were recorded for each subject at the end of every five minutes during all conditions. Thus for each half-hour test there were six simultaneous recordings of EKG and core temperature for each subject.

Comfort. At the end of each half-hour session, the subjects were signaled with the intercom. They then completed a subjective stress form. This form was adopted from a "Subjective Stress Scale" (Berkun, Bislek, Kern, and Yagi, 1962) and is presented in Table 9. The scale is a ranked list of words used to describe a specific situation. Table 10 gives the ranking of each word. The neutral or midpoint on the scale is the word "indifferent," whose scale value is 48. Groups under normal, mildly positive conditions generally have a mean score of less than 32; they are more positive than indifferent. Under stress conditions scores above 48 are expected.

Apparatus

Test Facility. The environmental test chamber at the Institute for Environmental Research, Kansas State University, was used for the experiment. Nevins, Rohles, and Feyerherm (1966) described this facility in

Table 9

Subjective Stress Form

Circle the one word or phrase in each group which best describes your feelings about the previous test session.

General Feelings	Feelings about Temperature	Feelings about Task
in agony	terrible	fine
wonderful	wonderful	comfortable
didn't both	fine	terrible
unsteady	worried	timid
unsafe	didn't bother me	frightened
nervous	in agony	steady
fine	indifferent	didn't bother me
steady	comfortable	unsteady
worried	unsafe	indifferent
frightened	scared stiff	worried
comfortable	nervous	nervous
indifferent	frightened	terrible
scared stiff		wonderful
timid		in agony

Table 10

Subjective Stress Scale Values

Item	Scale Value On Score
wonderful	00
fine	09
comfortable	17
steady	27
didn't bother me	40
indifferent	48
timid	57
unsteady	64
nervous	69
worried	74
unsafe	76
frightened	83
terrible	87
in agony	92
scared stiff	94

detail. Within the 12' by 24' by 8' chamber, temperature, humidity, and air velocity can be maintained at predetermined values. Figure 4 shows the layout of the test chamber and adjacent rooms.

The control room adjacent to the test chamber was used to house monitoring equipment. Figure 5 shows the control room and related equipment. Adjacent to the control room is the pretest room. The pretest room is where the subjects dressed and other arrangements such as electrode attachment, were accomplished.

Heart Rate Monitoring. Heart beats of the subjects were recorded by a Beckman Dynograph (Type RS). Two E and M Instrument Co. surface electrodes were attached to each subject's chest. This subject instrumentation may be seen in Figure 3. An E and M Instrument Company Telemetry unit consisting of three Transmitters FM-1100-E2, each operating on a different frequency, and a Receiver FM-1100-6 was used to transmit the heart beats from the surface electrodes of the three test subjects to the dynography. The dynograph was operated at a paper speed of 25 mm/sec.

Temperature Monitoring. As a criterion and as a safety precaution, rectal temperatures were recorded. A Yellow Springs Instrument Model 401 termistor was inserted 6 inches (15 cm) into the subjects anal canal. The thermometer leads were then connected by a junction box to a digital thermometer. This United Systems Corporation, model 500, digital thermometer can measure and visually display the thermister temperatures to an accuracy of 0.1 F (0.55C) in a range of 59 to 122 F (15 to 50 C).

A temperature print out capacity was provided by a United Systems Corporation Manual Identification Unit, Model 651. The unit has a total

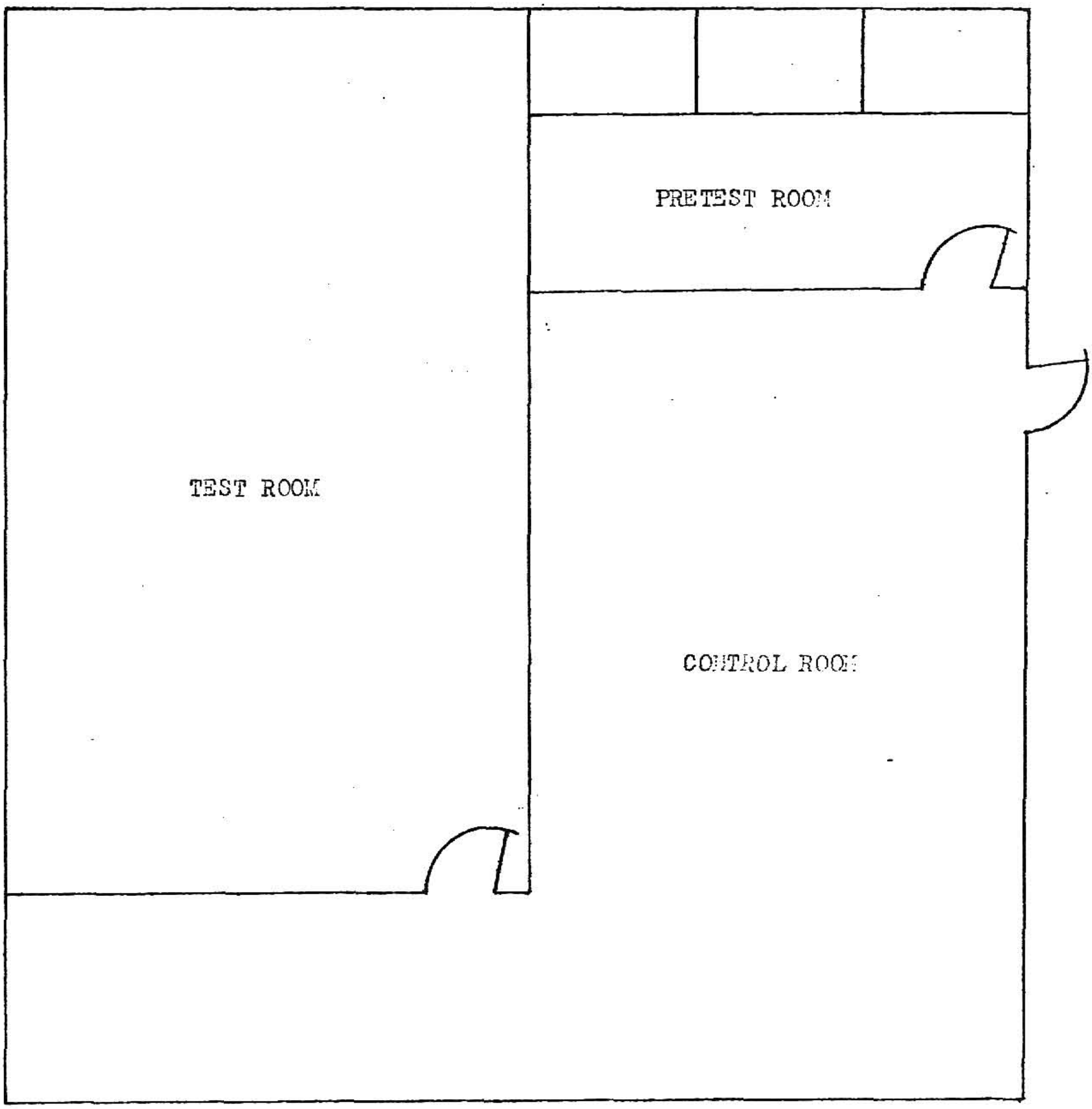
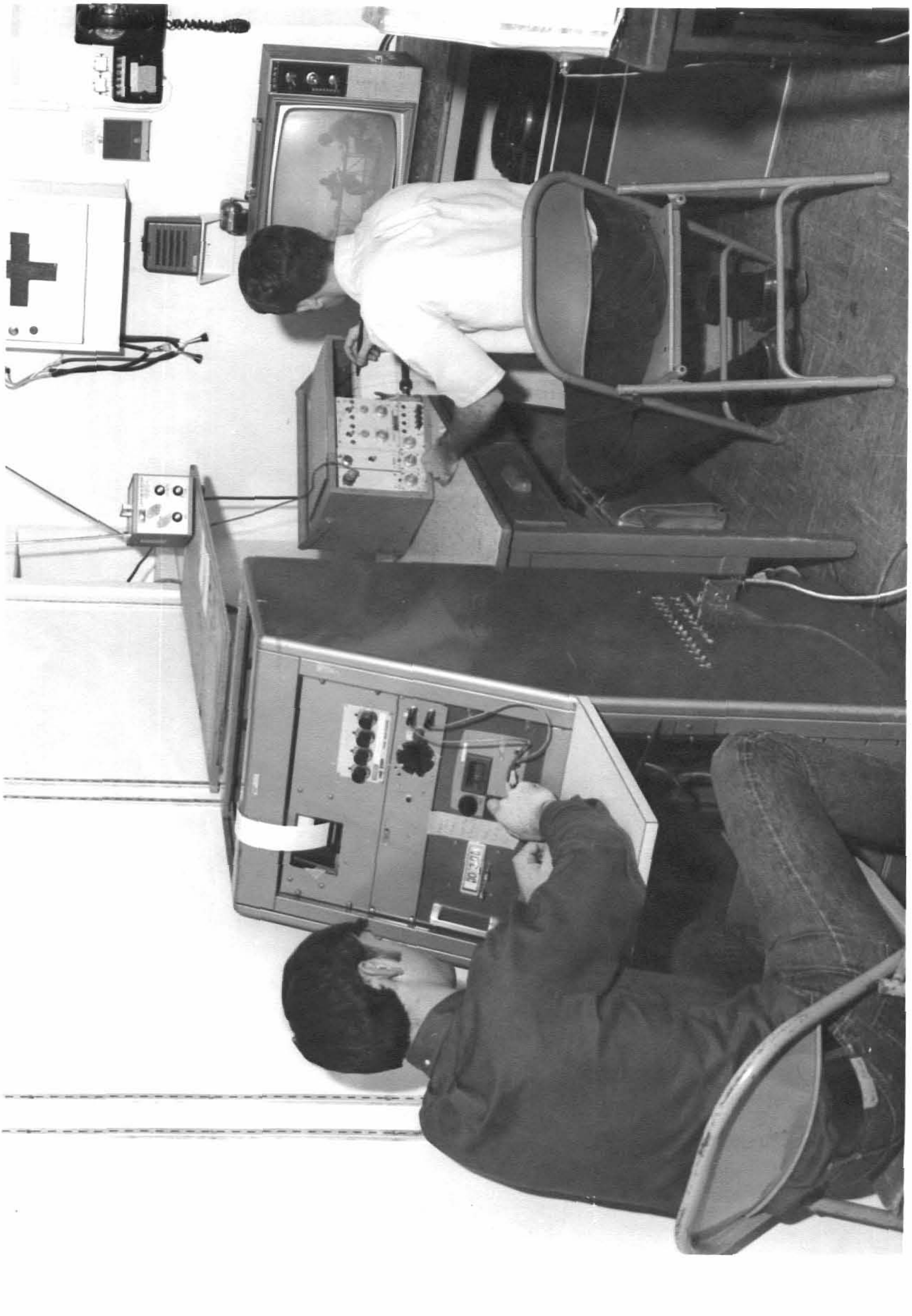


Figure 4

Floor Plan of Test Facility

Figure 5

Layout of Control Room



of eight information columns available; the first four columns, which are selected, are for identification and the last four are for temperature to the nearest 0.1 F.

Visual Monitoring. The subjects while in the test chamber were continuously monitored by closed circuit television. A Sony Video Camera, model VCK-2100A, was connected to a Sony Video Recorder, model CV-2100, which in turn was connected to a Sony TV monitor, model CVM-1800. The camera, fitted with a wide angle lens, was located within the chamber while the monitor and recorder were placed in the control room.

Audio Communications. While in the chamber subjects were instructed by an intercom call signal. Two wireless intercoms, Radio Shack Division of Tandy Corporation, Catalog Number 43-225, were used.

RESULTS

Data Analysis

All physiological performance and subjective measures (see Appendicies) were statistically analyzed by means of four-way analyses of variance (ANOVA). The K.S.U. Department of Statistics and Computer Science, "AARDVARK" program was utilized. Using this fixed model analysis, significance was established at the .05 level. For the physiological measures the ANOVA utilized the following variables:

	d.f.
H = heat or no heat	1
A = anagrams or no anagrams	1
S = subjects	7
R = replications or periods	5

The statistical analysis of productivity and the "subjective stress scales" are discussed in their respective areas.

Physiological Measures

Due to equipment failure no physiological measures were obtained for subjects three or four on Tuesday afternoon (see Table 5). The test however was run to completion thus subjective and performance information was recorded for this day. The test was rerun six days later and this was the source of the physiological data recorded.

Heart Rate. Table 11 gives the average heart rate in beats per minute (bpm) by condition for all eight subjects. The six periods

Table 11

Average Heart Rate (beats/minute)

by Subject and Condition

Subject	Condition: Neutral	Neutral plus Anagrams	Heat	Heat plus Anagrams	Subject Average
1.	73.9*	70.2	97.8	83.1	81.2**
2.	82.0	80.2	115.3	110.8	97.0
3.	74.6	80.8	99.3	120.6	93.8
4.	67.6	72.3	95.1	108.1	85.7
5.	85.9	104.5	100.8	113.6	101.3
6.	59.9	67.6	88.9	113.5	82.5
7.	84.9	90.0	113.6	102.2	97.6
8.	67.0	62.7	88.6	81.0	74.8
Mean	74.5	78.5	99.9	104.1	89.3***

* means of 6 periods each

** means of 24 periods each

*** mean of 192 periods

per half hour condition were averaged and these are reported in the body of the table. The subject averages are the means of all 24 periods per subject while the final average of 89.3 bpm is the average of all 192 recordings (24 periods/subject x 8 subjects.)

Table 12 presents the four-way ANOVA of the heart rate. All variables and interactions are considered and all significant effects ($p < .05$) are identified.

There were significant ($p < .05$) effects for heat, anagrams, and subjects. Heart rates were higher with heat and anagrams and individual differences existed. There was also a significant interaction of subjects by heat; three subjects had higher mean rates during heat of approximately 20 beats per minute, three were approximately 30 beats per minute higher, one was only about 10 beats per minute higher and another was about 40 beats per minute higher in heat. A subject by anagram significant interaction existed in which four subjects had higher mean rates and four had lower mean rates while performing anagrams. In the case of the significant heat by replication or period interaction temperatures rose for the first three periods and then leveled off for the duration. A three-way interaction also existed between subjects, heat, and anagrams.

It is evidenced from Table 11 that there were considerable individual differences and subjects generally had higher rates in heat than they did in neutral conditions. The mean heart rates in beats per minute (bpm) were 74.5 in the neutral condition, 78.5 in neutral with anagrams, 99.9 in heat, and 104.1 in heat plus anagrams.

Interbeat Variability. Two measures of interbeat variability were considered in this experiment; they were the standard deviation and the

Table 12

Analysis of Variance of Heart Rate

Variable	d.f.	mean square	F
H	1	31304.3671	417.20*
A	1	809.8457	10.79*
S	7	2148.9272	28.63*
R	5	173.9544	2.31
SH	7	475.9641	6.34*
SA	7	669.9836	8.92*
SR	35	45.1748	0.62
HA	1	0.2962	0.00
HR	5	223.0850	2.97*
AR	5	46.8720	0.60
SHA	7	217.2551	2.89*
SHR	35	29.7991	0.39
HAR	5	27.3556	0.36
SAR	35	39.9804	0.53
ERROR	35	75.0341	
TOTAL	191		

* .05 Level of Significance

coefficient of variation. Both measures were considered by period (see Appendix 1). The standard deviation may be considered an absolute measure of variability while the coefficient is a relative measure. The coefficient of variation for any particular period was the standard deviation of that period in seconds divided by the mean interbeat interval of that period in seconds.

Standard Deviation. Table 13 gives the average standard deviation by subject and condition. The average of six periods per condition are reported in the body of the table. The subject averages are the means of all 24 recordings per subject and the over-all mean of 0.040 seconds is the mean of 192 periods (24 recordings/subject x 8 subjects).

Table 14 presents the analysis of variance of the standard deviation. The four variables of heat, anagrams, subjects, and replications or periods and all of their interactions are considered. The variables heat, anagrams, and subjects and the interaction of subjects and heat were all significant ($p < .05$).

The mean standard deviation in seconds (see Table 13) decreased from 0.061 seconds in the neutral state to 0.045 in neutral plus anagrams to 0.031 in heat and ultimately to 0.025 seconds in heat plus anagrams. The analysis of variance (see Table 14) demonstrated significance for the main effect of heat. A lower mean standard deviation of the iv occured in heat. It is also seen that anagrams were a significant variate. During anagrams subjects had a lower standard deviation of the iv. Thus subjects were under greater stress, as indicated by this decrease, when in heat or when solving anagrams. Significant subject differences also existed. A subject by heat interaction also

Table 13

Average Standard Deviation (seconds) by Subject and Condition

Subject	Condition: Neutral	Neutral plus Anagrams	Heat	Heat plus Anagrams	Subject Average
1.	0.090*	0.068	0.041	0.039	0.060**
2.	0.044	0.051	0.020	0.017	0.033
3.	0.052	0.026	0.026	0.022	0.032
4.	0.073	0.059	0.039	0.020	0.048
5.	0.045	0.021	0.021	0.013	0.025
6.	0.084	0.060	0.029	0.018	0.048
7.	0.077	0.036	0.039	0.020	0.043
8.	0.029	0.040	0.036	0.031	0.034
Mean	0.061	0.045	0.031	0.025	0.040***

* means of 6 periods each

** means of 24 periods each

*** mean of 192 periods

Table 14

Analysis of Variance of Standard Deviation

Variable	d.f.	Mean Square	F
H	1	0.0322	98.46*
A	1	.0072	22.20*
S	7	.0030	9.17*
R	5	.0003	1.16
SH	7	.0013	4.19*
SA	7	.0006	2.10*
SR	35	.0004	1.31
HA	1	.0005	1.58
HR	5	.0002	0.85
AR	5	.0000	0.08
SHA	7	.0004	1.25
SHR	35	.0003	1.09
HAR	5	.0000	0.26
SAR	35	.0004	1.35
ERROR	35	.0003	
TOTAL	191		

* .05 Level of Significance

occured in that some subjects exhibited a much greater decrease than others and one subject demonstrated no change at all.

Coefficient of Variation. Table 15 gives the average coefficient of variation by subject and condition. The table values are the means of the six periods per half-hour condition (see Appendix 1) by subject. The subject averages are the means of 24 periods, six in each condition, for each subject. The total average of 0.055 or 5.5% is the mean of 192 periods (24 periods/subject x 8 subjects). The coefficient itself is the ratio of the period standard deviation in seconds divided by the period mean interbeat interval (see Appendix 1) in seconds.

The mean coefficient of variation of the iv (see Table 15), similar to the mean standard deviation, decreased with increasing stress; neutral condition (7.5%), neutral plus anagrams (5.6%), heat (5.2%) and heat plus anagrams (3.8%). In the neutral environment the addition of anagrams caused a mean reduction of 13.4% (5.6/7.5) and the addition of anagrams to the heat environment resulted in a 13.7% (3.8/5.2) reduction.

Table 16 gives the analysis of variance of the coefficient of variation. The variables of heat, anagrams, and subjects were all significant ($p < .05$); subjects demonstrated lower coefficients while in heat and while doing anagrams. Significant individual differences also existed. Two-way interactions existed for subjects by heat and subjects by anagrams. For the subjects by heat interaction six subjects had lower mean coefficients in heat, one subject demonstrated no change, and one subject had a higher mean coefficient in heat. For the subjects by anagram interaction one subject had a 5% decrease in mean coefficient

Table 15

Average Coefficient of Variation by Subject and Condition

	Condition				
Subject	Neutral	Neutral plus Anagrams	Heat	Heat plus Anagrams	Subject Average
1.	0.110*	0.077	0.067	0.052	0.076**
2.	0.060	0.068	0.039	0.031	0.049
3.	0.064	0.035	0.043	0.045	0.47
4.	0.082	0.070	0.061	0.037	0.063
5.	0.063	0.036	0.036	0.025	0.040
6.	0.083	0.069	0.044	0.035	0.058
7.	0.109	0.052	0.071	0.033	0.066
8.	0.031	0.041	0.051	0.042	0.042
Mean	0.075	0.056	0.052	0.038	0.055***

* means of 6 periods each

** means of 24 periods each

*** mean of 192 periods

Table 16

Analysis of Variance of Coefficient of Variation

Variable	d.f.	mean square	F
H	1	0.0213	53.73*
A	1	.0134	33.82*
S	7	.0039	9.96*
R	5	.0006	1.61
SH	7	.0015	3.78*
SA	7	.0013	3.50*
SR	35	.0007	1.78
HA	1	.0003	0.81
HR	5	.0004	1.04
AR	5	.0000	0.01
SHA	7	.0005	1.34
SHR	35	.0006	1.53
HAR	5	.0002	0.57
SAR	35	.0005	1.49
ERROR	35	.0003	
TOTAL	191		

* .05 Level of Significance

with anagrams three subjects had a 2% decrease, two subjects decreased 1% and two subjects demonstrated no change in mean coefficient of variation with the addition of anagrams.

Core Temperature. Table 17 presents the average core temperature (F) by subject and condition. The temperatures reported within the body of the table are the average of the six periods per condition for each subject. The subject averages are the mean of the total 24 periods for each subject and the total mean of 99.1 F is the average of the total of 192 periods analyzed.

Table 18 is the analysis of variance of core temperature. The main four variables as well as all interactions were considered. All variates significant at the 5% level or less are identified.

By observation (see Table 17) of the mean core temperatures (F) it appears that instead of four conditions this criterion distinguishes only two conditions, either neutral, means of 98.9 F, and 98.8 F, or heated, mean of 99.4 F. The analysis of variance of this data (see Table 18) recognizes eight significant variables and interactions, heat being only one. All subjects did have higher core temperatures in the heated environment and once again, subjects were significantly different.

For the first time, replications or periods were significant. This signifies that as time went on core temperatures became higher. The interactions of subjects by heat and subjects by anagrams were also significant and seven of the eight subjects had higher core temperatures in heat and four in anagrams. The heat-anagram interaction indicated that when the task was added to the neutral environment temperatures went down but they went up with anagrams in heat. For the heat-replication

Table 17

Average Core Temperature (F) by Subject and Condition

	Condition				
Subject	Neutral	Neutral plus Anagrams	Heat	Heat plus Anagrams	Subject Average
1.	98.8*	98.5	99.4	99.0	98.9**
2.	98.4	98.3	98.7	98.1	98.4
3.	99.4	99.6	99.6	100.0	99.6
4.	98.8	99.0	99.5	100.2	99.4
5.	98.8	98.8	99.2	99.9	99.1
6.	98.7	98.8	99.0	99.5	99.0
7.	99.1	99.0	99.8	99.4	99.3
8.	99.0	98.7	99.8	99.4	99.2
Mean	98.9	98.8	99.4	99.4	99.1***

* means of 6 periods each

** means of 24 periods each

*** mean of 192 periods

Table 18

Analysis of Variance of Core Temperature

Variable	d.f.	mean square	F
H	1	13.1253	681.21*
A	1	0.0033	0.17
S	7	3.3987	176.39*
R	5	0.1337	6.93*
SH	7	0.5074	26.33*
SA	7	0.7196	37.34*
SR	35	0.0154	0.80
HA	1	0.1301	6.75*
HR	5	0.4215	21.87*
AR	5	0.0311	1.61
SHA	7	0.2910	15.10*
SHR	35	0.0088	0.45
HAR	5	0.0125	0.65
SAR	35	0.0230	1.19
ERROR	35	0.0192	
TOTAL	191		

* .05 Level of Significance

interaction temperatures fell with time in the neutral but rose, over time, in heat. The three-way interaction of subjects by heat by anagrams was also significant.

A special ANOVA was run to determine if this criterion was stable over time, A.M. versus P.M. This did involve confounding in that A.M. subjects, 1, 2, 5 and 6, were compared to P.M. subjects 3, 4, 7 and 8. The morning subjects had significantly ($p < .05$) lower core temperatures than the afternoon subjects.

Performance

Table 19 gives the average word production rate by subject and presentation order (see Appendix 2). Subjects 1, 2, 3, and 4 solved anagrams in heat during their second day while subjects 5, 6, 7 and 8 had anagrams in heat during their first day (see Table 5). All other rates were determined from anagrams solved in the neutral environment. As the subjects had five minutes per page of anagrams, the rate is presented in terms of word output per five minutes. Presentation three for subjects 3 and 4 and presentation 10 for the confederate was the retest session.

Table 19 also includes the production rates of the confederate by presentation order. A comparison of the mean production rates for all the subjects and the rates of the confederate are given in Figure 6. In that the confederate was tested with all four subject pairs, three times as much data was obtained from him. An ANOVA was made of the means to determine if heat was a significant factor. By this analysis neither heat nor subjects were significant ($p < .05$) variates. Performance was not affected significantly by the presence of heat. The main consideration was that

Table 19

Word Production Rate (words/5 minutes)

by Subject and Presentation Order

	Presentation Order											
	0**	1	2	3	4	5	6	7	8	9	10	Mean
1.	17.0	23.0	28.3*									25.8
2.	19.5	22.1	26.5*									24.3
3.	19.5	22.5	22.3*	25.0***								22.3
4.	18.5	24.5	26.8*	23.5***								23.3
5.	19.5	25.8*	34.5									27.3
6.	14.5	25.8*	33.0									27.3
7.	13.0	21.6*	30.0									25.5
8.	12.5	19.0*	24.1									24.0
Mean	16.8	23.0	28.2	24.3								24.9
Con-federate	23.0	28.0	35.0	40.0	44.0	43.0	46.5	57.5	54.0	51.0	43.0***	

* heated environment

** pretest

*** retest

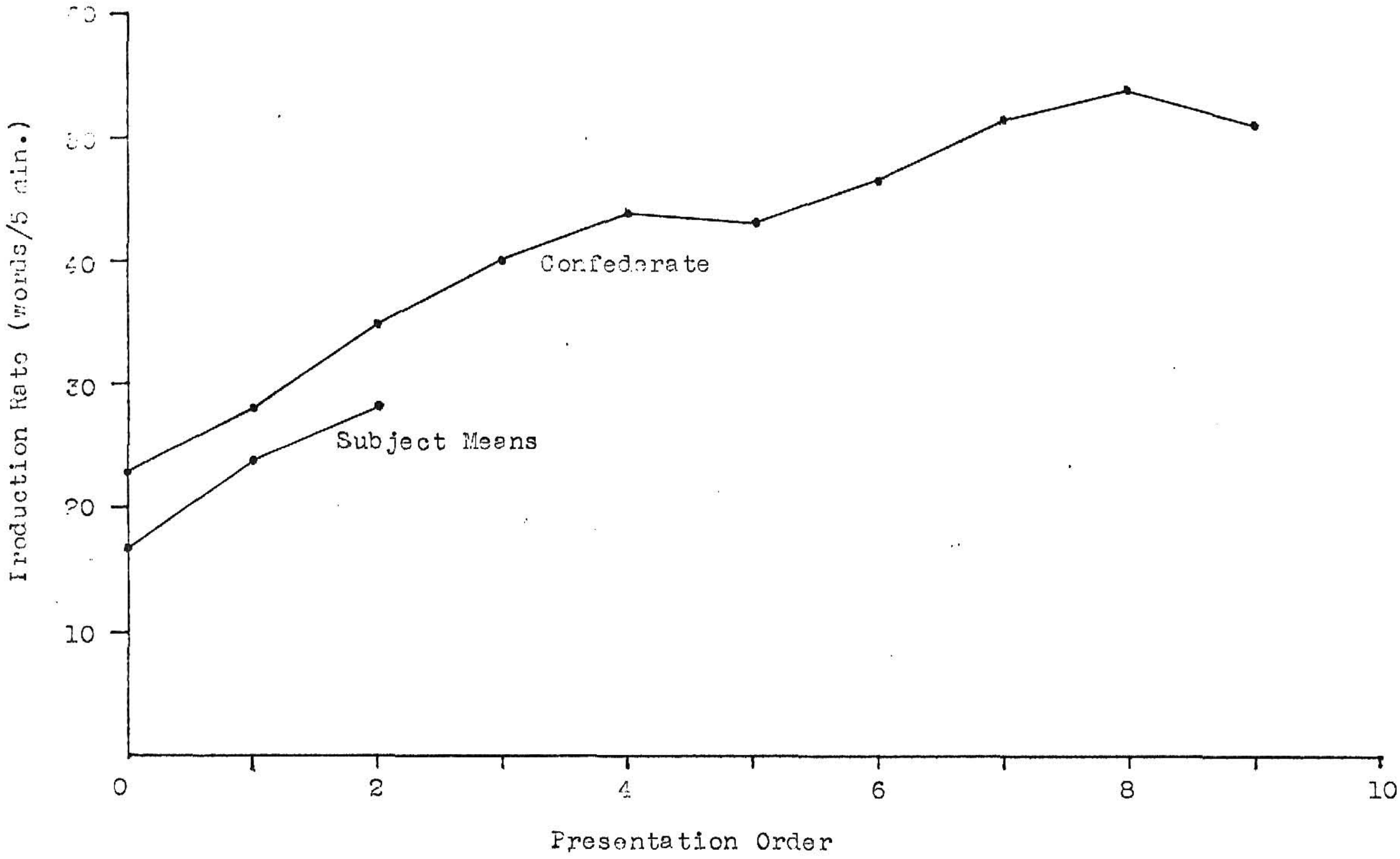


Figure 6 Mean Production Rates by Presentation Order

there was significant ($p < .01$), by Wilcoxon (one tail), improvement, presumably learning, involved with this task. Subjects solved more anagrams with each presentation regardless of the presence of heat.

Subjective Measure

Table 20 presents the average subjective stress votes by subject and condition. Each table value is the mean of three votes, one for general feeling, one for the task and one for the environment (see Appendix 2). The scale midpoint is a value of 48, this scale word being "indifferent". One vote was taken at the end of each half-hour of testing.

An analysis of variance of the main variables of heat, subjects and anagrams and all their interactions was made. There was a significant ($p < .05$) heat effect and subjects were significantly different. All other variates were insignificant. Table 21 gives the analysis of variance of the subjective measure.

Table 20

Mean Subjective Stress Votes

by Subject and Condition

	Condition				
Subject	Neutral	Neutral plus Anagrams	Heat	Heat plus Anagrams	Subject Mean
1.	48*	48	74	61	58.8
2.	30	31	89	70	55.0
3.	09	09	31	41	22.5
4.	30	12	74	74	47.5
5.	11	28	29	71	34.8
6.	00	19	35	25	19.8
7.	17	34	51	66	42.0
8.	06	03	48	52	27.3
Mean	19	23	55	58	38.5

* The scale midpoint is the word "indifferent," scale value 48. Values above this are considered stressful and scores below this are considered more positive than indifferent.

Table 21

Analysis of Variance of Subjective Measure

Variable	d.f.	Mean Square	F
H	1	8096.2812	60.64*
A	1	7.0312	0.05
S	7	1065.5668	7.98*
SH	7	163.7812	1.22
SA	7	271.1025	2.03
HA	1	81.2812	0.60
ERROR	7	133.4921	
TOTAL	31		

*.05 level of significance

DISCUSSION

Table 22 gives a summary of the significant condition differences demonstrated by the criteria utilized in this experiment. Table 23 presents all the criterion means by condition. From Table 22 it can be seen that all the measures associated with the heart, both rate and iv, were able to distinguish both the physical (heat) and the mental (task) stress. The heart rate, the standard deviation and the coefficient of variation of the interbeat interval successfully distinguished the heated from the neutral environment and the anagrams from a sedentary task. The other measures, core temperature and the subjective scale, were unable to do this.

Core temperature and the subjective scale were limited to distinguishing between heated and the neutral environments; no significance was found for the mental task to sedentary comparisons. Performance was not significantly affected by the addition of heat.

The criterion means (Table 23) were expressed in terms of standardized scores relative to the neutral condition. These z's, in absolute values, are presented in Table 24 and Figure 7 presents a plot of these z's by condition.

Wing (1965) in reviewing some of his earlier work, tested 15 subjects for one hour in Effective Temperatures (E.T.) of 72 F, 90 F and 95 F. The subjects performed a paced short-term word list recall task for the last 50 minutes of the hour exposure. Wing found a significant ($p < .01$) performance decline in the 95 F E.T. environment over the 72 F E.T. Wing noted that other authors have been unable to find any statistically reliable decreases in performance for one hour exposures at 91.5 F

Table 22

Summary of Criterion Significances

by Analysis of Variance

Criterion	Heat(H)	Anagrams(A)	Interaction(HA)
Heart Rate (beats/min.)	*	*	NS
Standard Deviation (sec.)	*	*	NS
Coef. of Variation	*	*	NS
Core Temperature (F)	*	NS	*
Performance (during task)	NS	--	--
Subjective	*	NS	NS

* = $p < .05$

NS = Not Significant

Table 23

Criterion Means by Condition

	N	NA	H	HA
Heart Beat (beats/min.)	74.5	78.5	99.9	104.1
Std. Dev. (sec.)	.061	.045	.031	.025
Coef. of Var. (%)	7.5	5.6	5.2	3.8
Core Temp (F)	98.9	98.8	99.4	99.4
Performance (production rate)	--	26.7	--	24.5*
Subjective (scale value)	19	23	55	58

* does not include retest session

Table 24

Criterion z Scores (Absolute Value)

by Condition

Criterion	Neutral plus* Anagrams (NA)	Heat (H)	Heat plus Anagrams (HA)
Heart Rate (beats/min.)	.03	.25	.29
Std. Dev. (sec.)	.14	.26	.31
Coef. of Variation (%)	.17	.21	.34
Core Temp. (F)	.05	.24	.24
Subjective (scale)	.08	.68	.75

*Neutral equals zero

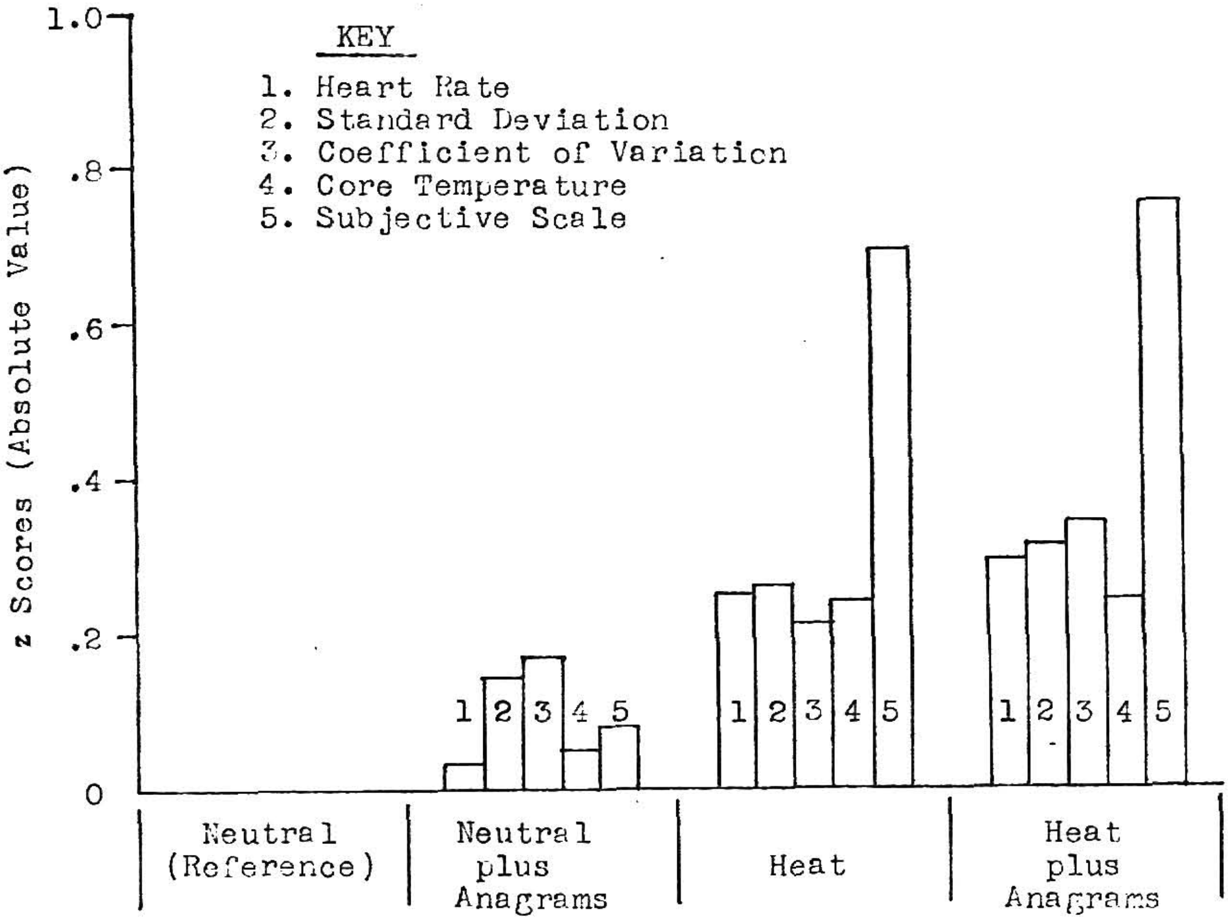


Figure 7 Criterion z Scores by Condition

and 91 F E.T. To Wing this implied that for one hour exposures a thermal limit for performance decay does exist and it lies between 91.5 F and 95 F E.T.

This experiment exposed subjects to 95 F E.T. for one hour. Subjects, however, performed the task only for the first or the second half-hour of exposure. This procedure plus the fact that significant performance increases (learning) was evidenced could be the reason for an insignificant heat effect on performance in this experiment.

Core temperature distinguished between exposure temperatures but not tasks. This criterion was the only measure that demonstrated a significant interaction between heat and anagrams; when the task was added to the neutral environment temperatures went down whereas they went up when the task was added to heat. This could imply some relation of mental (task) stress to the ability of the body to adjust to its thermal environment.

Authors who have investigated the iv (Kalsbeck, 1968; Cahill, 1969) and report the heart rates they observed have found that rates generally increase with task while variability decreases. It could well be that the task itself, moving the hands in writing or responding with the feet to an audio stimulus, could be the cause. In this study, anagrams, which necessitated writing, did have a significant effect ($p < .05$) on heart rate. In both heated (95 F E.T.) and the neutral (71 F E.T.) environments the heart rate increased with the addition of task. This significant change may be seen in Table 24 and Figure 7. The heart rate scores, relative to the neutral plus anagrams (NA), were .25 in heat (H) and .29 for heat plus anagrams (HA).

Future research, which involves even minor movements by the subjects, should utilize control conditions on the task; one session would involve 'thinking' and the other would involve only the physical aspects of the task. The need for such a hand-moving control condition was demonstrated by this experiment. Following such a procedure the mental and physical aspects of even the most sedate mental task could be differentiated.

The iv, as also reported by other authors, decreased with the addition of stress. Significant reductions ($p < .05$) in both the standard deviation and the coefficient of variation were observed when both mental (anagrams) and physical (thermal) stresses were added. The absolute values of the standardized (z) scores for the standard deviation were .14 (NA), .26 (H) and .31 (HA) and for the coefficient of variation they were .17, .21 and .34 respectively. These three criteria, the heart rate, the standard deviation of the iv and the coefficient of variation of the iv, were the only measures that could distinguish a mental task from a sedentary level in both heat and neutral environments.

To examine further the relationships among heart rate, standard deviation and the coefficient of variation product movement correlations ($N = 192$) were calculated. The correlation between heart rate and standard deviation was -.58, between heart rate and coefficient of variation it was -.36, and between standard deviation and coefficient of variation it was +.94. The iv criteria, standard deviation and coefficient of variation, apparently give the same information. Only part, however, of the changes in the iv criterion may be attributed to changes in heart rate. From this it appears that factors other than rate effect the iv.

From this correlation information it may be seen that the task that the subjects perform may dictate the applicable criteria; some mental tasks may be appropriately measured by rate whereas others may dictate an iv measure. Future researchers would do well to evaluate both heart rate and variability of the interbeat interval during tasks until such time that the appropriate measure is evidenced.

The subjective measure was only able to significantly distinguish between the neutral and the heated environment but as can be seen from Figure 7 these differences were relatively drastic. The standard scores went from .08 in the neutral plus anagram condition to .68 in heat and .75 for anagrams in heat. These differences were much greater than those demonstrated by the other measures. It appears that subjective measures hold great potential in their ability to quantify or rank stresses. With further refinement it could be expected that an appropriate measure would evolve. They also have the ability of being readily attainable.

At the conclusion of the experiment subjects were asked for their comments. Two subjects admitted that the presence of the confederate forced them to work harder. The other subjects were noncommital. Another comment was that the subjective votes after the non-task conditions was related to the social success of the group; if the subjects and the confederate enjoyed each others company than the environmental stress became secondary. From hindsight, this appears to be a valid criticism and worth considering when subjects are exposed simultaneously and certainly so when criteria may be related to emotions.

It should be noted that this thesis presents an evaluation of a new physiological index of mental stress under conditions of both unpaced mental and physical stress. Conditions involving greater emotional stress and various blends of paced and unpaced physical-mental stress should present quantitatively different results.

SUMMARY AND CONCLUSIONS

This thesis presented an evaluation of the variability of interbeat interval as an index of stress. This variability has been generally utilized to indicate mental stress (Kalsbeck, et. al 1965) with some applications (Konz and Cahill, 1970) in thermal stress. Decreased variability is associated with the addition of stress. Consideration has not previously been given to a direct comparison between results obtained by this index during the physical stress of heat, mental stress, and a combination of the two, mental stress in heat.

Variability of the interbeat interval, the iv, has generally been measured by Kalsbeck's variability score or by the standard deviation or coefficient of variation. The coefficient of variation (a relative variability measure) is the standard deviation divided by the mean and thus it is a ratio of changing values. For this study the denominator was the period mean as opposed to the mean for all periods in a condition or the mean of all conditions, the subject mean. Comparison criteria were heart rate, core temperature, performance during the task and a subjective measure during all conditions.

The following conclusions were drawn from this experiment:

1. The iv measures, the standard deviation and the coefficient of variation, decreased with stress. These criteria were able to distinguish a mental task from a sedentary level in both the heated and the neutral environments.

2. Similar to the iv measures, the heart rate was able to distinguish the mental task from the sedentary level in both exposure temperatures. Heart rate rose with the addition of stress.

3. The standard deviation and the coefficient of variation apparently measured the same information. The correlation coefficient between the two was +.94, between heart rate and standard deviation it was -.58, and between heart rate and coefficient of variation it was -.36.

4. Core temperature of the subjects distinguished only between exposure temperatures. No difference was established by this criterion between the sedentary level and the mental task.

5. Performance was not effected by heat. Significant increase in performance (learning) was demonstrated on the anagram task.

6. The subjective measure, similar to core temperature, distinguished only between exposure temperatures; no difference was demonstrated between the task and the sedentary level by this measure.

In general this study shows that the variability of the interbeat interval is a valid index of mental stress; it does decrease significantly with mental stress. Also associated with this decrease of the iv was a significant increase in the heart rate. Both rate and variability were significantly different with task and thermal stress, rate increased and variability decreased.

It could be that the physical context of this task, merely writing, was sufficient to increase the rate. This would indicate an extreme sensitivity of heart rate to task, which could well be the case. This author suggests that tasks used to evaluate mental stress be extremely sedate or utilize control conditions.

The variability of the interbeat interval does show great potential in its ability to objectively measure mental load. Of the criteria utilized the variability and the heart rate measures were the only two that could distinguish both mental and physical stress. Much research is needed, however, before this index is ready for use by itself. Some important questions are still unanswered.

One implication of this study is that heart rate may be much more sensitive than previously expected and thus in tasks involving minimum physical activity, such as writing, heart rate may be just as valid and a much more easily attained criterion than the iv. Future research should be directed at answering this important question.

In this experiment a subjective scale demonstrated the potential to evaluate mental stress. With further refinement subjective measures should be able to distinguish levels of mental stress within a task.

At present the iv is an interesting research tool but until such time that many studies document decreases in the iv without significant increases in rate the variability of the interbeat interval will remain a part of scientific knowledge rather than a useful analytical tool.

This author believes that iv will become such a useful tool. Potential uses could be in the area of mental health, job placement and perhaps even wage incentives. "The future is only as vivid as your imagination."

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FOOTNOTES

1. Leopold, F. F., Personal Communication, November, 1970.

2. Leopold, F. F., Personal Communication, November, 1970.

APPENDIX 1

Physiological Measures by Subject

Subject 1

Condition	Period	Heart Rate (Beats/min.)	Mean Interval (Sec.)	Std. Dev. (sec.)	Coef. of Variation	Core Temperature
Neutral	1.	76.4	0.7846	0.0761	0.0970	99.0
	2.	70.5	.8509	.1228	.1514	98.9
	3.	80.4	.7457	.0808	.1084	98.8
	4.	72.0	.8333	.0949	.1139	98.8
	5.	64.7	.9272	.1154	.1245	98.8
	6.	79.2	.7569	.0482	.0637	98.7
	Mean	73.9	.8164	.0907	.1098	98.9
Neutral and Anagrams	1.	72.8	0.8233	0.0773	0.0939	98.7
	2.	76.5	.7833	.0381	.0487	98.5
	3.	60.9	.9844	.0823	.0837	98.5
	4.	66.0	.9090	.0684	.0752	98.5
	5.	62.2	.9636	.1029	.1068	98.5
	6.	82.3	.7285	.0375	.0515	98.5
	Mean	70.1	.8653	.0678	.0766	98.5
Heat	1.	104.5	0.5741	0.0361	0.0629	99.1
	2.	91.8	.6533	.0454	.0695	99.2
	3.	97.1	.6175	.0315	.0510	99.3
	4.	101.1	.5929	.0517	.0873	99.4
	5.	93.3	.6425	.0386	.0601	99.5
	6.	99.2	.6047	.0431	.0713	99.7
	Mean	97.8	.6141	.0411	.0670	99.4
Heat and Anagrams	1.	79.2	0.7569	0.0246	0.0325	98.8
	2.	91.4	.6560	.0284	.0434	98.9
	3.	83.3	.7200	.0302	.0419	99.0
	4.	87.8	.6828	.0384	.0562	99.0
	5.	71.1	.8433	.0701	.0832	99.1
	6.	85.7	.7000	.0392	.0561	98.9
	Mean	83.1	.7265	.0385	.0522	99.0
Subject Mean		81.2	0.7555	0.0595	0.0764	98.9

Subject 2

Condition	Period	Heart Rate (bpm)	Mean Interval (sec.)	Std. Dev. (sec.)	Coef. of Variation	Core Temperature(F)
Neutral	1.	81.2	0.7384	0.0199	0.0270	98.5
	2.	86.4	.6942	.0324	.0467	98.3
	3.	79.5	.7538	.0492	.0653	98.4
	4.	77.6	.7732	.0454	.0588	98.3
	5.	83.3	.7720	.0692	.0962	98.4
	6.	84.0	.7142	.0450	.0636	98.3
	Mean	82.0	.7322	.0435	.0595	98.4
Neutral and Anagrams	1.	81.0	0.7400	0.0495	0.0669	98.4
	2.	80.7	.7428	.0391	.0527	98.4
	3.	84.3	.7114	.0223	.0313	98.2
	4.	79.2	.7569	.0760	.1004	98.2
	5.	75.5	.7938	.0749	.0944	98.1
	6.	80.2	.7476	.0454	.0607	98.2
	Mean	80.2	.7487	.0512	.0677	98.3
Heat	1.	124.0	0.4838	0.0243	0.0504	98.2
	2.	117.1	.5120	.0160	.0312	98.5
	3.	115.8	.5180	.0230	.0455	98.7
	4.	101.1	.5929	.0152	.0257	98.8
	5.	116.2	.5160	.0249	.0484	99.0
	6.	117.3	.5111	.0166	.0325	99.1
	Mean	115.3	.5223	.0201	.0389	98.7
Heat and Anagrams	1.	103.2	0.5811	0.0199	0.0343	98.1
	2.	100.3	.5976	.0166	.0278	98.2
	3.	109.7	.5466	.0188	.0344	98.0
	4.	110.2	.5444	.0236	.0433	98.0
	5.	125.4	.4781	.0150	.0313	98.0
	6.	115.8	.5181	.0085	.0164	98.1
	Mean	110.8	.5443	.0171	.0313	98.1
Subject Mean		97.0	.6369	.0330	.0494	98.4

Subject 3

Condition	Period	Heart Rate (bpm)	Mean Interval (sec.)	Std. Dev. (sec.)	Coef. of Variation	Core Temperature (F)
Neutral	1.	79.2	0.7569	0.8516	0.1125	99.5
	2.	73.7	.8133	.0471	.0579	99.5
	3.	76.4	.7846	.0194	.0248	99.4
	4.	73.7	.8133	.0188	.0231	99.3
	5.	67.9	.8836	.0732	.0829	99.4
	6.	76.4	.7846	.0657	.0837	99.4
	Mean	74.6	.8060	.0516	.0642	99.4
Neutral and Anagrams	1.	80.9	0.7415	0.0253	0.0342	99.6
	2.	79.2	.7569	.0292	.0385	99.8
	3.	78.6	.7630	.0291	.0382	99.5
	4.	80.9	.7415	.0199	.0269	99.5
	5.	83.6	.7171	.0237	.0331	99.5
	6.	81.7	.7342	.0287	.0391	99.4
	Mean	80.8	.7424	.0260	.0350	99.6
Heat	1.	95.2	0.6300	0.0412	0.0654	99.4
	2.	86.2	.6960	.0196	.0281	99.5
	3.	104.0	.5764	.0196	.0341	99.5
	4.	107.1	.5600	.0274	.0490	99.7
	5.	104.5	.5741	.0235	.0409	99.7
	6.	98.7	.6075	.0253	.0417	99.7
	Mean	99.3	.6073	.0261	.0432	99.6
Heat and Anagrams	1.	113.5	0.5284	0.0208	0.0394	99.8
	2.	115.8	.5180	.0267	.0516	99.8
	3.	121.4	.4940	.0290	.0588	99.8
	4.	121.7	.4926	.0185	.0377	99.9
	5.	120.9	.4960	.0196	.0395	100.1
	6.	130.1	.4609	.0199	.0433	100.3
	Mean	120.6	.4983	.0224	.0450	100.2
Subject Mean		97.0	0.6369	0.0330	0.0494	99.6

Subject 4

Condition	Period	Heart Rate (bpm)	Mean Interval (sec.)	Std. Dev. (sec.)	Coeff. of Variation	Core Temperature (F)
Neutral	1.	68.7	0.8733	0.0876	0.1004	98.9
	2.	72.2	.8300	.0591	.0712	98.9
	3.	63.5	.9440	.0763	.0808	98.7
	4.	57.4	1.0440	.0768	.0736	98.7
	5.	67.3	.8909	.0485	.0544	98.7
	6.	75.9	.7900	.0896	.1134	98.9
	Mean	67.5	.8953	.0730	.0823	98.8
Neutral and Anagrams	1.	65.7	0.9127	0.0561	0.0614	99.1
	2.	73.1	.8200	.0346	.0422	99.1
	3.	75.5	.7938	.0410	.0517	99.0
	4.	74.3	.8066	.0485	.0601	99.0
	5.	77.6	.7723	.0396	.0513	98.9
	6.	67.0	.8945	.1367	.1528	98.8
	Mean	72.2	.8333	.0594	.0699	99.0
Heat	1.	80.5	0.7446	0.0533	0.0715	99.4
	2.	90.0	.6666	.0404	.0606	99.4
	3.	88.2	.6800	.0546	.0803	99.4
	4.	91.0	.6586	.0247	.0375	99.6
	5.	113.0	.5405	.0427	.0805	99.7
	6.	107.5	.5577	.0209	.0375	99.7
	Mean	95.0	.6397	.0394	.0613	99.5
Heat and Anagrams	1.	105.3	0.5694	0.0218	0.0383	99.8
	2.	103.0	.5825	.0198	.0340	100.1
	3.	106.2	.5647	.0128	.0228	100.0
	4.	109.3	.5488	.0260	.0473	100.2
	5.	111.5	.5377	.0239	.0445	100.4
	6.	113.3	.5294	.0169	.0320	100.5
	Mean	108.1	.5554	.0202	.0365	100.1
Subject Mean		93.8	0.6635	0.0315	0.0625	99.4

Subject 5

Condition	Period	Heat Rate (bpm)	Mean Interval (sec.)	Std. Dev. (sec.)	Coeff. of Variation	Core Temperature (F)
Neutral	1.	96.0	0.6250	0.0278	0.0445	98.9
	2.	84.3	.7143	.0458	.0643	98.9
	3.	87.1	.6885	.0344	.0499	98.8
	4.	86.0	.6971	.0471	.0676	98.8
	5.	78.6	.7630	.0575	.0754	98.8
	6.	83.3	.7200	.0545	.0757	98.8
	Mean	85.9	.7008	.0445	.0629	98.8
Neutral and Anagrams	1.	108.8	0.5511	0.0314	0.0570	98.8
	2.	101.1	.5924	.0282	.0476	98.8
	3.	104.0	.5764	.0196	.0341	98.8
	4.	104.6	.5733	.0188	.0328	98.7
	5.	102.0	.5883	.0182	.0309	98.9
	6.	106.7	.5622	.0091	.0163	98.9
	Mean	104.5	.5740	.0209	.0364	98.8
Heat	1.	98.7	0.6075	0.0156	0.0257	98.8
	2.	95.6	.6275	.0272	.0434	99.0
	3.	97.9	.6125	.0185	.0302	99.0
	4.	99.6	.6023	.0215	.0358	99.1
	5.	101.5	.5905	.0257	.0436	99.2
	6.	111.5	.5377	.0198	.0369	99.8
	Mean	100.8	.5963	.0214	.0359	99.2
Heat and Anagrams	1.	107.1	0.5600	0.0133	0.0238	99.6
	2.	116.3	.5157	.0122	.0238	99.7
	3.	109.1	.5494	.0176	.0320	99.8
	4.	115.8	.5178	.0089	.0172	99.9
	5.	116.8	.5160	.0120	.0232	100.2
	6.	117.1	.5120	.0160	.0312	100.2
	Mean	113.6	.5285	.0133	.0252	99.9
Subject Mean		101.2	0.5999	0.0250	0.0401	99.1

Subject 6

Condition	Period	Heart Rate (bpm)	Mean Interval (sec.)	Std. Dev. (sec.)	Coeff. of Variation	Core Temperature (F)
Neutral	1.	64.7	0.9272	0.0759	0.0818	98.8
	2.	59.5	1.0080	.0711	.0705	98.8
	3.	60.2	0.9955	.0831	.0835	98.8
	4.	59.5	1.0080	.0775	.0769	98.6
	5.	58.5	1.0240	.0408	.0398	98.7
	6.	56.9	1.0533	.1554	.1476	98.7
	Mean	59.9	1.0026	.0840	.0833	98.7
Neutral and Anagrams	1.	66.2	0.9054	0.0572	0.0632	98.8
	2.	66.2	.9054	.0572	.0632	98.8
	3.	70.8	.8466	.0977	.1154	98.7
	4.	72.0	.8333	.0585	.0702	98.7
	5.	66.2	.9054	.0490	.0541	98.7
	6.	63.9	.9381	.0430	.0458	98.9
	Mean	67.6	.8890	.0604	.0687	98.8
Heat	1.	84.0	0.7138	0.0264	0.0370	98.8
	2.	87.1	.6885	.0164	.0238	99.8
	3.	90.3	.6640	.0196	.0295	99.0
	4.	84.0	.7142	.0396	.0554	98.9
	5.	94.1	.6375	.0519	.0814	99.0
	6.	94.1	.6373	.0229	.0359	99.2
	Mean	88.9	.6759	.0294	.0438	99.0
Heat and Anagrams	1.	101.6	0.5900	0.0173	0.0293	99.4
	2.	108.8	.5511	.0213	.0386	99.4
	3.	114.9	.5221	.0089	.0171	99.5
	4.	116.7	.5140	.0261	.0508	99.5
	5.	118.1	.5080	.0183	.0360	99.4
	6.	120.4	.4980	.0199	.0399	99.8
	Mean	113.4	.5305	.0186	.0353	99.5
Subject Mean		82.4	0.7745	0.0481	0.0578	99.0

Subject 7

Condition	Period	Heart Rate (bpm)	Mean Interval (sec.)	Std. Dev. (sec.)	Coeff. of Variation	Core Temperature (F)
Neutral	1.	85.0	0.7057	0.0358	0.0507	99.2
	2.	78.6	.7630	.0366	.0480	99.2
	3.	82.3	.7285	.1220	.1675	99.1
	4.	84.6	.7085	.1232	.1739	99.1
	5.	89.6	.6693	.0660	.0987	99.1
	6.	89.2	.6720	.0761	.1133	99.1
	Mean	84.9	.7078	.0766	.1087	99.1
Neutral and Anagrams	1.	121.6	0.4933	0.0188	0.0382	99.1
	2.	81.7	.7342	.0388	.0529	99.0
	3.	87.5	.6857	.0474	.0692	99.1
	4.	79.9	.7057	.0356	.0474	99.0
	5.	82.6	.7257	.0423	.0584	99.0
	6.	85.0	.7057	.0324	.0459	99.0
	Mean	89.7	.6825	.0359	.0520	99.0
Heat	1.	121.9	0.4920	0.0183	0.0372	99.4
	2.	118.7	.5052	.0296	.0586	99.7
	3.	110.4	.5431	.0455	.0838	99.7
	4.	100.3	.5976	.0894	.1496	99.9
	5.	116.8	.5136	.0297	.0579	99.8
	6.	113.0	.5305	.0218	.0412	100.3
	Mean	113.5	.5303	.0390	.0714	99.8
Heat and Anagrams	1.	80.3	0.7466	0.0188	0.0252	99.4
	2.	81.0	.7400	.0200	.0270	99.5
	3.	111.7	.5368	.0197	.0367	99.4
	4.	108.0	.5555	.0374	.0674	99.4
	5.	115.8	.5178	.0089	.0172	99.4
	6.	116.3	.5157	.0122	.0238	99.4
	Mean	102.2	.6021	.0195	.0329	99.4
Subject Mean		97.6	0.6307	0.0428	0.0662	99.3

Subject 8

Condition	Period	Heart Rate (bpm)	Mean Interval (sec.)	Std. Dev. (sec.)	Coeff. of Variation	Core Temperature (F)
Neutral	1.	74.6	0.8033	0.0256	0.0318	99.0
	2.	62.5	.9600	.0000	.0000	98.9
	3.	65.2	.9200	.0241	.0262	98.9
	4.	59.7	1.0040	.0768	.0765	98.9
	5.	67.6	.8872	.0230	.0259	99.0
	6.	72.2	.8300	.0238	.0286	99.0
	Mean	67.0	.9007	.0289	.0315	99.0
Neutral and Anagrams	1.	64.2	0.9345	0.0192	0.0206	98.9
	2.	65.4	.9163	.0317	.0346	98.8
	3.	62.2	.9640	.0377	.0391	98.7
	4.	61.4	.9760	.0512	.0524	98.7
	5.	59.2	1.0120	.0538	.0531	98.5
	6.	63.4	.9454	.0460	.0486	98.4
	Mean	62.6	.9580	.0399	.0414	98.7
Heat	1.	82.6	0.7257	0.0450	0.0620	99.5
	2.	78.0	.7692	.0802	.1043	99.6
	3.	90.0	.6600	.0244	.0371	99.7
	4.	85.3	.7028	.0198	.0281	99.8
	5.	74.4	.8061	.0213	.0264	99.8
	6.	120.0	.5000	.0250	.0501	100.1
	Mean	88.5	.6939	.0359	.0513	99.8
Heat and Anagrams	1.	83.6	0.7171	0.0237	0.0331	99.4
	2.	78.3	.7661	.0264	.0345	99.5
	3.	74.6	.8033	.0303	.0378	99.4
	4.	80.9	.7415	.0599	.0808	99.4
	5.	85.0	.7057	.0191	.0271	99.4
	6.	83.3	.7200	.0261	.0363	99.4
	Mean	80.9	.7423	.0309	.0416	99.4
Subject Mean		74.8	0.8237	0.0339	0.0415	99.2

APPENDIX 2

Subject Performance Data

Subject Performance Data

Words Generated per Five Minute Periods

Subject	Condition 1: 1	2	3	4	5	6	Mean	Condition 2: 1	2	3	4	5	6	Mean	Subject Mean
1	44	08	20	21	19	25	23.0	29	24	30	25	26	36	28.3	25.75
2	36	08	25	18	16	30	22.1	34	21	28	19	29	29	26.5	24.25
3	25	24	24	20	18	24	22.5	22	25	18	16	26	27	22.3	22.50
4	31	22	22	21	23	28	24.5	26	27	30	25	26	27	26.8	25.75
5	26	32	29	18	23	27	25.8	28	27	57	33	32	30	34.5	27.25
6	25	25	29	26	24	26	25.8	26	30	43	28	31	35	33.0	27.25
7	26	17	18	23	27	19	21.6	31	23	38	24	26	38	30.0	25.50
8	23	14	21	17	24	15	19.0	23	20	20	25	27	30	24.1	24.00
Mean							23.0							28.2	25.28

APPENDIX 3

Subjective Measure by Conditions

Condition	Subject	Votes: General	Temperature	Task	Subject Mean
Neutral	1	48	48	48	48
	2	40	40	09	30
	3	09(17)*	09(09)	09(09)	09
	4	40(09)	09(40)	40(40)	30
	5	09	17	09	11
	6	00	00	00	00
	7	17	17	17	17
	8	00	00	17	06
	Mean	20	18	19	19
Neutral and Anagrams	1	48	48	48	48
	2	27	40	27	31
	3	09(27)*	09(09)	09(09)	09
	4	09(09)	17(17)	09(40)	09
	5	40	17	27	28
	6	17	00	40	19
	7	17	17	69	34
	8	00	00	09	03
	Mean	21	19	30	23
Heat	1	87	87	48	74
	2	87	92	87	89
	3	27	48	17	31
	4	87	87	48	74
	5	40	48	00	29
	6	40	17	48	35
	7	48	87	17	51
	8	48	87	09	48
	Mean	58	69	34	55
Heat and Anagrams	1	48	87	48	61
	2	48	87	74	70
	3	27	87	09	41
	4	87	87	48	74
	5	87	87	40	71
	6	27	40	09	25
	7	64	87	48	66
	8	69	48	40	52
	Mean	57	76	40	58

* data from Tue. p.m. run

APPENDIX 4

Confederate Physiological Measures by Work Group

Confederate (with Subjects 1 and 2)

Condition	period	Heart Rate (beats/min.)	Mean Interval (sec.)	Std. Dev. (sec.)	Coef. of Variation	Core Temperature
Neutral	1	85.3	0.7028	0.0751	0.1069	99.0
	2	82.6	.7257	.0722	.0996	98.9
	3	90.0	.6666	.0559	.0831	98.8
	4	80.5	.7446	.0761	.1022	98.8
	5	81.7	.7342	.0998	.1359	98.8
	6	86.5	.6933	.1570	.2265	87.7
	Mean	84.4	0.7112	0.0894	0.1258	98.7
Neutral and Anagrams	1	75.5	0.7938	0.1073	0.1352	98.7
	2	83.3	.7200	.1036	.1439	98.6
	3	77.0	.7784	.1071	.1376	98.5
	4	84.0	.7142	.1179	.1875	98.5
	5	84.0	.7138	.1339	.1875	98.5
	6	85.7	.7000	.1487	.2124	98.5
	Mean	81.6	0.7367	0.1197	0.1636	98.6
Heat	1	100.7	0.5952	0.0188	0.0316	99.1
	2	106.2	.5644	.0125	.0222	99.2
	3	98.4	.6094	.0218	.0358	99.3
	4	96.7	.6200	.0529	.0853	99.4
	5	100.8	.5410	.0540	.0999	99.5
	6	108.4	.5533	.0323	.0602	99.7
	Mean	103.6	0.5805	0.0322	0.0558	99.4
Heat and Anagrams	1	94.1	0.6373	0.0722	0.1133	98.8
	2	95.6	.6275	.0560	.0893	98.9
	3	96.3	.6225	.0509	.0818	98.9
	4	98.0	.6117	.0948	.1550	99.0
	5	100.3	.5976	.0664	.1112	99.1
	6	112.0	.5355	.0195	.0364	98.9
	Mean	99.4	0.6053	0.0600	0.0978	98.9
Confederate Mean		92.2	0.6584	0.0753	0.1108	[illegible]

Confederate (with Subjects 3 and 4)

Condition	Period	Heart Rate (beats/min.)	Mean Interval (sec.)	Std. Dev. (sec.)	Coef. of Variation	Core Temperature (F)
Neutral	1	54.8	1.0933	0.0462	0.0422	99.2
	2	75.3	0.7966	.0576	.0723	99.1
	3	56.7	1.0577	.1321	.1249	99.2
	4	58.1	1.0320	.0392	.0379	99.1
	5	59.2	1.0120	.0820	.0811	99.1
	6	63.2	0.9480	.0947	.0999	99.1
	Mean	61.2	0.9899	0.0753	0.0764	99.1
Neutral and Anagrams	1	66.5	0.9018	0.0199	0.0221	99.3
	2	68.1	.8800	.0241	.0274	99.3
	3	67.3	.8909	.0514	.0577	99.4
	4	68.7	.8733	.0319	.0366	99.2
	5	69.3	.8654	.0192	.0222	99.2
	6	69.3	.0654	.0519	.0600	99.2
	Mean	68.2	0.8794	0.0331	0.0376	99.3
Heat	1	89.4	0.6705	0.1135	0.1693	99.4
	2	86.5	.6933	.0834	.1204	99.4
	3	91.0	.6586	.0322	.0489	99.4
	4	102.8	.5835	.0999	.1712	99.6
	5	103.2	.5811	.0242	.0[illegible]16	99.7
	6	117.6	.5100	.0173	.0339	99.7
	Mean	98.4	0.6162	0.0618	0.0976	99.5
Heat and Anagrams	1	114.4	0.5244	0.0226	0.0432	99.8
	2	125.0	.4800	.0219	.0456	99.8
	3	128.5	.4666	.0498	.1069	99.8
	4	130.2	.4606	.0199	.0433	100.0
	5	133.6	.4490	.0167	.0373	100.1
	6	134.6	.4454	.0367	.0825	100.3
	Mean	127.7	0.4710	0.0280	0.0598	100.0
Confederate Mean		88.9	0.7391	0.0495	0.0678	99.5

Confederate (with Subjects 5 and 6)

Condition	Period	Heart Rate (beats/min.)	Mean Interval (sec.)	Std. Dev. (Sec.)	Coef. of Variation	Core Temperature
Neutral	1	72.2	0.8300	0.0404	0.0486	98.8
	2	66.8	0.8981	.0199	.0221	98.9
	3	72.5	0.8266	.0340	.0411	98.8
	4	62.5	0.9600	.0505	.0527	98.5
	5	73.8	0.8123	.0454	.0559	98.7
	6	57.9	1.0360	.0488	.0471	98.7
	Mean	67.6	0.8938	0.0398	0.0446	98.7
Neutral and Anagrams	1	79.5	0.7542	0.0140	0.0185	98.8
	2	80.2	.7476	.0184	.0247	98.8
	3	80.7	.7428	.0446	.0600	98.7
	4	75.2	.7969	.0246	.0309	98.7
	5	75.8	.7907	.0168	.0213	98.7
	6	77.0	.7784	.0199	.0256	98.9
	Mean	78.1	0.7685	0.0230	0.0302	98.8
Heat	1	80.2	0.7476	0.0672	0.0899	98.8
	2	89.6	.6693	.0472	.0706	99.0
	3	74.6	.8033	.1088	.1355	99.0
	4	90.3	.6640	.0770	.1159	99.0
	5	80.5	.7446	.0693	.0931	99.2
	6	102.0	.5882	.0299	.0509	99.6
	Mean	86.2	0.7028	0.0666	0.0926	99.1
Heat and Anagrams	1	103.4	0.5800	0.0200	0.0344	99.5
	2	105.3	.5694	.0292	.0512	99.5
	3	114.9	.5220	.0153	.0294	99.6
	4	117.6	.5100	.0214	.0420	99.6
	5	135.8	.4418	.0083	.0188	99.4
	6	120.4	.4980	.0199	.0399	99.9
	Mean	116.2	0.5202	0.0190	0.0360	99.6
Confederate Mean		87.0	0.7213	0.0371	0.0508	99.0

Confederate (with Subjects 7 and 8)

Condition	Period	Heart Rate (beats/min.)	Mean Interval (sec.)	Std. Dev. (sec.)	Coef. of Variation	Core Temperature
Neutral	1	59.5	1.0080	0.0890	0.0883	98.8
	2	63.2	0.9490	.0684	.0720	98.8
	3	65.4	0.9163	.0465	.0508	98.9
	4	57.0	1.0520	.0877	.0834	98.9
	5	63.9	0.9381	.0521	.0556	99.0
	6	70.5	0.8500	.0493	.0580	99.0
	Mean	63.2	0.9522	0.0655	0.0680	98.9
Neutral and Anagrams	1	68.9	0.8700	0.1179	0.1355	98.9
	2	71.4	.8400	.0886	.1055	98.9
	3	69.2	.8666	.1087	.1254	98.7
	4	67.3	.8909	.0299	.0336	98.7
	5	66.0	.9090	.0345	.0379	98.5
	6	68.7	.8733	.0274	.0314	98.4
	Mean	68.6	0.8750	0.0678	0.0782	98.7
Heat	1	123.5	0.4857	0.0140	0.0288	99.4
	2	119.0	.5040	.0344	.0682	99.7
	3	122.4	.4900	.0173	.0353	99.7
	4	118.1	.5080	.0421	.0829	99.9
	5	107.5	.5577	.0209	.0375	99.8
	6	118.5	.5060	.0190	.0377	100.2
	Mean	118.2	0.5086	0.0246	0.0484	99.8
Heat and Anagrams	1	94.9	0.6320	0.0747	0.1182	99.4
	2	100.4	.5975	.0174	.0286	99.5
	3	94.8	.6325	.0405	.0641	99.4
	4	103.2	.5811	.0199	.0343	99.4
	5	110.5	.5428	.0198	.0364	99.4
	6	118.5	.5060	.0190	.0377	99.4
	Mean	103.7	0.5820	0.0318	0.0532	99.4
Confederate Mean		88.5	0.7295	0.0475	0.0620	99.2

APPENDIX 5

Confederate Subjective Measure by Work Group

Confederate Votes

Subject Group (Confederate with)	Condition	Vote by Condition: General	Temperature	Task	Confederate Mean
1 and 2	Neutral (N)	09	17	09	11
	Neutral and Anagrams (NA)	40	17	09	22
	Heat (H)	87	87	48	74
	Heat and Anagrams (HA)	48	09	09	22
3 and 4	N	48(09)*	17(17)	58(09)	38
	NA	48(27)	17(40)	48(27)	38
	H	87	87	40	71
	HA	87	87	64	79
5 and 6	N	00	00	09	03
	NA	17	00	09	09
	H	48	48	40	45
	HA	48	87	09	48
7 and 8	N	00	00	09	03
	NA	09	00	09	06
	H	48	48	09	35
	HA	40	48	27	38
Confederate Means	N	14	08	17	14
	NA	29	09	19	19
	H	68	68	34	55
	HA	56	58	27	47

* Data from Tues. P.M. run

INTERBEAT INTERVAL AS AN INDICATOR
OF MENTAL AND THERMAL STRESS

by

KEVIN ROBERT CAHILL

B. SC. (Engg.) Indus.,

Kansas State University, Kansas 1969

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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ABSTRACT

The variability of interbeat interval, the iv, was evaluated from EKG data to determine if it could be reduced by mental stress, physical (thermal) stress and the two combined, mental stress in heat. The criteria of variability were the standard deviation and the coefficient of variation while comparison criteria were core temperature, heart rate, productivity and a subjective measure. Eight subjects and a confederate were exposed in groups consisting of two subjects and the confederate, to four conditions.

The conditions tested consisted of two thermal environments, one a neutral environment of 75 F (23.8 C) at 60% relative humidity (71.0 E.T.) and the other a heat stress environment of 110 F (43.3 C) at 50% relative humidity (95.2 E.T.). In each environment all subjects were both sedentary and performing a mental task, anagrams. The four conditions tested were neutral (N), neutral plus anagrams (NA), heat (H), and heat plus anagrams (HA).

The following significant ($p < .05$) results were obtained:

1. Variability was reduced with the addition of both mental and thermal stresses.
2. Heart rate increased with the addition of all stresses
3. Productivity did not decrease in heat
4. Core temperature and the subjective measure increased in heat but were unchanged by task.

The standard deviation, the coefficient of variation, and the heart rate were able to distinguish the mental task from the sendentary

level in both the neutral and the heat stress environments. Core temperature and the subjective measure were only able to make the environmental distinction.

In general, both the heart rate and the iv criteria gave the same information. From this, it is suggested that studies investigating the objective measurement of mental stress utilize more sedate tasks or control conditions.