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THE IMPACT OF COMBINED HEAT AND NOISE ON SHORT-TERM RETENTION

A Thesis

by

JOHN SCOTT PARENT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 1993

Major Subject: Industrial Engineering

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Approved as to style and content by:

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December 1993

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ABSTRACT

The Impact of Combined Heat and Noise on Short-Term

Memory Retention. (December 1993)

John Scott Parent, BS, U.S. Air Force Academy

Chair of Advisory Committee: Dr. R. Dale Huchingson

This thesis reports on the impact of combined heat and noise on the performance of a short-term memory retention task with two levels of difficulty. Thirty-two males, ages 18 - 35, were exposed to four different treatment conditions during four one hour sessions. These four treatment conditions consisted of: a control environment, a noise environment, a heat environment, and a combined heat and noise environment. Temperatures during the control and noise conditions were maintained between 68 and 70 degrees Fahrenheit, while temperatures during the heat and combined conditions were maintained at 105 degrees Fahrenheit. Sound exposure levels during the noise and combined conditions averaged at 83.7 decibels with peak frequency exposures never exceeding 93.5 decibels for ten seconds. The task to be performed was a computerized version of game "Concentration". Subjects were presented with both a 6 x 8 and an 8 x 8 grid of blank tiles and asked to correctly match as many tile pairs as they could in three minutes. The task was

repeated twice for each grid.

Results from the 6 x 8 grid showed performance decrements for all three stress conditions with combined heat and noise showing the greatest performance decrement. However, none of these decrements were found to be significantly different from the control environment or from each other at an Alpha level of .05. Further, no significant evidence was found to show that the combined effects of heat and noise exceed the effects of either stressor singularly. Results from the 8 x 8 grid proved to be different. While performance decrements were observed for the heat and noise conditions alone, the greatest overall performance scores were observed during the combined stress condition. Again, none of these scores were found to be significantly different from the control environment or from each other at an Alpha level of .05. It appears, from these results, that heat and noise stress, experienced either singularly or in combination does not have a significant effect on short-term memory or overall performance degradation.

ACKNOWLEDGEMENTS

This thesis reflects the culmination of over eighteen months of intensive studying, writing, reflecting, collecting, and learning. Through it all, one professor has constantly been there as my mentor, guidance counselor, and problem solver. It is for these reasons that I would like to extend a special thanks to this gentleman, who also happens to be my Committee Chairman, Dr. R. Dale Huchingson for his many hours of guidance and support. I also wish to thank Dr. Newton C. Ellis and Dr. Omer C. Jenkins for their assistance and advice.

One individual who I would like to especially recognize is that of my research partner and classmate, Mattisson S. Pope. Without his guidance and assistance I can guarantee that I would have been putting in many more hours at the office. But, it was not Matt that had to put up with the many moods and complaints accompanying a researcher with a deadline. That responsibility fell squarely on the shoulders of my beautiful fiance, Kimberly. Without her continuing support and encouragement, this could not have been done.

J. Scott Parent

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INTRODUCTION

As officers in the U.S. Armed Forces, we are aware of the decisions that must be made in a combat environment and the disastrous results that could occur if an improper decision is made due to lack of time or concentration. Most importantly, these decisions are most often made under the harshest of conditions. Whether a tank commander fighting in the arid desert, or a pilot flying a low-level bombing run, the probability of successfully accomplishing a mission objective is being compounded by the adverse effects of such outside stressors as heat, noise, and time.

Operational aviation environments are known to inflict many forms of stress on the aircrew member. Vibration and acceleration, the two most frequently studied aviation environmental stressors, have been shown to degrade performance by impairing vision, accelerating fatigue onset, and impairing control functions (Bowman and von Beckh, 1979). In addition to these stresses,heat and noise are also two major stressors that are felt by the aircrew members and shown to affect mission performance. In older aircraft, ventilation and air-conditioning systems are often inadequate. This coupled with the heat produced by extensive survival gear and prolonged exposure due to excessive mission length can create a heat environment that is quite often dangerous. Pilots of all kinds of aircraft are also exposed to noise, and

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although the pilot's helmet provides some attenuation of external noise, the noise levels at a pilot's ears often approaches, or exceeds, the Medical Department's criteria for hazardous levels (von Beckh, Bowman and Voge, 1976). The aviation environment is just one small example of the multiple stress conditions that confront all military decision makers in a combat scenario. Yet, the critical question always remains the same such as, "Will the tank commander be able to make the correct decisions despite the background noise of constant artillery fire and an outside air temperature of 120 degrees Fahrenheit ?"

It is this question and its possible answers that formed the basis of my thesis research. Previous studies evaluated the effects of heat and noise on psychomotor skills (Viteles and Smith, 1946; Pepler, 1960; Dean and McGlothen, 1965; Grether, 1970). The focus of this research is on the effects of heat and noise on short-term memory or concentration, since the military leader is most often required to recall as well as to react.

Histo ally, most research studies regarding the effects of heat and noise on human performance has been conducted individually by presenting the subject with a single stressor presented in isolation. Of these same studies, the vast majority have concentrated on the effects of heat and noise on physiological and psychomotor performance levels while only a few have concentrated on the effects of these stressors on intellectual performance, especially memory.

Decades of experimentation have produced only fragmentary support for the common belief that distracting noises, even those of a continuous and high intensity nature, can seriously disturb performance on intellectually demanding tasks (Weinstein, 1977). Weinstein stated that there are at least two possible explanations for the disappointing findings of recent experiments. One explanation is that noise affects only those tasks which are intellectually demanding, while another possibility is that tasks in these noise experiments are so straightforward and unidimensional that the best strategies to use are self-evident (Weinstein, 1974). Ironically, these studies most often found that in certain areas of memory and intellectual performance, noise served to enhance performance rather than cause a significant performance decrement.

Concerning short-term retention, several studies which presented words on a projection screen and asked subjects to recall them in order, found that noise seems to improve the retention of order information (Davies and Jones, 1975). Other studies showed an improvement (Hockey and Hamilton, 1970) or at least no decrement in ordered recall (Davies and Jones, 1975) observed in multi-component memory tasks (Tempest, 1985).

Several studies have also indicated that the long-term retention of verbal materials originally presented in noise is enhanced (Tempest, 1985). However, it was Broadbent who best summarized the effects of noise on memory in his chapter in the Handbook of Noise Control. In it he states,

> Average performance at a memory task is unaffected by noise, if tests are made in the usual way by requiring recall of a group of items, presenting another group and requiring recall of that, and so on. Effects do appear, however, if the demand on memory is continuous, so that at no point in the task can the person relax and cease to remember the materials carried in the head. (Broadbent, 1979)

Similarly, decades of experimentation have produced less than concrete results on the effects of elevated ambient temperature on human intellectual performance. However, a more recent study conducted by Hancock (1981) seems to clarify the issue. In his research, Hancock suggested a marginal decrement in mental ability before imminent heat collapse. In this study, Hancock concludes that the impairment of mental performance in a heated environment can be attributed to the gross effects of imminent heat collapse and that the limit for unimpaired mental performance lies in close proximity to that of the physiological tolerance of the human subject (Hancock, 1981). Enander best summarized the results of Hancock's study in a 1989 journal article by stating,

> He (Hancock) makes a clear distinction between conditions under which body temperature is undergoing a dynamic increase and those under which body temperature is unchanged or established in a static hyperthermic state. According to Hancock's analysis, dynamic temperature change is associated with performance decrement, while subjects in a stable state show no change or even improvement in performance. (Enander, 1989)

Grether found similar results in his 1973 review of human performance at elevated temperatures. In all of the research studies that he reviewed using tasks to measure cognitive performance almost half of the studies yielded essentially negative results; namely, little or no effect of elevated temperatures on cognitive performance (Grether, 1973). Of the remaining studies, some have shown performance decrements only at the highest temperatures to which subjects were exposed (Grether, 1973). As Grether states,

> Cognitive performance scores remain approximately normal or even surpass normal levels, until elevated temperatures exceed 85 degrees Fahrenheit. Above 85 degrees ET the data falls into two clusters. Most of the data points continue to cluster near or just below the normal performance line. There is another cluster of data points showing performance decrements of 30% or greater. (Grether, 1973)

Although considerable knowledge has been gained from all of these studies on the effect of a single stressor (heat or noise) on human performance, these studies yield very little applicability in an applied combat or industrial environment since these environments never expose the human subject to a single stressor occurring in isolation. Instead, these stressors occur in multiple combinations and the possibility exists, therefore, that the combination of heat and noise stresses as they occur in a combat environment could cause physiological disturbances and performance impairment that are more or less severe than would be predicted from laboratory single-stress studies (Grether, Harris, Mohr, Nixon, Ohlbaum, Sommer, Thaler, and Veghte, 1971).

Several studies have been performed that have looked at the combined effects of heat and noise on human performance. The most intensive study of this nature was performed by Grether et al., in 1971 and examined the effects of combined heat, noise and vibration stress on human performance. Surprisingly, on none of the measures taken were the effects of the combined stress condition more marked than the effect of the single greatest stressor (Grether et al., 1971). This included the results obtained from the mental arithmetic test which was the only mental task performed. In fact, some of the experiments showed that the combined stress condition was less disturbing to the subjects and their performance (Grether et al., 1971). This led to the conclusion that the combined stress conditions produced no additive stress interactions and that the effects of heat and noise on human performance were of a highly independent nature.

Hancock and Pierce conducted a review in 1985 of all of the studies that looked at the combined effects of heat and noise on human performance and found similar results. In a pioneering study conducted by Viteles and Smith in 1946, Hancock and Pierce concluded that the overall detailed results of this study indicated the relative independence of the action of the thermal and acoustic stressors, although the result of the manual coordination Lathe test did suggest some degree of interaction (Hancock and Pierce, 1985). In studies conducted by Pepler (1960), Bell, Provins, and Hiorns (1964), Arees (1963), and Dean and McGlothen (1965), Hancock and Pierce came to the same conclusions. Dean and McGlothen's study, conducted in 1965, was one of the most complete investigational series on heat and noise stressor interaction and was generated in response to the forecast problems of space exploration (Hancock and Pierce, 1985). In one of these studies extremes of both thermal and acoustic stress were imposed in combination (93 degrees Fahrenheit with 110 dB white noise) while subjects performed various tasks which simulated pilot or astronaut activity (Hancock and Pierce, 1985). These tasks included object tracking, and radar and meter monitoring for irregularly occurring action signals. Results from this study indicated no interactive effects between heat and noise on any of the twelve performance tasks undertaken (Hancock and Pierce, 1985).

Hancock and Pierce did review some studies using combined heat and noise stress that yielded both additive and subtractive effects on mean performance when compared to the performance caused by either stressor singularly. But as the authors of those studies note, even those accounts with interactional effects are beset by methodological problems, which cast doubt on the positive results found (Hancock and Pierce, 1985). More importantly, it should be noted that the vast majority of all of these studies that looked at the combined stresses of heat and noise concentrated on the effects that these stresses had on psychomotor performance and task completion. Only a select few concentrated on some aspect of cognitive processing or memory, mainly through mental arithmetic tasks or ordered recall of word lists, and the ability to make correct and effective decisions. The main goal of this study was to concentrate my research in this particular area and, since it is not a replication of any previous study's task performance procedures, hopefully shed a new, if not different light, on the combined effects of heat and noise on human performance.

The principal objectives of this study were:

(1) To determine the degree that heat and noise affect short-term memory retention as compared to no heat and noise as measured during one hour of exposure to these stressors.

(2) To determine if the combined effects of heat and noise exceed the effects of either stressor singularly (i.e. determine if the effects of heat and noise are independent of each other or if some type of interaction between the two stressors occurs).

(3) To set some specified standard of performance for the simulated environment and determine whether the effects of heat and noise causes performance scores (percent correct) to fall below this specified level rendering the environment unsuitable for effective decision making.

METHOD

Subjects

Thirty-two volunteer male subjects participated in this experiment. All of the subjects used were either graduate students who are still on active duty status in the U.S. Air Force or undergraduate members of the Texas A&M Corps of Cadets. Ages for the subjects ranged between 19 and 34 years of age approximately. Job experience of the subjects covered all areas of the military spectrum including: pilots, intelligence officers, computer operators, maintenance specialists, and field meteorology officers. All subjects also had current medical examinations which is a requirement for active duty military personnel and any active member in the Corps of Cadets. This ensured that all subjects were in excellent health and capable of successfully completing the study.

In accordance with procedures established by the Texas A&M University Institutional Review Board for Human Subjects in Research, subjects were briefed on the procedures to be followed in the experiment and the purpose of the study. Their rights as subjects were explained, and a voluntary informed consent form was signed prior to beginning the first treatment condition.

All subjects were required to wear long pants and a shirt of a loose fitting nature. This was done to more realistically simulate the nature of the type of clothing worn by military personnel in a combat environment. Each subject participated in four one-hour sessions, one at each of the four treatment conditions. Sessions were scheduled at the participants' convenience to maximize participation and avoid interference with their daily class schedule.

Apparatus

All tasks were performed under strictly controlled environmental conditions in the environmental chamber room of the Human Factors Laboratory. These tasks consisted of two computer games and one paper and pencil mental arithmetic task that measured various levels of the subject's cognitive performance and decision making ability. Both of the computer games were presented to the subject through a IMTEC 1430V VGA color monitor located in the chamber and required only a mouse to provide the responses. The paper and pencil math tasks were performed at the computer desk that contained the monitors. Noise was presented to the subject through normal stereo speakers located inside the chamber on opposite corners from the subject. This noise was controlled by a Realistic stereo amplifier located outside of the chamber. Fluids and a first aid kit were located inside the chamber making them readily available for any subject possibly experiencing complications during the study.

Experimental Design

This research study involved three independent performance tasks each identified by either its own computer-based simulation game or paper and pencil. The first task was a paper and pencil mental arithmetic quiz, while the other two tasks were a computer simulation of the famous televised game "Concentration" and a computer game called "Solitile" which requires the participant to successfully remove pairs of tiles from a pyramid. Each session was performed under one of four possible treatment conditions. These four treatment conditions consisted of: a control environment, a noise environment, a heat environment, and a combined heat and noise environment. All three tasks were performed during each treatment condition and all subjects were required to complete all four treatment conditions. While the arithmetic quiz was the first task performed under all conditions, the order in which the subjects performed each of the two computer performance tasks was altered.

To eliminate any outside sources of experimental error a Repeated Latin Square design was implemented to alter the order in which the subjects were exposed to each environment. Eight subjects performed in each of the four balanced orders for a period of one hour over three successive weeks. The order of the experimental design is outlined in Table 1.

For each of the four experimental conditions involving the performance of three tasks, a within-subject experimental design was used for the analysis of variance on the resulting data. However, it should be noted, that this thesis

TABLE 1

Experimental Design

Subject	Session 1	Session 2	Session 3	Session 4
1	H	C	A	N
2	H	A	C	N
3	H	N	C	A
4	H	N	C	A
5	H	C	N	A
6	H	A	N	C
7	H	A	C	N
8	H	A	N	C
9	N	C	H	A
10	N	H	A	C
11	N	H	A	C
12	N	H	A	C
13	N	A	H	C
14	N	A	H	C
15	N	H	C	A
16	N	A	C	H
17	A	C	N	H
18	A	C	H	N
19	A	N	C	H
20	A	N	H	C
21	A	C	N	H
22	A	C	H	N
23	A	N	H	C
24	A	C	H	N
25	C	A	N	H
26	C	N	A	H
27	C	N	A	H
28	C	N	H	A
29	C	A	N	H
30	C	H	N	A
31	C	A	N	H
32	C	A	N	H

H = Heat C = Combined A = Ambient N = Noise evaluation has only analyzed the resulting data obtained from the "Concentration" memory task. Analysis was based upon the four environmental treatment conditions and the two levels of difficulty of task performance.

Stimulus Material

The "Concentration" memory task was a screen, approximately 4 x 5 inches when displayed on the monitor, that consisted of an informational area with SCORE, POINTS, TIME, and PAUSE displays, and the playing grid. The playing grid was made up of blank, square tiles. Each tile had sides one-half inch in length and under each tile was one of twenty possible shapes. The shapes occurred on the game board in pairs. Depending on the size of the grid, pairs could be repeated a varying amount of times and not every shape appeared on every playing grid. The object of this task was to match as many pairs of tiles as possible within a three minute time period. This three minute time limit was used for both the 6 x 8 and 8 x 8 playing grids. The mouse was used to turn over each tile. If the two tiles that were turned over were a matching pair, the score increased, and the game continued. If the tiles did not match, the shapes were shown for a short period of time, approximately one second, then the tiles were turned back over. This constantly tested the short-term memory capabilities of each subject as they were forced to memorize the location grid of several different shapes at any one time. The game continued until the three minute time limit had elapsed. An example of the

"Concentration" playing screen and the twenty possible shapes can be found in Appendix A.

After each three minute trial had been completed the total game score would be shown in the "SCORE" display box. Each pair of tiles was potentially worth 50 points. As a result, the possible maximum score for the 6 x 8 grid was 1200 points, while the possible maximum score for the 8 x 8 grid was 1600 points. The points for the next matching pair were shown on the "POINTS" informational display box. There were two things that could take away from those 50 points: time and mistakes. For each second that passed on the clock without a successful match, 1 point was taken away from the total "POINTS" value. Each time two tiles were turned over and failed to be a matching pair, 5 points were taken away from the total "POINTS" value. Once two tiles were correctly matched, whatever remained on the "POINTS" value display was added to the score and the "POINTS" value returned to 50. If the "POINTS" value ever got to 0, no points were awarded to the next matching pair. The total score as it appeared in the "SCORE" display box was then recorded and averaged after certain trials to give the mean performance data that appears in the results.

Procedure

Prior to the arrival of the subjects, controls of the environmental chamber were adjusted to establish either ambient or heated environmental conditions. Direct control of dry bulb temperature and relative humidity provided the temperatures and humidities shown in Table 2. Temperatures and humidities for all four treatment conditions were measured using a Belfort Hygrothermograph. For an example of a 7-day Hygrothermograph chart reflecting operating conditions during one week of the study please refer to Appendix B. It should be noted that Grether obtained his greatest performance decrements above 85 degrees Fahrenheit, so our experimental temperature should have facilitated any performance decrements if they were to occur (Grether, 1973).

For the noise environmental condition 85 dBs of continuous noise were transmitted to the subjects through a standard set of stereo speakers located inside the chamber. Direct control of the continuous noise levels provided the decibel levels shown in Table 2. Continuous noise levels were measured using a Quest M-27 Noise Logging Dosimeter. For realistic military situations, the noise consisted of jet engines, artillery explosions, heavy weapons and missile firings all amplified by a stereo receiver located outside of the chamber. 85 dBs of continuous noise falls well within OSHA's standards for maximum allowable exposure time and would not induce hearing damage of any kind to the subject. It should also be noted that peak decibel levels during the noise treatment conditions never exceeded 95 dBs for a maximum exposure time of less than ten seconds. These levels usually occurred during intermittent sounds such as single gun fire shots or artillery explosions.

TABLE 2

Environmental Chamber Temperatures

Condition	Mean Temperature Fahrenheit	Relative Humidity	Sound Level "A" Scale	Sound Level "C" Scale
AMBIENT	70 degrees	70 %	---	---
HEAT	105 degrees	40 %	---	---
NOISE	70 degrees	70 %	82.7 dBs	83.7 dBs
COMBINED	105 degrees	40 %	82.7 dBs	83.7 dBs

-- Sound Levels for both the "A" and "C" scales are average values as measured by the dosimeter over the entire duration of noise exposure during the treatment condition.

Prior to entering the chamber, the subject was asked a series of questions regarding his present state of health. Each subject was then briefed on the purpose of this research study and the exact nature of the environmental conditions that he would be experiencing throughout the experiment. After signing a consent form, the subject was brought into an adjacent room to perform a hearing test. All audiological examinations were performed on Grason-Stadler Model 1703 Recording Audiometers. In order to complete the study all research participants had to complete two audiological examinations, one prior to entering the chamber for the first time and the second following completion of the subjects last treatment condition. Audiometers were taken and stored in the laboratory to show each research participant that no hearing loss had incurred as a result of this study.

After completing the initial audiological examination, the subject was offered some fluids for hydration and then brought into the chamber. It should be noted that upon arrival on all three of the remaining treatment conditions, subjects were immediately brought into the chamber after being offered some fluids. In the chamber, the subject was asked to sit down in a chair located in front of the color monitor. The desk in the chamber actually had two color monitors, each one facing away from each other, allowing two subjects to be run during each session. The first ten minutes of each session were used to read to each subject a set of instructions which explained how to correctly perform each task and answer any last questions. For an example of the set of instructions that was read to each subject please refer to Appendix C. More importantly, these first ten minutes allowed the subjects to start to feel the effects of the environmental condition (noise was not presented to the subject until just prior to the start of the three performance tasks).

After the initial ten minutes were over, the subject began to perform the first performance task which was the mental arithmetic quiz. The subject was presented with multiplication, addition, and subtraction problems involving no more than four digits and was asked to record his answer for each problem on the test sheet. This task only lasted for fifteen minutes during which four three minute trials were completed. Sixteen different test sheets were created allowing for a different test during each trial of each treatment condition. Although the subjects were not aware of this, data was not collected from the mental arithmetic quiz since it was being used primarily to induce fatigue and enhance the subjects exposure to the environmental condition. An example of the first four test sheets can be found in Appendix D.

Both the "Concentration" short-term memory task and the "Solitile" decision-making task were performed in the next fifteen minute and twenty minute sessions respectively. For the "Concentration" task, both a 6x8 and an 8x8 grid were used subjecting each participant to two levels of difficulty. For this task, four three minute trials were completed. The first trial with each kind of grid was used as practice trials while data was recorded on the second trial with each kind of grid.

The "Solitile" task, the results of which are the topic of another study, was conducted during the experimental procedure and followed much of the same order. During this task, each subject was required to successfully remove all of the tiles from a predetermined solvable board, two at a time. On each board, there were 144 tiles, four each of 36 different types (0-9 and A-Z). For a tile to be removed, its face must not be covered by any portion of another tile, and it must have either the entire left or entire right edge (or both) exposed. Only a mouse was required by the subject to play the game and the computer kept score during each trial of the number of tiles successfully removed. For this task, four four minute trials were completed. The first two were used as practice trials while data was recorded on the third and fourth trials. Sixteen different pyramids were programmed into the computer allowing for a different pyramid during each trial of each treatment condition.

A researcher was present in the environmental chamber at all times to monitor the progress and safety of each research participant and record the data after each trial. An example of the data collection sheet can be found in Appendix E. One or two subjects could be run in the environmental chamber during each session since the chamber contained two color monitors. Each session lasted approximately one hour with each subject completing all four treatment conditions. In order to minimize any possible learning effects, subjects were asked to only sign up for one or two sessions per week to allow at least four days between conditions. The average participant took about three weeks to complete the study.

RESULTS

6 x 8 Grid Results

Performance scores for all thirty-two subjects were recorded for the second 6 x 8 trial during each treatment condition. These raw performance scores can be found in Appendix F. These scores were then averaged over all thirty-two subjects to obtain the resulting means and standard deviations for each condition that appear in Table 3.

TABLE 3

6 x 8 Grid Results

Condition	Mean Performance Score	Standard Deviation
AMBIENT	782.91	179.75
NOISE	742.06	212.82
HEAT	739.44	205.40
COMBINED	712.34	217.63

As can be seen in Figure 1 the ambient environment yielded the highest short-term memory performance scores while performance was poorer during all three treatment conditions with the combined treatment condition yielding the poorest performance. A repeated measures analysis of variance done on the performance task showed the model to be significant with a F-value of

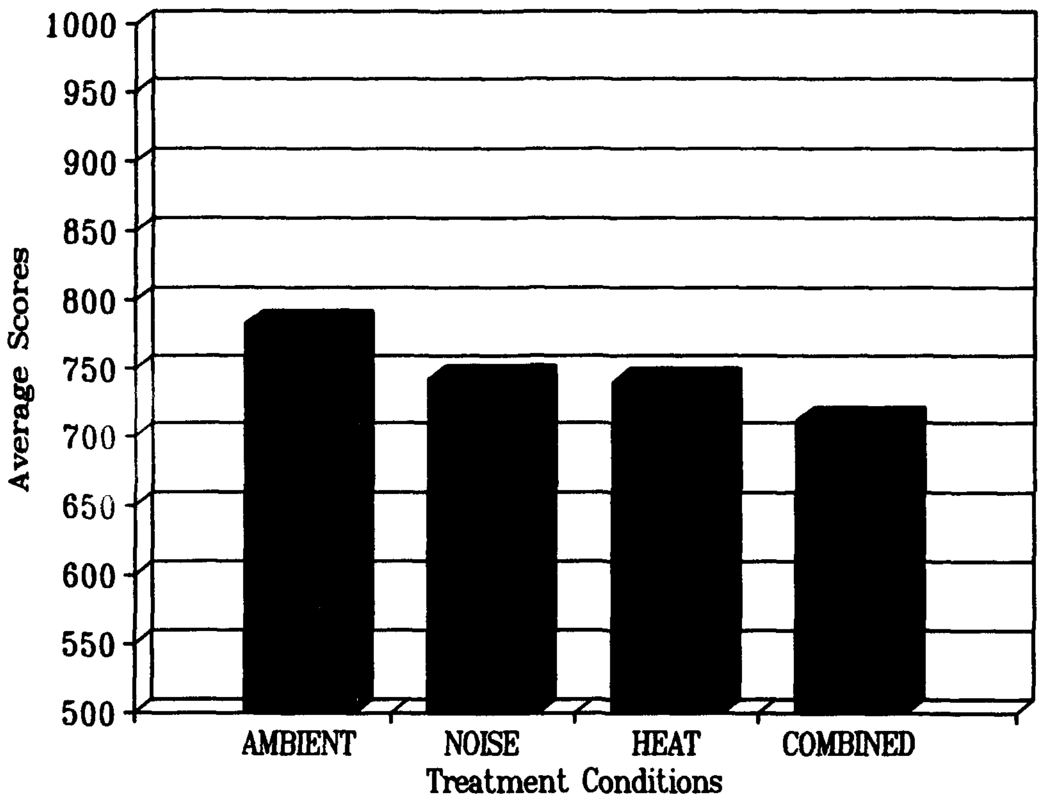

Figure 1. Average performance scores for the 6 x 8 grid during all treatment conditions.

1.84 and p < .0116. However, further analysis using both Fischer's Least Significant Difference and Duncan's New Multiple Range Test procedures failed to reveal any significant differences between any of the four treatment conditions. For Fischer's LSD the critical range was determined to be 91.6 with 93 degrees of freedom, MSE = 33851.28, and alpha = .05. For Duncan's New Multiple Range Test the smallest critical range for r = 2 was determined to be 91.5 with 93 degrees of freedom, MSE = 33851.28, and alpha = .05. The largest mean difference was between the ambient and the combined conditions

and was only 70.6 which is well within the critical range for both procedures.

Further analysis and breakdown of the model showed that subject variability was statistically significant with a F-value of 1.94 and $p < .0081$, and therefore the most important cause of any mean differences that occurred between treatment conditions. None of the treatment conditions proved to have any significant effect on the overall scores. In fact, the combined condition had the smallest overall effect with a F-value of 0.04 and $p < .8331$, yielding little, if no, interaction between the two stressors. For complete results of the statistical analysis, please refer to Appendix G.

Another analysis was done to see if there were any order by treatment effects. These results can be seen in Figure 2. The figure shows that there was a curvilinear relation with best performance on trials 2 and 3. Learning appears to have taken place since mean scores for the last three conditions were all higher than the average mean score for the first condition. The average performance scores for the four conditions respectively were: 663.2, 775.6, 800.3, and 756.3. Although a mean separation test was not performed on this data, the largest mean difference between the first condition run and a latter condition was 137.1, while the smallest mean difference between the first condition run and a latter condition was 93.1. Compared to the critical ranges given earlier, these differences yield statistical significance between the first condition run and all latter conditions.

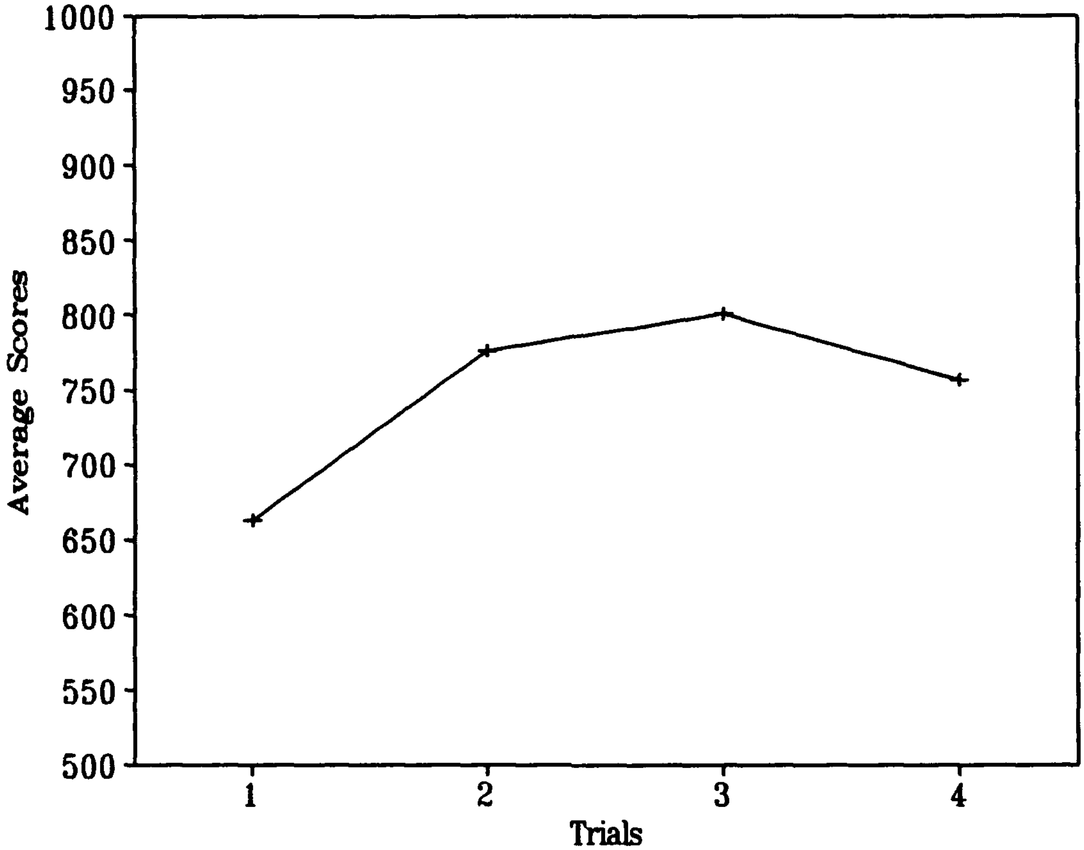

Figure 2. 6 x 8 order by treatment effects.

A final analysis was done to see if the average performance scores determined under the three stressed conditions caused performance to decrease below 90% of the standard performance score as determined by the unstressed or ambient treatment condition. As can be seen by the results obtained in Table 4 none of the three stressed treatment conditions yielded unsatisfactory performance and would therefore be considered suitable environments under combat conditions.

TABLE 4

Comparison of Stressed Performance Scores to the Unstressed Standard

Condition	Percentage of Standard
AMBIENT	100 %
NOISE	94.8 %
HEAT	94.4 %
COMBINED	91.0 %

8 x 8 Grid Results

Performance scores for all thirty-two subjects were recorded for the second 8 x 8 trial during each treatment condition (See Appendix F). These scores were then averaged over all thirty-two subjects to obtain the resulting means and standard deviations for each condition that appear in Table 5.

TABLE 5

8 x 8 Grid Results

Condition	Mean Performance Score	Standard Deviation
AMBIENT	712.56	250.70
NOISE	700.87	215.71
HEAT	684.50	218.74
COMBINED	735.47	272.93

As can be seen in Figure 3 for this level of difficulty the combined environment yielded the highest short-term memory performance scores while performance decreased during the other three treatment conditions with the heat condition yielding the greatest performance decrement. Although a repeated measures analysis of variance done on the performance task showed the model to be significant with a F-value of 3.21 and $p < .0001$, further analysis using both Fisher's Least Significant Difference and Duncan's New Multiple Range Test procedures failed to reveal any significant differences between any of the four treatment conditions. For Fischer's LSD the critical range was determined to be 94.1 with 93 degrees of freedom, MSE = 35761.25, and alpha = .05. For Duncan's New Multiple Range Test the smallest critical value for $r = 2$ was also determined to be 94.1 with 93 degrees of freedom, MSE = 35761.25, and alpha = .05. The largest mean difference was between the combined and the heat conditions and was only 51.0 points which is well within the critical range for both procedures.

Further analysis and breakdown of the model showed that subject variability was statistically significant with a F-value of 3.48 and $p < .0001$, and therefore the most important cause of any mean differences that occurred between treatment conditions. None of the treatment conditions proved to have any significant effect on the overall scores. In fact, the heat condition had the smallest overall effect with a F-value of 0.01 and $p < .9224$. The combined condition yielded little interaction between the two stressors with a F-value of 0.88 and $p < .3511$. For complete results of the statistical analysis, please refer to Appendix G.

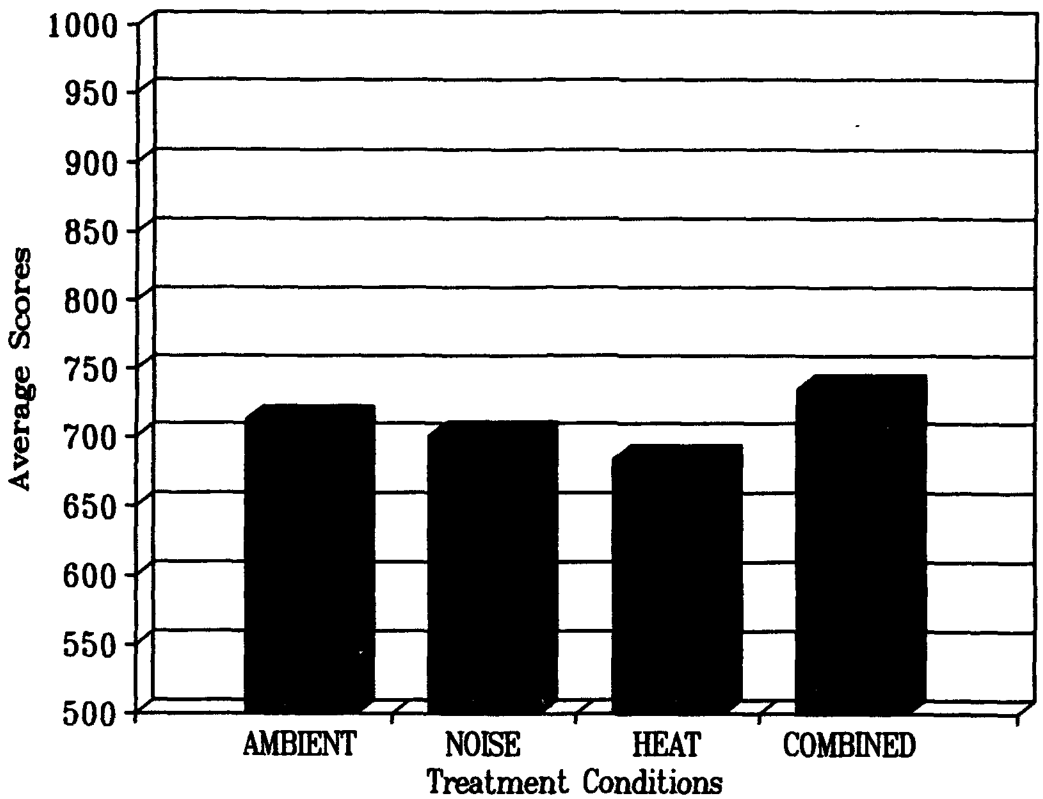

Figure 3. Mean performance scores for the 8 x 8 grid for all four treatment conditions.

Another analysis was performed to see if there were any order by treatment effects. These results can be seen in Figure 4. This figure shows that although there was not a steady increase in performance, learning of some degree may have taken place since the average performance scores for the last three conditions were all higher than the average performance score for the first condition administered. The average performance scores for the four conditions respectively were: 657.4, 705.8, 774.0, and 691.0. Although a mean separation test was not performed on these results, the largest mean difference between the first condition run and a latter condition was 116.6 points, while the smallest mean difference between the first condition run and a latter condition was 33.6 points. A comparison of these mean performance differences to the critical ranges given earlier for this level of difficulty, yielded statistical significance between the first condition run and the third condition that was run.

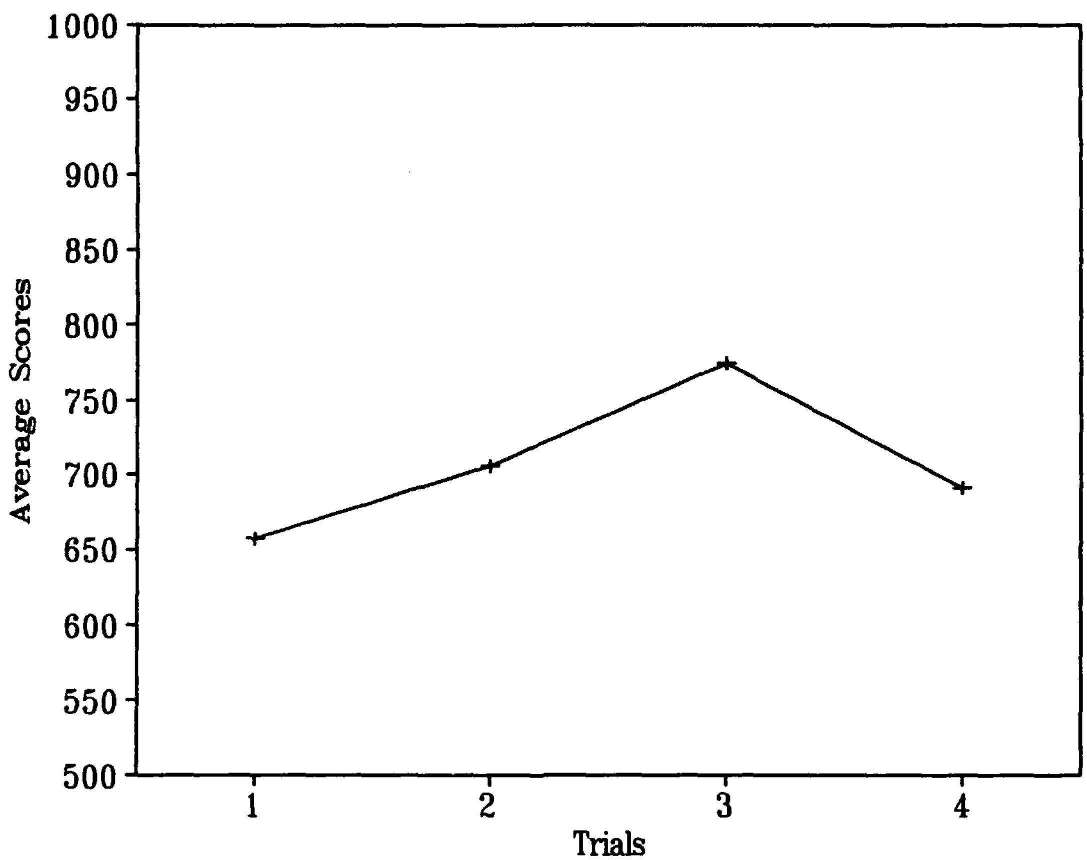

Figure 4. 8 x 8 grid order by treatment effects.

A final analysis was done to see if the average performance scores determined under the three stressed conditions caused performance to decrease below 90% of the standard performance score as determined by the unstressed or ambient treatment condition. As can be seen by the results obtained in Table 6 none of the three stressed treatment conditions yielded unsatisfactory performance anu would therefore be considered suitable environments under combat conditions. In fact, the combined condition even caused a substantial performance increase.

TABLE 6

Comparison of Stressed Performance Scores to the Unstressed Standard Established by the Ambient Environment

Condition	Percentage of Standard
AMBIENT	100 %
NOISE	98.3 %
HEAT	96.1 %
COMBINED	103.2 %

A comparison of average performance scores for both levels of difficulty can be seen in Figure 5. As the figure shows the 8 x 8 grid, or higher level of difficulty, produced lower mean performance scores in every treatment condition except for the combined stress condition. In fact, performance under this condition exceeded performance in every other category except for the ambient environment at the lower level of difficulty.

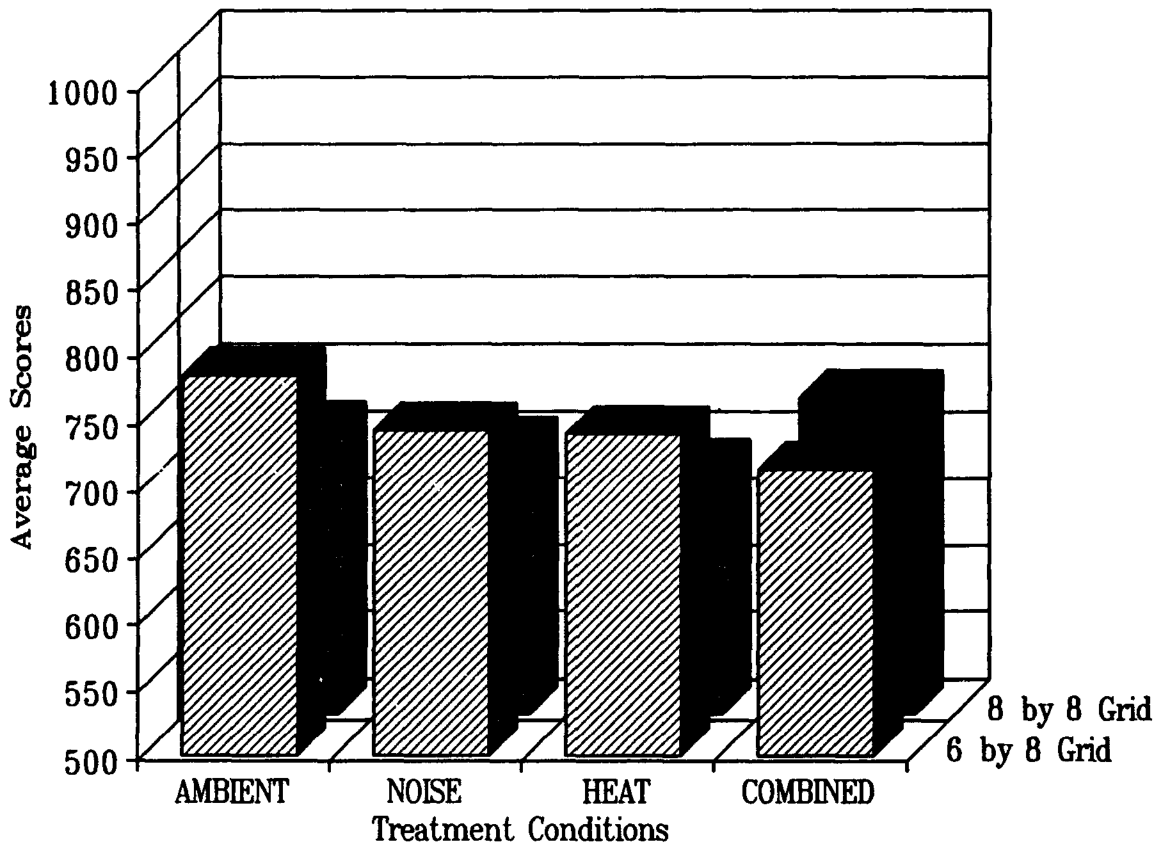

Figure 5. Comparison of mean performance scores for both levels of difficulty.

The data obtained from performance of the "Concentration" short-term memory task did yield different results than those obtained from performance of the "Solitile" decision-making task. It was expected that stressor conditions would cause performance to degrade for this task. However, the subjects' performance increased under heat and noise as compared to the control condition with the combined condition yielding the greatest performance and the ambient condition yielding the worst performance (Pope, 1993). More importantly, these results showed significant differences between some of the mean performance scores as a direct result of treatment condition. Statistically significant differences were found between ambient condition performance and performance during all three stress conditions at an alpha level of .01. Statistically significant differences were also found between performance during the noise and combined heat and noise conditions at an alpha level of .01. No significant differences were found between performance during heat alone or noise alone, as well as between heat alone or combined heat and noise.

DISCUSSION AND CONCLUSIONS

A comparison of the findings of this study to the expectations created by previous research and our own experience should actually be broken down into each one of the three stressed treatment conditions used: noise, heat, and heat and noise.

According to Broadbent (1979) noise as an isolated stressor seemed to have its greatest detrimental effect on performance if the performance task created a continuous demand on memory and did not give the subject a chance to relax and forget materials already being stored in the head. The "Concentration" short-term memory task did create such a continuous demand on memory since the subject was constantly being required to store in memory the locations of several shapes throughout the entire duration of the trial. Therefore, resulting data should have reflected some degree of performance decrement. The results obtained for both levels of difficulty did show a small decrease in performance although in both cases they were statistically insignificant. One possible explanation for these disappointing results was the familiarity of the noises presented since all of the research participants had worked under similar noise conditions either in the field or on base. Another possible explanation for these results was that the task was not intellectually demanding which was revealed by Weinstein (1974) to only produce fragmentary evidence of a performance decrement. There is also the possibility that one hour of exposure to this environment was not enough to induce fatigue on highly disciplined and physically fit subjects who may be used to working with noise of some degree for up to 12 hours a day.

Performance decrements were also found at both levels of difficulty when the research participants were exposed to the heat treatment condition. Again, the results obtained for both levels proved to be statistically insignificant. These results closely parallel Grether's findings in his 1973 review of human performance at elevated temperatures. In this review, Grether found that in elevated temperatures above 85 degrees fahrenheit most of the data points continued to cluster near or just below the normal performance line. It would appear from our resulting data that subjects during this condition were able to maintain a stable body state, despite the chamber temperature of 105 degrees Fahrenheit, and were therefore able to maintain performance close to normal. One explanation for this was that our study was conducted during the beginning of summer where the average outside temperature was consistently in the high eighties. As a result, the chamber temperature was only 15 to 20 degrees higher than the outside temperature and may have been easier to adapt to.

The greatest diversity in the resulting data for both levels of difficulty was found during the combined heat and noise condition. While it caused the greatest performance decrement during the 6 x 8 trial, it actually caused an increase in performance during the, more difficult, 8 x 8 trial. These results follow the conclusion made by Grether (1971) that combined stress conditions produce no additive stress interactions and that the effects of heat and noise on human performance were of a highly independent nature. None of our results revealed any significant interaction between the two stressors and while the 6 x 8 grid showed a small additive effect, the 8 x 8 grid showed a subtractive effect proving the highly independent nature of the combined stress condition on human performance.

Since the data revealed some order by treatment effect for both levels of difficulty some concern may arise as to whether the resulting data may be skewed for each treatment condition. However, this error was eliminated by use of the Repeated Latin Square, and as a result, the data should accurately reflect the change in performance if it were to occur. Concern may also arise over the significant variability that occurred between subjects. This error was eliminated by use of the repeated measures design. A final concern that may arise is that an accurate performance decrement was not reflected under the three stress conditions due to the Hawthorne Effect; namely, subject arousal was increased under the stressed conditions and therefore skewed performance. It was felt that this particular source of error was eliminated by adding a time limit to each trial and running subjects across from each other. It was observed that subjects were constantly trying to complete the grid before the three minute time limit and were often trying to compete with the other subject to try to beat his score. It should also be noted that all of the subject for this study were volunteers and therefore highly motivated. The end result was that the data accurately reflected the highest performance possible under all four treatment conditions and that any change in performance should have been caused by the stress condition alone.

RECOMMENDATIONS

Performance and the maintainability of that performance at an acceptable level under all stress conditions is a necessary requirement for any individual that makes the military his profession. Therefore, an extensive understanding of all stresses and the amplitude at which they finally degrade mental and physical performance to an unacceptable level should be essential.

Further studies on the effect of stress on short-term memory should be conducted. However, in reevaluating this research study there are certain changes that if made could increase the validity. First, this study should be replicated during a cooler time of the year when there is at least a 40 degree difference between the outside and heated chamber temperatures. This would make it harder for the subject to adapt to his new environment during the short exposure and would more accurately reflect performance under a dynamic body state. Second, research participants should perform short-term memory tasks that more closely resemble real-life activities such as recalling radio messages, grid coordinates and specific directions. In this way, activities of the combat environment can be more realistically simulated.

An emphasis should be made on optimizing the validity of the task and the validity of the overall environment. One way that this could be done is to take this research experiment to the field during a live training exercise, like Red Flag, which is the closest simulation to a live combat environment that can be experienced. Have each subject perform the tasks repeatedly during certain times of a full working day for the entire duration of the exercise. This will not only show the effects of stress on performance during certain parts of the day after a full day of exposure, but, it also incorporates the effects of morale and the motivation of the troops on performance as they successfully complete critical aspects of the training.

Finally, an effort should be made to utilize noises that induce above average stress. For many subjects, the sound of jets flying overhead everyday may be less stressful and actually enhance performance while the sound of a baby crying or a dog barking may make that particular subject cringe. By finding these sounds, we can get a more accurate depiction of how noise stress truly affects performance.

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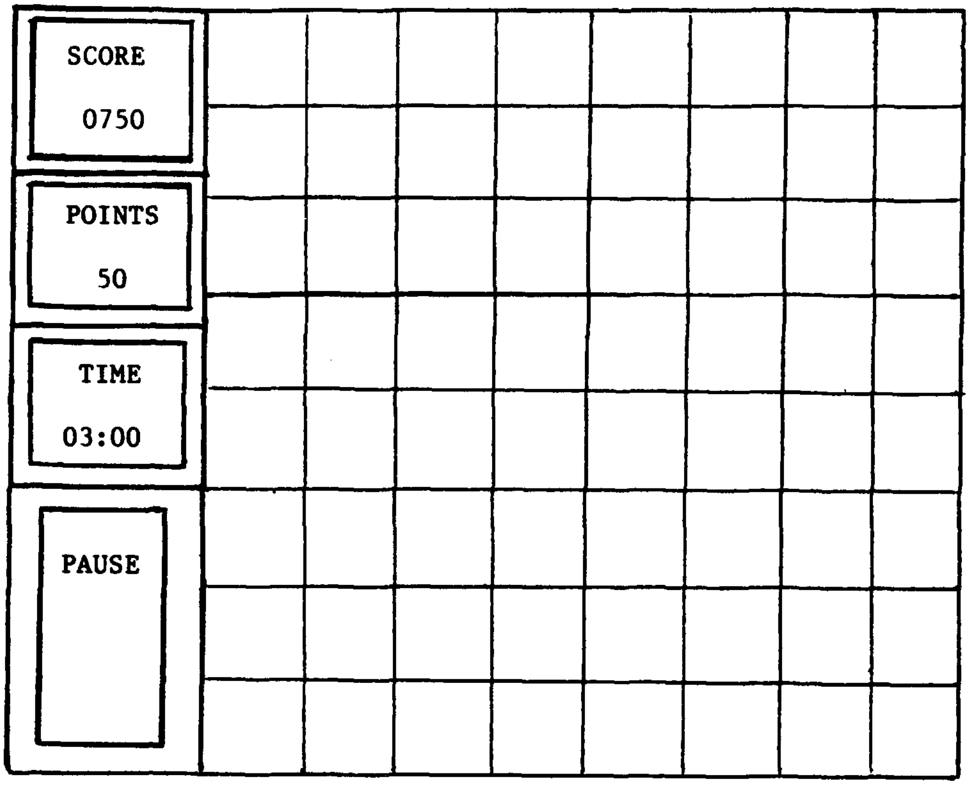
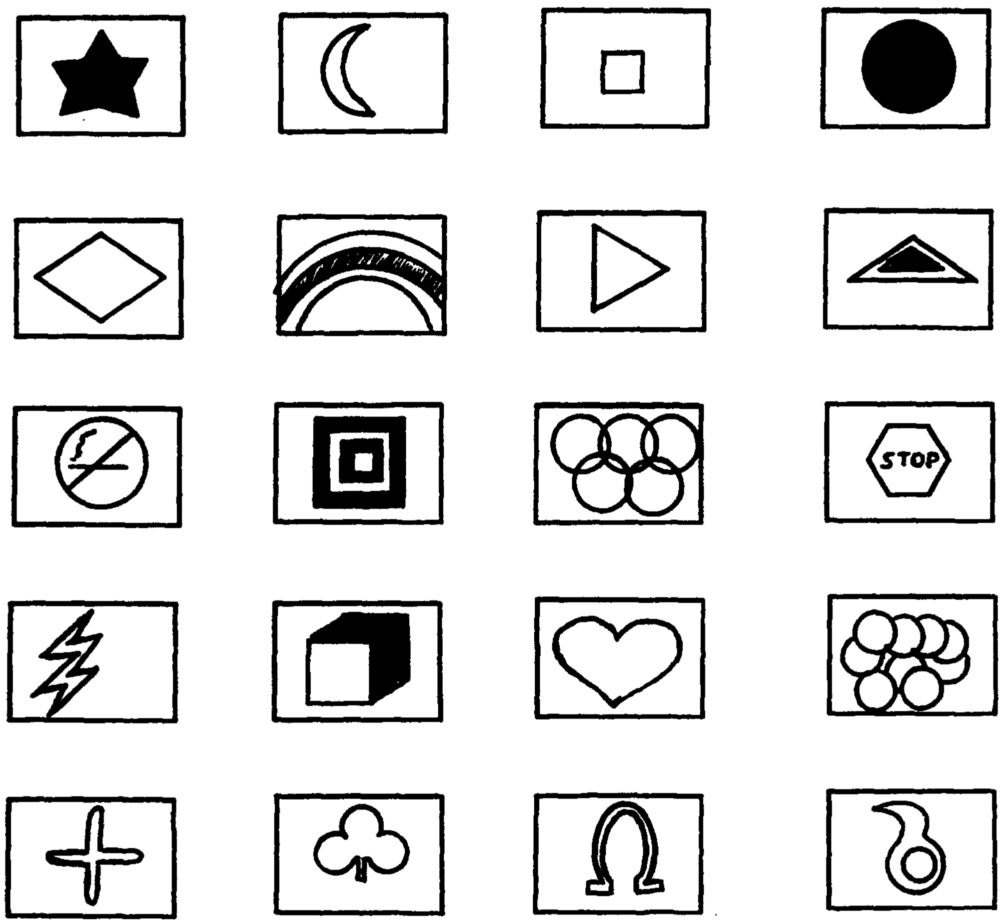
APPENDIX A

EXAMPLE OF "CONCENTRATION" PLAYING SCREEN AND SYMBOLS

"Concentration" Playing Screen:



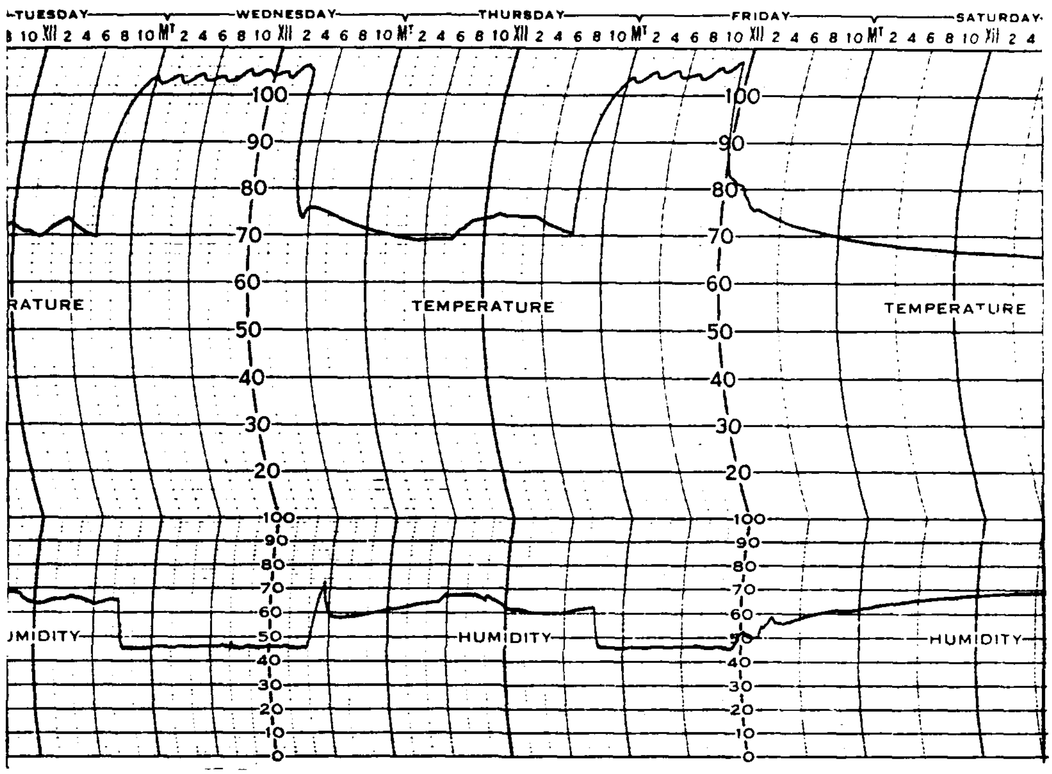
Representative Drawing of the Twenty Possible Symbols:



APPENDIX B

EXAMPLE OF HYGROTHERMOGRAPH CHART

Hygrothermograph Chart for the five day period of 11 - 15 May:



APPENDIX C

INSTRUCTION SHEET FOR RESEARCH PARTICIPANTS

INSTRUCTIONS

You will be participating in a research project to help determine if performance deteriorates under heat and noise conditions. The study will consist of four different treatment conditions and you will be required to complete the same three performance tasks during each session.

The first task that you will perform is a simple mental arithmetic quiz. Using only your pencil and the paper provided, you have three minutes to complete as many problems as possible. However, you must work from left to right and work all of the problems on that row to the best of your ability before moving on to the next row. This task will be repeated four times.

The next task that you will perform will be either one of two computer simulation games. One game is a computerized version of the game "Concentration". During this task you will be presented with either a 6 x 8 or 8 x 8 grid of blank tiles. Using only the mouse to position the cursor and the left button to designate the proper tile you have three minutes to correctly match as many pairs of tiles as possible. This task will be repeated four times, twice with each kind of grid.

The other computer simulation task that you will perform is a computerized version of the game "Mahjongg". During this task you will be presented with 144 tiles that are stacked in the shape of a pyramid. Using only the mouse to position the cursor and the left button to designate the proper tile you will have four minutes to correctly remove as many pairs of tiles as possible. You can only remove tiles that have either the left or right side free. This task will be repeated four times.

APPENDIX D

MENTAL ARITHMETIC QUIZ TEST SHEETS

642	8625	374	4723	8671
- 56	- 1446	x 49	- 593	x 71
73	8732	1379	3742	632
x 592	- 436	+ 246	+ 853	+ 93
743	2648	2723	62	672
- 52	- 867	+ 677	x 16	x 29
4106	1642	83	217	231
- 737	+ 189	x 7	+ 62	x 18

1233	428	5418	6342	1106
x 26	- 62	- 3264	- 593	x 63
917	62	3244	7452	621
+ 97	x 459	+ 179	+ 367	+ 67
541	749	6574	82	642
x 16	- 87	+ 177	x 44	x 56
469	3779	67	447	516
x 11	- 697	x 9	+ 84	x 73

2723	251	8186	593	2769
x 73	- 91	- 3937	x 16	- 919
514	37	2564	6724	8618
+ 81	x 245	- 779	+ 381	+ 866
158	376	4210	6115	94
x 68	- 81	- 359	+ 145	x 28
391	1824	2169	52	657
x 45	- 771	+ 776	x 8	+ 56

5036 x 23	744 - 67	7690 - 5774	256 x 71	1957 - 735
873 + 68	69 x 821	8682 - 329	6125 + 347	3925 + 185
593 x 40	902 - 95	6203 - 757	2758 + 883	99 x 29
717 x 81	9191 - 363	5424 + 356	85 x 4	649 + 41

APPENDIX E

DATA COLLECTION SHEET

Data Collector:____________ Subject:____________ Date:____________

Condition:____________ WX:H______ L______ Other____________

Subject's Weight: Before:____________ After:____________ Visit:____________

Note: Before running subjects for the first time, and after their final trial, check their hearing.

Math Section:	Sheet Numbers:				
	Number Correct:				
Solitile Section:	Board Numbers:				
	a. # remaining::				
	b. # removed (144-a):				

Concentration Section:	6x8			8x8:		
	Score:					

APPENDIX F

RAW PERFORMANCE SCORES FOR ALL TREATMENT CONDITIONS

RAW PERFORMANCE SCORES

6 x 8 Grid

SUBJECT	AMBIENT	NOISE	HEAT	COMBINED
1	848	448	859	867
2	853	865	903	881
3	846	709	814	463
4	909	955	832	589
5	842	446	638	898
6	824	885	805	923
7	265	674	168	814
8	850	859	521	862
9	912	933	496	526
10	486	649	813	840
11	951	873	972	899
12	810	228	888	884
13	606	498	457	487
14	952	931	789	962
15	978	942	939	582
16	906	818	776	878
17	803	878	856	514
18	812	850	363	574
19	955	877	868	876
20	453	268	850	823
21	958	926	961	936
22	893	534	869	536
23	897	879	789	903
24	675	952	859	879
25	886	621	858	898
26	835	915	771	558
27	502	449	874	556
28	926	491	929	939
29	548	845	806	297
30	604	819	458	492
31	868	932	468	507
32	600	797	413	152

RAW PERFORMANCE SCORES

8 x 8 Grid

SUBJECT	AMBIENT	NOISE	HEAT	COMBINED
1	927	993	415	726
2	339	809	864	687
3	520	974	471	431
4	738	988	605	1043
5	1158	801	775	1221
6	807	848	749	807
7	431	532	519	215
8	680	767	513	473
9	839	691	659	464
10	508	429	391	632
11	792	708	843	1048
12	600	887	1174	514
13	438	392	583	809
14	1023	875	918	1267
15	568	924	816	952
16	418	699	815	569
17	651	346	693	393
18	730	441	567	521
19	979	449	984	913
20	865	597	753	986
21	1248	805	806	929
22	615	763	364	743
23	537	681	972	1062
24	895	822	835	864
25	1224	672	762	979
26	436	510	405	504
27	551	258	469	601
28	959	1044	1059	1056
29	750	545	436	738
30	459	986	309	654
31	764	774	722	454
32	353	418	658	280

APPENDIX G

STATISTICAL ANALYSIS RESULTS

General Linear Models Procedure

6 x 8 Grid

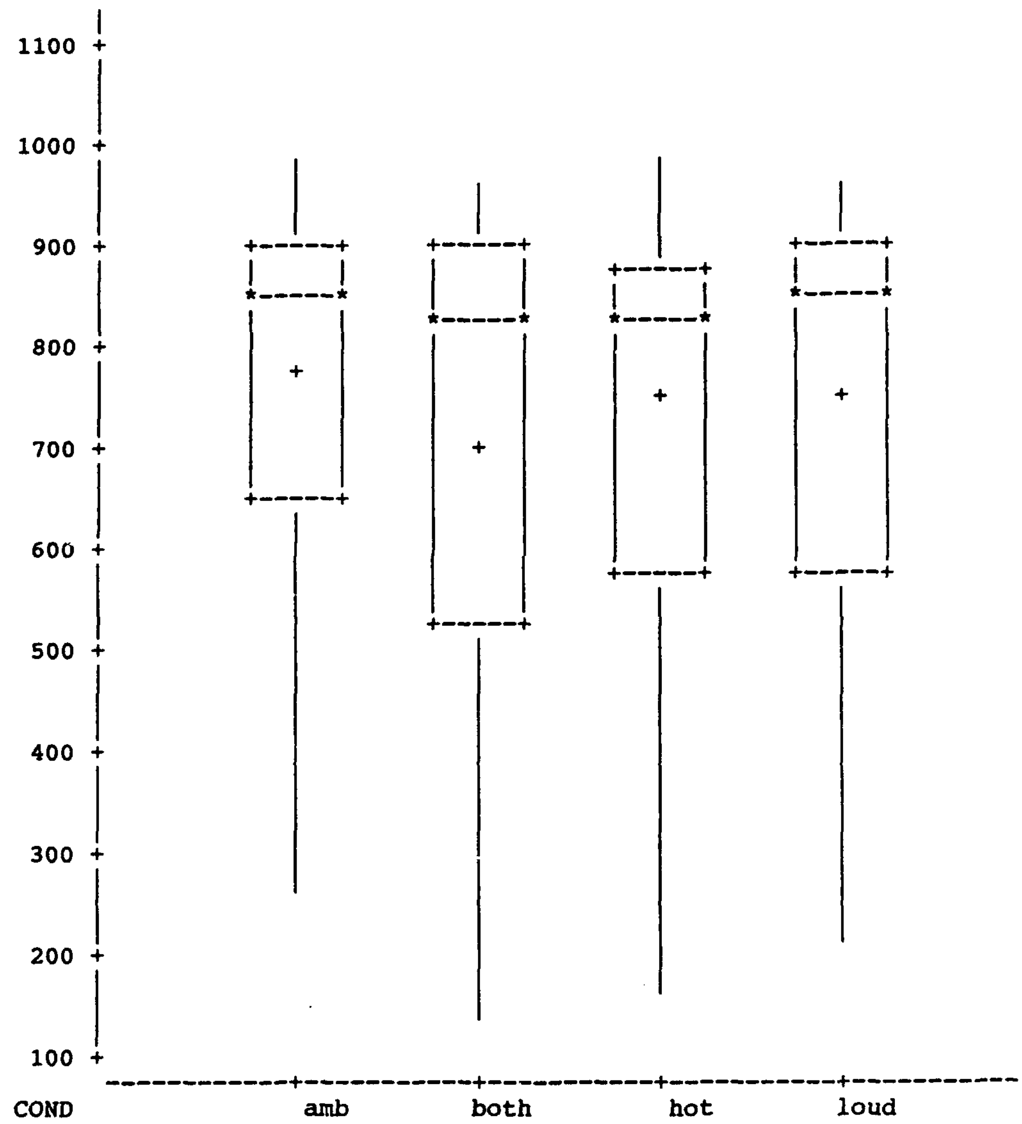
Source	DF	Sum of Squares	F Value	Pr > F
Model	34	2114920.31250	1.84	0.0116
Error	93	3148169.18750		
Corrected Total	127	5263089.50000		

R-Square	C.V.	6 x 8 Mean
0.401840	24.72323	744.187500

Source	DF	Type I SS	F Value	Pr > F
Subject	31	2033632.5000	1.94	0.0081
Temperature	1	42851.2813	1.27	0.2634
Noise	1	36924.0313	1.09	0.2990
Temp*Noise	1	1512.5000	0.04	0.8331

Source	DF	Type III SS	F Value	Pr > F
Subject	31	2033632.5000	1.94	0.0081
Temperature	1	42851.2813	1.27	0.2634
Noise	1	36924.0313	1.09	0.2990
Temp*Noise	1	1512.5000	0.04	0.8331

UNIVARIATE PROCEDURE
Schematic Plots



General Linear Models Procedure

8 x 8 Grid

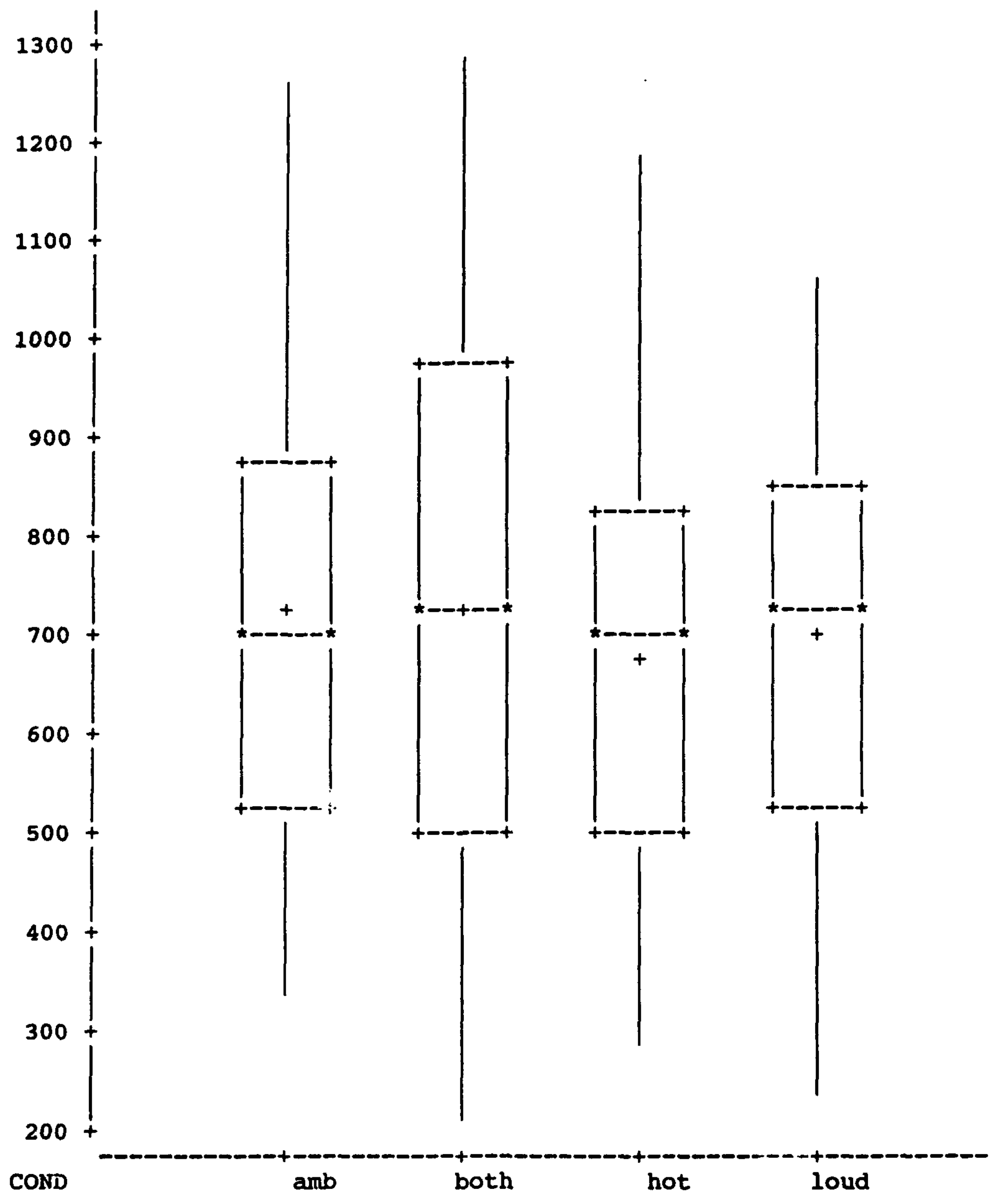
Source	DF	Sum of Squares	F Value	Pr > F
Model	34	3901597.26562	3.21	0.0001
Error	93	3325795.91406		
Corrected Total	127	7227393.17969		

R-Square	C.V.	8 x 8 Mean
0.539835	26.69669	708.351562

Source	DF	Type I SS	F Value	Pr > F
Subject	31	3857505.4297	3.48	0.0001
Temperature	1	341.2578	0.01	0.9224
Noise	1	12344.1328	0.35	0.5583
Temp*Noise	1	31406.4453	0.88	0.3511

Source	DF	Type III SS	F Value	Pr > F
Subject	31	3857505.4297	3.48	0.0001
Temperature	1	341.2578	0.01	0.9224
Noise	1	12344.1328	0.35	0.5583
Temp*Noise	1	31406.4453	0.88	0.3511

UNIVARIATE PROCEDURE
Schematic Plots



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