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ABSTRACT OF DISSERTATION

for the Degree of

DOCTOR OF PHILOSOPHY

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Title of Dissertation: Effects of Work/Rest Schedules on Monitoring Performance in the Heat

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The purpose of this investigation was to study the effects of work/rest schedules on human performance in hot climates. A visual monitoring task was used as the performance criterion and two performance parameters were measured, percent correct detections and percent correct responses. Temperatures studied were 74, 82 and 90 degrees Fahrenheit on the effective temperature scale. Three work periods, 20, 40 and 60 minutes, and two work/rest ratios, 2/1 and 3/1, yielded the six work/rest schedules under investigation. Total exposure to heat and total work duration were held

constant per session at three and two hours, respectively. Performance was evaluated over the full two hours of work.

Each of one hundred and eight subjects participated in a single session of the experiment. Their task was to detect any movements of a usually stationary small dot of light and indicate the size of that movement, whether small (1/4 inch) or large (1/2 inch). Detecting the signals only indicated the percent correct detections while detecting the signals and identifying their size comprised the percent correct responses.

The significant conclusions drawn from this research were:

1. High ambient temperature (82 and 90°FET) had a significantly detrimental effect on vigilance performance.
2. Long work periods (60 minutes) caused a significant deterioration in performance only at 90°F (ET) ambient temperature and 3/1 work/rest ratio (shorter rest periods).
3. Similarly, high work/rest ratios (3/1) produced a significant decrement in performance only at 90 °F (ET) ambient temperature and 60 minutes work period.
4. The combined effects of high temperatures (90°FET), long work periods (60 minutes) and

high work/rest ratios (3/1) had a strongly detrimental effect on vigilance performance.

5. There was a significant difference in subjective reactions to various experimental conditions, especially at high heat.
6. Performance showed a slight improvement over time. No vigilance decrement was detected possibly due to the effects of work/rest schedules, learning and heat acclimatization.
7. Discrimination, which adds to the complexity of the vigilance task, was strongly impaired by severe experimental conditions. Detection was also impaired but to a lesser degree.

EFFECTS OF WORK/REST SCHEDULES ON MONITORING PERFORMANCE IN THE HEAT

by

AMR K. MORTAGY, B.M.E., M.S. in I.E.

A DISSERTATION

IN

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was found to decrease and subjects' movements were much slower at the hot temperature.

Mackworth (1946) studied the accuracy of artificially acclimatized subjects when translating morse code messages in hot temperatures. He found a logarithmic increase in faulty messages with the increase of room temperature. However, even at high temperatures, highly skilled operators performed at a much superior level when compared to less-skilled operators working at the same temperature.

Pepler (1953) performed a similar experiment in the tropics using naturally acclimatized subjects. The results showed a continuous increase in error scores with the increase of temperature from 86 to 91°F (ET) and from 91 to 96°F (ET). No decrement of performance was found at the three lower temperatures of 71, 76 and 81°F (ET).

Effects of Work/Rest Schedules on Human Performance

Work/rest schedules and the efficient utilization of crew members have aroused much interest lately. The problem is no longer how efficient an operator is, but rather, how efficiently crews, of two or more operators, can perform alternatively a certain task? Most of the investigations in the area studied work/rest periods of one hour or more, few studied shorter periods. Following

CHAPTER I

INTRODUCTION

Statement of the Problem

Since early time, man has always been concerned about shaping the raw materials of nature to suit his needs. To some extent he has managed to create tools which satisfactorily served his purposes and controlled more adequately the surrounding environment. However, in many instances, it has been necessary for man to work and survive in unusual environments, very different from those to which he is accustomed. His performance under such circumstances has usually been inefficient and inadequate.

Hot climates represent one of the difficult environments that modern man encounters in everyday activity. Despite the advancement of science and the increasing sophistication of today's technology, controlled climates are enjoyed by only a small minority of the world's population and have a great deal of technical limitations. Building construction, shipyards, road construction, mining and steel mills are among those industrial sites that usually experience uncontrolled climates, and probably will do so for some time to come.

Although man has proved his ability to survive in hot climates, his performance in such climates has been, to say the least, erratic and often unpredictable. These changes in human performance under heat stress have recently drawn much attention and considerable interest has been given to the optimum conditions of performing various tasks at different degrees of heat stress.

Investigators have been concerned with ways and means of defining and measuring heat stress. Tolerance limits of safe exposures to heat and optimum exposure periods have been investigated to determine the maximum duration of heat exposure beyond which man's ability to perform work would be seriously impaired.

The recent developments in space, military and industrial situations have emphasized the concept of crew performance, where two or more people perform alternatively the same task for extended periods of time. Such situations are encountered whenever adding or changing operators-on-duty is extremely difficult, or virtually impossible, as in space flights. The only alternative is to allow operators to work and rest according to a certain schedule so as to insure efficient performance from each individual throughout the mission.

Crew performance or work/rest schedules have received considerable attention over the last ten years. Work/rest schedules that insure optimum utilization of manpower have been determined for various kinds of tasks and different periods of time. Most of the early studies were conducted in normal environments and only recently, interest in work scheduling for unusual environments has been developed.

Research in hot environments has emphasized the length of the work period where no decrement in performance is likely to occur. However, very little has been done to investigate two or more work periods separated by a rest interval. In other words, work/rest schedules in heat are not well investigated. In many instances, when performance suffers due to an external factor like heat, determining an optimum work period will not guarantee efficient performance at all times. But, determining such an optimum work period together with an adequate work/rest schedule might insure efficient work performance by all operators over extended periods of time. The purpose of this research was to evaluate the combined effects of heat stress and work/rest schedules on human performance.

Purpose and Scope

The purpose of this research was to study the performance characteristics of man while performing a visual vigilance task according to six specified work/rest schedules and under three degrees of heat stress. Two parameters, percent correct detections and percent correct responses were used as indicies of performance. Studying the above mentioned factors was hoped to provide a better understanding of the combined effects of work/rest schedules and heat stress on human performance. The following specific conditions, which will be discussed in greater details later, were investigated:

1. Ambient temperatures of 74, 82 and 90 degrees Fahrenheit on the effective temperature scale.
2. Work periods of 20, 40 and 60 minutes.
3. Work/rest ratios of 2/1 and 3/1.
4. Total work duration of 2 hours.
5. Total exposure to heat of 3 hours.
6. A visual monitoring task as the performance criterion.

Review of the Literature

From the earliest writings of recorded history, man has taken an interest in the effects of climate. However, quantitative studies were not possible until Galileo had produced the first thermometer at the begining of the 17th century. It was more than a century later when Fahrenheit and Celsius devised the more accurate instruments and convenient scales that we use today. Early in the 20th century, De Sasaure devised his wet-bulb thermometer. Since then progress in the field of heat has rapidly gained momentum.

In reviewing the previous research, three areas are pertinent to this investigation:

1. Indices of heat stress.
2. Effects of heat stress on human performance.
3. Effects of work/rest schedules on human performance.

A separate section will be devoted to review each of the above areas.

Indices of Heat Stress

As the interest in heat stress increased, a common index which would integrate all factors contributing to the heat load became a necessity. Unfortunately it proved to be extremely difficult to include all the factors involved, according to their respective level of importance, in one signle index. Nevertheless, there are a few indices which do take into account certain combinations of these factors. Following is a brief discussion of three groups of indices: subjective, biophysical and physiological indices, respectively.

Effective Temperature.--A subjective index, effective temperature was developed by Houghten and Yagloglou (1923-1924). It is defined by the American Society of

Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 1961) as:

> An arbitrary index which combines into a single value the effect of temperature, humidity and air movement on the sensation of warmth or cold felt by the human body. The numerical value is that of the temperature of still, saturated air which would induce an identical sensation.

The introduction of the globe thermometer led Bedford (1946) to propose the use of globe temperature instead of air temperature to make allowance for radiant heat, and the scales became known as the Corrected Effective Temperature scales. Two scales are available, one referring to men stripped to the waist and the other to men fully dressed in indoor clothing.

The scales have the great merit of relating the environmental conditions to an important physiological quality, subjective sensation of warmth. However, the meaning of their units in terms of physiological strains is not apparent (McCormick, 1964), and they did not prove to correlate well with other physiological parameters (Lind, 1963). The scales tend to overemphasize the effect of humidity at moderate temperatures and underestimate the effect of air speed at high temperatures and humidities, but they are reasonably accurate at moderate levels of heat and activity. They are the most widely used to study the effects of heat stress on performance (Teichner, 1967).

Equivalent Warmth.--Another subjective index, equivalent warmth was introduced by Bedford in 1936. It accounts for the same factors as effective temperature namely; dry-bulb temperature, wet-bulb temperature and air velocity; plus one more factor, mean dry-bulb room temperature. Its major drawback is the upper limit imposed on its usage which is 95°F at low humidity and 86°F at high humidity. Also, at high humidity it underestimates the effect of air speed.

Resultant Temperature.--Suggested in 1948 by Missenard, resultant temperature takes into account dry-bulb temperature, wet-bulb temperature and air velocity. It is similar to the effective temperature in two respects, it is a subjective index and it accounts for the same factors. However, it has not been as widely used for its underestimation of air velocity at high temperatures and/or humidities.

Equivalent Temperatures.--The equivalent temperature index was derived by Bedford in 1936. It accounts for air temperature, air flow and radiant heat. It is computed from the simple equation:

$$EQT = 0.522\, T_A + 0.478\, T_R - 0.0474\, V\,(100 - T_A)$$

where:

EQT = equivalent temperature

T_A = air temperature

T_R = mean radiant temperature

V = air velocity

The index has the advantage of simplicity and has been used by ventilating engineers. However, it suffers the drawback of neglecting the effect of humidity.

Wet Bulb Globe Temperature.--A biophysical index, wet bulb globe temperature was derived from the effective temperature scales by transforming them to a simplified form. It combines the effects of dry-bulb temperature, wet-bulb temperature and globe temperature in the simple equation:

$$WBGT = 0.1\ T_{DB} + 0.7\ T_{WB} + 0.2\ T_{BG}$$

where:

WBGT = wet-bulb globe temperature, °F

T_{DB} = dry-bulb temperature, °F

T_{WB} = wet-bulb temperature, °F

T_{BG} = black globe temperature, °F

The index has found rapid popularity, especially among the armed forces, primarily because of its simplicity and reasonable accuracy. Recently, the index has been recommended as a measure of heat stress in the newly proposed Threshold Limit Values (TLV, 1971).

Wet-Bulb-Dry-Bulb Index.--Similar to the WBGT index, wet-bulb-dry-bulb index accounts for both dry-bulb and wet-bulb temperatures.

$$WD = 0.15\,T_{DB} + 0.85\,T_{WB}$$

where:

WD = wet-bulb-dry-bulb index, °F

T_{DB} = dry-bulb temperature, °F

T_{WB} = wet-bulb temperature, °F

The index was derived in 1957 by Lind et al. and is criticized for not making an allowance for heat radiated or air flow.

Operative Temperature.--Operative Temperature was proposed in 1938 by Winslow, Herrington and Gagge. A biophysical index, it takes into consideration heat radiated as well as heat convected and heat evaporated.

$$T_O = (K_R T_W + K_C T_A) / (K_R + K_C)$$

where:

T_O = operative temperature, °C

T_W = mean wall temperature, °C

T_A = mean dry-bulb temperature, °C

K_R = radiation constant

K_C = convection constant

The index does not account for humidity or air flow and is inadequate for temperatures above 80°F.

Heat Stress Index.--Developed by Belding and Hatch in 1955, and modified in 1963 by Hatch and by Herting and Belding, heat stress index is considered to be one of the most comprehensive heat indices yet proposed. The index expresses the thermal stress of a hot climate as the ratio of the amount of sweat that must be evaporated to maintain the body in thermal equilibrium, to the maximum evaporative capacity of climate (Edholm & Bacharach, 1965).

$$HSI = (E_{req} / E_{max})\ 100$$

where:

HSI = heat stress index

E_{req} = energy required to maintain balance, BTU/hr

E_{max} = maximum evaporative energy, BTU/hr

The index accounts for the following heat factors: dry-bulb temperature, wet-bulb temperature, globe temperature, air velocity, metabolism and heat of evaporation. The index has some drawbacks. First, the approximations and assumptions introduced for the sake of simplicity reduce its accuracy. Secondly, the index does not bear any simple relationship to physiological strain and equivalent levels on the index produced by different combinations of levels of variables, do not produce the same degree of physiological strain (Edholm & Bacharach, 1965). However, Peterson (1970), in a study of heat stress indices, showed that the index correlates well with some physiological parameters. The index is reliable for still air between 80 and 95°F and R.H. 30 to 80%, but it exaggerates the humidity effect at high humidity and the air speed effect at low humidity.

Predicted 4 Hour Sweat Rate.--The P4SR index, devised by McArdle et al. in 1947 is a physiological index which represents the heat stress of an environment in terms of the sweat produced in four hours. The index considers four heat stress factors: dry-bulb temperature, wet-bulb temperature, air velocity and metabolism. The scale allows for wide variations in dry-bulb and wet-bulb temperatures, globe temperature, air movement, clothing and rate of work. The index does not allow the estimation of the amount of sweat produced in given conditions, but it provides a measure of heat stress at these conditions. To get a direct correlation between the index and the observed sweat rate of a group of individuals, the following conditions must be satisfied (Edhom and Bacharach, 1965): subjects must be fully acclimatized to heat, exposure must last 4 hours, and climatic conditions must not be so severe as to indicate a P4SR of above 5.0. Although the index is rather complicated to use, its comparison with experimental results led to a gradually accumulating body of support for it, and to confirm its reliability, especially above 80°F (Lind, 1963; Edholm and Bacharach, 1965).

Effects of Heat Stress on Human Performance

Research concerning the effects of heat on human performance has covered a wide variety of tasks. However, with the advancement of military science and space technology, certain related tasks received much more attention than the rest. Mental and memory capabilities, vigilance watch, tracking efficiency and psychomotor performance were among those tasks receiving considerable interest. A brief review of literature in the area of performance under heat with a special emphasis on the above mentioned tasks is pertinent at this point.

Most of the studies reviewed were task oriented and their results depended to a great extent on the type of task selected as a performance criterion. Grouping various investigations by the type of task adopted, provided accurate means of evaluation and comparison. However, further subgrouping within each task according to an adequate basis proved to be extremely difficult. Grouping according to various parameters of heat stress, like temperature, humidity, clothing, duration of exposure and acclimatization, was attempted. Nevertheless, it proved unsatisfactory and resulted in a great deal of repetitions and duplications. Therefore, it was decided to arrange various investigations within each group in a chronological order. This prevented unnecessary duplications and is expected to facilitate reference to these studies, if need be.

Vigilance Tasks.--Vigilance literature had a special importance for this investigation as a result of selecting it as the criterion for performance evaluation. Such selection was influenced by the wide spread applications for monitoring stations in various fields, as will be discussed in detail later.

In studying the effects of heat on vigilance, Mackworth (1946) used artificially acclimatized subjects at effective temperatures of 70, 79, 87.5 and 97°F. Two groups of experienced and non-experienced subjects were to perform the clock test for a 2 hours period. Optimum performance was achieved at 79°F with decrement increasing at higher or lower temperatures. Experienced subjects performed better only at high temperatures (87.5 and 97°F), while at lower temperatures experience had no effect on performance. The decrement in performance at 70°F was attributed to the temperature being lower than desirable.

Pepler (1953) conducted a similar experiment using the Cambridge clock test. Effective temperature of 67, 82 and 92°F were used and naturally acclimatized subjects performed the task for 2 hours. He found that performance was worse at 82°F compared to 67 and 92°F. This result is in contradiction with those of Mackworth, discussed above, who found continuous decrement in performance with the rise in temperature. However, when Pepler repeated basically the same experiment, but improved conditions to maintain interest on the part of the subjects, results similar to those of Mackworth were found and the poorest performance occured at 92°F. Later, Pepler (1958) reported the critical range for a vigilance task, where a significant decrement in performance takes place, to be between 81 and 86°F. This range decreases at high humidities.

Frazer and Jackson (1955) used the Cambridge clock test to measure simple and serial reaction times at temperatures ranging from 90 to 104°F and humidities from 90 to 95% R.H. The results showed no significant changes on simple reaction time due to temperature. However, serial reaction time increased significantly with the rise in temperature.

In a complex field study, Loeb and Jeanthean (1958) investigated the individual and compound effects of heat, noise and vibration on performance. Subjects were exposed to desert heat of 100 to 125°F while performing a vigilance task in their armored cars for a period of 3.75 hours. Reaction time did not change significantly due to heat alone. However, when adding noise and vibration to heat a significant additional decrement was produced, much higher than that produced due to noise and vibration alone.

In studying the interaction effects of two tasks, Bursill (1958) used two levels of dry-bulb/wet-bulb temperatures, 70/60 and 105/95°F at 120 fpm air velocity. Subjects responded to a peripheral task concurrently while performing a continuous control tracking task. Performance was found to be more severely impaired at the higher temperatures and more signals were missed in the peripheral than the central field of vision.

In a study by Fine, Cohen and Crist (1960), subjects performed an anagram task for 35 minutes at the begining of, and after 5.5 hours of a 6 hours exposure to effective temperatures of 65, 69, 81 and 93°F. Performance did not change significantly with heat except in one trial at 93°F. However, there was no evidence of performance deterioration as a result of heat.

Carleson (1961), reported no significant effects of temperature on performance of a simulated radar watch. Subjects performed the task for a period of 1, 2, or 3 hours at temperatures 68, 77 and 122°F and relative humidity 20%. Also the duration of the watch had no apparent effect on performance.

To study the tolerance limit of man under heat stress, Provins (1962) used a visual vigilance task and correlated tolerance time with each of the following: partial pressure of water vapour, wet-bulb temperature and a weighted average of dry-bulb and wet-bulb temperatures.

Bell, Provins and Hiorns (1964) conducted another experiment to study tolerance limits. Subjects performed a visual vigilance task until exhaustion at dry-bulb/wet-bulb combinations of: 29.5/24.5, 43/35, 51/37, 51/43 and 63/47°C (86.1/77.1, 109.4/95, 123.8/98.6, 123.8/109 and 145.4/116.6°F). At these temperatures the mean tolerance limits were 240, 187.5, 67.8, 28.4 and 19.3 minutes respectively. However, there was no significant difference in subjects'performance as a result of heat.

In a different approach to the problem, Fox, Goldsmith and Hampton (1963) raised the body temperatures of the subjects under test to 37.3, 37.9 and 38.5°C. Subjects then performed a vigilance task and an arithmetic task. Only the speed and accuracy in mathematics were impaired by raising the body temperature, but the vigilance performance was improved.

Edholm (1963) reported slight differences in performance of a vigilance task between naturally acclimatized, artificially acclimatized, and non-acclimatized subjects when subjected to comfortable conditions and high temperature. In the latter part of the trial artificially acclimatized subjects and non-acclimatized subjects had very similar performances.

Youngling (1965) investigated the effects of temperature and sleep loss on performance of two concurrent central and peripheral tasks. Temperatures of 75 and 105°F were studied with normal sleep and 36 hours of sleep loss at two speeds of the pursuitmeter (central task).

The high temperature together with sleep loss and task difficulty produced a significant decrement in peripheral signal detection. Heat stress alone, resulted in funneling of peripheral detection. These results support those found earlier by Bursill.

Mental and Memory Tasks.--The vigilance task selected for this investigation involved a discrimination process, as will be discussed later. This process required and depended on mental and memory capabilities. For this reason a thorough review of mental and memory performance in the heat was deemed necessary.

Viteles (1946) investigated the effects of heat on seven different tasks, two of which were mental (mental multiplication and number checking). Four levels of effective temperatures were studied, 73, 80, 87 and 94°F. The duration of heat exposure was 4 hours. None of the six subjects could complete the experiment at 94°F on their first exposure and only four completed the 4 hours on the second exposure. For the other three levels of temperature, a significant decrement in performance was detected as a result of increasing temperature, with the lowest output at 87°F.

In studying a resistance box task, Carpenter (1946) measured the time needed to trace a simple electrical circuit containing only resistors at four levels of effective temperatures ranging from 79 to 97°F. He determined 89°F the temperature at which a statistically reliable impairement in performance would have occured.

Blockley and Lyman (1950), studied the performance of mental arithmetic and number checking tasks at extremely high temperatures, 160, 200 and 235°F. The humidity was maintained constant at a vapour pressure of 0.8" Hg. These conditions are equivalent to effective temperatures of 100.5, 109 and 114°F. At the two extremes, there was a significant drop in performance. The insignificance at 109°F was attributed to the irregularities in procedure at that temperature.

Mackworth (1950) used a coding test to study the temperature effects on performance during three hours of exposure. He used five levels of effective temperature, 79, 83, 87.5, 92 and 97°F. There was a slight difference in performance between 79 and 83°F, but a significant increase in error score was found at higher temperatures. He also fitted a logarithmic curve to the data correlating the environmental temperature in °F on the effective temperature scale and the subject's performance.

Pepler (1953) studied the performance of naturally acclimatized subjects on a symbol identification task. Three speeds of presentation were used at four levels of effective temperatures, 76, 81, 86 and 91°F. Performance at the last hour and a half of a two hours session was significantly affected by temperature only at the slow speed, with an optimum at 81°F. The fast speed showed an optimum at the same temperature, while the medium speed had an optimum at 86°F. To increase the subjects' motivation Pepler (1953) repeated the same experiment, but used only two levels of speed, and introduced two levels of incentive. Again performance changed significantly with temperature only at the slow speed. Temperature effects at the low incentive level was significant but not at the high. In other words, high incentives offset the effect of temperature on performance.

Chiles (1957) conducted an experiment using the same task, procedure and temperature levels used by Pepler. However, he found no significant effects due to temperature, which partially contradicts the results by Pepler. After improving the procedure Chiles (1958) repeated the same experiment at four levels of effective temperatures, 76, 81, 93 and 96°F. He also tested 3 subjects at a dry bulb temperature of 120°F, 105°F wet bulb temperature at 100 fpm air velocity. Again there was no significant change in performance. The 120, 105°F combination seemed to be an upper limit for this task. In discussing his results, Chiles attributed the negative results he found, and its contradiction to Pepler's results, to the simplicity of the task and the differences between his artificially acclimatized subjects compared to those naturally acclimatized by Pepler.

Barlett and Gronow (1953) investigated the effects of temperatures, 72.5, 82 and 91.5°F effective temperatures, on the performance of a mental task during the second half hour of a one hour exposure time. Error score and time needed to reach a decision were the performance criterion. None of them was significantly affected by temperature. However, decision time appeared to slightly decrease with the increase in temperature.

Mayo (1955) conducted a four weeks full time course in electronics to two groups: group I at 71°F and group II at 81°F. Tests were given midway and at the end of the course. There was no significant difference in the scores between the two groups. However, group II scored an average grade lower than that of group I on both tests. Since the groups were carefully selected to represent equal mental capabilities, an impairment effect due to temperature could be suggested there.

Givoni and Rim (1962) investigated a work/rest schedule in a hot environment. After entering the work chamber, subjects rested for 35 minutes, worked for 30 minutes on a multiplication task, rested for another 25 minutes, worked for another 30 minutes on the same task, then the test was terminated. Temperatures ranged from 70.2°F to 90.1°F on the effective temperature scale. There was no significant effect on performance due to temperature. However, performance deteriorated constantly with time of exposure.

Wing et al. (1965) used three levels of effective temperatures, 72, 90 and 95°F, to study the performance characteristics of short term memory. Despite the fact that performance declined with the increase in temperature, only at 95°F was it found statistically different from the other two.

To check the ability of time judgements at high body temperatures, Fox et al. (1967) used five groups of subjects with body temperatures of: normal, 37.5, 38, 38.5 and 39°C (99.5, 100.4, 101.3, 102.2°F, respectively). The results showed a continuous shortening of time judgements as body temperature increased.

Holmberg and Wyan (1968) reported that Swedish students achieved best reading and arithmetic results when the classroom temperature was maintained at 20°C (68°F), as compared to 27°C (80.6°F) and 30°C (86°F). Also as temperature increased, female students performed significantly better than males.

Yeremin et al. (1968) tested the decrement in working ability at temperatures 40, 60 and 80°C, (104, 140 and 176°F respectively), 15 to 25% R.H. and air velocity of 0.1 to 0.2 mps. The results showed a slight decrement in working ability at 40°C. However, a sharp decrement was detected at 60 and 80°C.

Miura (1968) reported 25°C (77°F) at 50 to 60 percent R.H. as the optimum conditions for Japanese laborers engaged in mental tasks. Also the comfort zone was slightly higher, in summer than in winter, and for Japanese than for British.

Tracking and Psychomotor Tasks.--Tracking and psychomotor performance is related to the task adopted for this investigation. It represents a type of activity which is usually associated with vigilance behavior. For example, pressing the response button after detecting a signal is a definite psychomotor activity. These similarities emphasize the importance of psychomotor literature for this research.

In studying the effects of heat on psychomotor tasks Mackworth (1945 b) attached a 50 lbs weight to the control lever of a pursuitmeter. The subjects performed the tracking task continuously for three hours at the following environmental effective temperatures: 79, 83, 87.5, 92 and 97°F. The results showed a rapid deterioration in performance with the increase in temperature, but it was only significant at 87.5°F. Also a logarithmic curve was suggested to correlate room temperature and average error score.

Carpenter (1950) tried to correlate the effects of handle load and room temperature on performance of a tracking task. By increasing the temperature from 80 to 90°F, the increase in error was comparable to that obtained when the load on the control handle was increased from 8 to 30 lbs. However, at higher temperatures, the effect of temperature was much greater than that of handle loads.

Pepler (1953, b, c, e) conducted a series of experiments in the hot chamber using tracking tasks. He used naturally acclimatized subjects to perform a pointer alignment task. In his first experiment the levels of temperature were 66, 76.2, 84.5 and 91.5°F effective temperatures. The run consisted of eight 15 minutes trials. He found subjects' performance to be poor at the two high temperatures. At 91.5°F subjects performed erratically and less accurately compared to 84.5°F. Efficiency was greater at 66°F than at 76.2°F. In his second experiment, Pepler studied the effects of high and low humidities (20 and 80 percent relative humidity). Temperature was changed from 72.5, 79.5, 84.5 to 92.5°F on the effective temperature scale. The run was shortened to sixteen 3 minutes trials. Here again performance at 84.5°F was significantly different from that at 79.5°F. Performance was optimum at 72.5°F and then declined with the rise in temperature. The 80% R.H. caused a decline over a range of temperature lower than that observed for 20% R.H. However, the effect of humidity on performance was not significant. In the last experiment, Pepler used two levels of incentives and two levels of display speed at temperatures 76, 81, 86 and 91°F effective temperature. Unlike the previous two experiments, optimum performance was achieved at 81°F. High incentives increased performance at both display speeds, but the increase did not offset the drop in performance due to high temperatures.

Pepler (1959) tried to correlate warmth and lack of sleep with respect to their effects on performance. He used a pursuit tracking for 30 minutes followed by a serial-choice task for 20 minutes. The results showed that both high temperatures and lack of sleep were detrimental to performance. They caused more errors in tracking and gaps in serial response. However, there was a qualitative difference in response. Warmth reduced accuracy but sleep loss reduced activity.

Teichner and Wehrkamp (1954) investigated the effects of temperature and learning on a pursuitmotor task. Subjects performed the task at effective temperatures of 55, 70, 85 and 100°F for 5 successive days. Both temperatures and days had a significant effect on performance which was optimum at 70°F and declined continuously below or above this temperature with the worst performance at 100°F. Learning had a strong effect since performance improved from one day to another.

Russel (1957) studied two types of tracking skills, free movement and pressure control. Temperature ranged from -10°C to 40°C. He found a narrow range of temperatures outside which a serious impairment in performance occured. This range was different for the two tasks, 10-27°C (50-80.6°F) for the free movement tracking and 20-40°C (68-104°F) for the pressure control tracking. However, the nature of impairment was different for the two types of tracking.

In a study to investigate the effects of heat exposure rate upon performance, Masters (1968) elevated the rectal temperature of subjects by 2°F. This was achieved by three different temperature levels: 80, 100 and 120°F at 80% R.H. Response time on a psychomotor task changed significantly with temperature. When comparing the means at each temperature, 80 versus 120, and 80 versus 100 were significantly different, but 100 versus 120 was not different. Masters concluded that the faster response time at high temperatures is a result of the amount of heat storage in the body and not of the rate of storage.

London (1968) reported that performance, on a pursuitmotor, under heat stress was considerably improved when subjects were either hypnotized or motivated. The latter had a slightly greater effect.

In a recent study by Ramsey and Mortagy (1971), subjects performed a psychomotor task for 90 minutes.

Performance was recorded every five minutes at the following effective temperatures, 70, 80 and 90°F. Temperature had a significant effect on the number of attempts on the task, the number of hits, and the percentage correct attempts. The results showed a significant drop in all performance measure associated with increasing temperature from 70°F to 80 or 90°F. However, there was no difference in performance between 80 and 90°F.

Miscellaneous Other Tasks.--In a study of the effects of heat and humidity on reaction time, Ivy et al. (1944) found no significant differences between hot-wet conditions (86/86°F DB/WB and 100% R.H.) and hot-dry conditions (117/85°F DB/WB and 17% R.H.).

Pace et al. (1945) exposed two groups to hot environments during the day with the first group spending the night in a cool environment and the second group remaining in the hot environment. No differences in auditory reaction time were found between the two groups. However, the second group proved to be generally superior in simple and complex visual reaction time.

The effects of heat on a coordination test were investigated by Weiner and Hutchinson (1945). Subjects were required to move steel ball-bearings from an inner ring to an outer ring with forceps, and then return them, at ordinary room temperature and at 91°F (ET). Accuracy was found to decrease and subjects' movements were much slower at the hot temperature.

Mackworth (1946) studied the accuracy of artificially acclimatized subjects when translating morse code messages in hot temperatures. He found a logarithmic increase in faulty messages with the increase of room temperature. However, even at high temperatures, highly skilled operators performed at a much superior level when compared to less-skilled operators working at the same temperature.

Pepler (1953) performed a similar experiment in the tropics using naturally acclimatized subjects. The results showed a continuous increase in error scores with the increase of temperature from 86 to 91°F (ET) and from 91 to 96°F (ET). No decrement of performance was found at the three lower temperatures of 71, 76 and 81°F (ET).

Effects of Work/Rest Schedules on Human Performance

Work/rest schedules and the efficient utilization of crew members have aroused much interest lately. The problem is no longer how efficient an operator is, but rather, how efficiently crews, of two or more operators, can perform alternatively a certain task? Most of the investigations in the area studied work/rest periods of one hour or more, few studied shorter periods. Following is a brief review of some of the studies reported in the area, utilizing a vigilance task as a criterion for performance evaluation.

Some of the early studies conducted by Mackworth (1961) investigated the effects of crews on performance of a vigilance task. The subjects performed the clock test for a total of 2 hours. Two groups were used. The first group consisted of two crews, each performing the task for 1 hour. The second group performed the task continuously for 2 hours. Results were analyzed for each 1/2 hour period. The two groups performed similarly during the first hour and the last half hour. However, there was a significant difference in performance between the two groups during the third 1/2 hour, with group I performing at a high level, similar to that of group II during the first 1/2 hour of the watch. In other words, fresh subjects at the start of the second hour performed efficiently and significantly better than those who had been on the watch for one hour. In a second experiment using the same task, Mackworth divided his group I into two crews. Each crew alternated on and off the job for 1/2 hour periods. Group II performed the task for the entire 2 hours period. The results showed that group I maintained a high level of performance at all times, similar to that of group II during the first 1/2 hour of the watch. However, for the next 1 1/2 hours, the two groups performed significantly different, with group I maintaining a much higher level of performance. Mackworth concluded that fresh subjects usually maintain a high level of performance during the first 1/2 hour of the watch.

Colquhoun (1959) reported a marked decline in efficiency during the last 30 minutes of a 1 hour simple checking task. However, by introducing a 5 minutes pause after 30 minutes of work, performance was maintained at its usually high level.

Adams and Chiles (1960, 1963) conducted a series of experiments to investigate the effects of work/rest schedules on five performance tasks: mental computation, pattern discrimination, monitoring and vigilance. The first experiment utilized equal work and rest periods of two, four, six and eight hours. The 2/2 and 4/4 hours schedules showed slight decrement in performance but the 6/6 and 8/8 hours schedules showed significant decrement. This high decrement was attributed mainly to boredom. A second experiment showed the superiority of 4/2 hours work/rest schedule as compared to a 6/2 hours schedule. High decrement was developed in the latter. A third experiment using the same tasks investigated a 4/2 hours work/rest schedule over a twelve hours period for 15 days. Performance was maintained at an acceptable level and motivation seems to have had a strong effect on it. Learning was significant only in the pattern discrimination task. These studies emphasize the importance of 2/1 and 3/1 work/rest ratios for continuous operations.

In a vigilance study, Bergum and Lehr (1962) compared performance of 90 minutes of work to that of three 30/10 minutes work/rest periods. At the two signal rates used, 24 and 6 per hour, there was a highly significant facilitation of detection performance as a result of using the work/rest schedules.

Smith, Lucaccini, Groth and Lyman (1966) studied the effects of a secondary task, performed during the rest period, on vigilance performance. Subjects were alerted before signals and one group spent the time between signals resting while the other group performed a problem solving task. The two groups had similar performance patterns and the problem solving task did not interfere with detection performance.

In an industrial field study, Douglas (1967) investigated the effects of three work/rest schedules on an inspection task. The first schedule was a self-determined work/rest cycle where subjects stopped inspection and rested whenever they felt like it. The other two schedules were fixed 13/2 and 3/2 minutes work/rest cycles. Subjects performed a secondary task during the rest periods.

Gross speed was significantly affected by the schedule, with the self-determined and the 13/2 work/rest schedules almost identical and much higher than the 3/2 schedule. However, net speed was not significant.

Summarizing a 10 years program of research in work/rest scheduling, Alluisi and Chiles (1967) reported the ability of man to work on a 4/4 hours work/rest cycle for a long time with no decrement in performance. However, maintaining the same performance on a 4/2 hours cycle could be done for 2 or 4 weeks, and only by men well selected for the job.

In a similar study Chiles, Alluisi and Adams (1968) investigated man's ability to perform 12 and 16 hours per day on a 4/4 and 4/2 work/rest cycles respectively. They concluded that the first schedule could be followed for at least 30 days with no serious decrement. However, the second schedule could be maintained only for shorter periods and at a significant cost to man's reserves for meeting emergencies.

In a study by Ware, Baker and Drucker (1964), results different from those presented above, were reported. Three work/rest schedules were used for a 24 hours vigilance watch. The first group used a self-paced work/rest schedule. The second group worked and rested for equal periods of 2 hours each, and the third group worked continuously for 24 hours. There was no significant difference in detection performance between the three groups. All groups showed performance decrement with the elapse of time, but rest periods induced no recovery. These results strongly contradict the ones presented earlier and assert the need for further research in the area of work/rest scheduling.

Summary

The results of the above mentioned investigations in the area of heat could be categorized into two distinctly different and contradictory groups. The first group demonstrated performance decrements in hot environments, while the second group showed no such decrements. Nevertheless, it could be concluded that there is a critical zone of temperature above which performance of most tasks is likely to be impaired (Pepler, 1961).

In the area of work/rest schedules contradictory results are also found. Few investigations agreed fully with each other and the main difficulty in comparison stems from the various conditions of each experiment which are almost impossible to maintain at the same level.

The above variations in results and the many unanswered questions in the area of crew performance under heat stress have provided impetus for this investigation.

CHAPTER II

EXPERIMENTAL EQUIPMENT AND MEASUREMENTS

Equipment-General

The equipment used in this investigation can be divided into four major groups as follows:

1. Equipment for maintaining the independent variables.
2. Equipment for producing the experimental task.
3. Equipment for recording and measuring the dependent variables.
4. Supporting equipment.

A separate section will be devoted to describe the equipment used in each group.

Equipment for Maintaining the Independent Variables

The equipment used for maintaining the independent variables consisted of an environmental chamber which controlled ambient temperature, and a light switches circuit which controlled work/rest schedules.

Environmental Chamber

A controlled environment room model no. CER1216 manufactured by Sherer-Gillett Company, Marshall, Michigan, was used to maintain the required climatic conditions. The room measured 12' x 16' x 9' and was partitioned so as to allow separate quarters for each subject. The chamber featured a wide range of controlled dry-bulb temperatures, from 36°F to 140°F, and controlled relative humidities ranging from 10 to 95%. Such wide ranges of temperature and relative humidity were controlled and maintained by the use of two temperature programmers, model RFC-52. One programmer controlled dry-bulb temperature and the other controlled wet-bulb temperature. The chamber and programmers provided adequate control of the required temperatures ± 1.5°F. The sound proof chamber had two one way windows to enable experimenters to visually monitor subjects throughout the experiment.

A simplified layout of the environmental chamber is shown in Figure 1. The work place layout showing the two experimental stations is shown in Figure 2.

Light Switches Circuit

A small red light placed on the table in front of each subject was used to signal the start and end of each rest period. Rest periods started when the red light came on and ended when it went off. Having the lights in this position made it possible for subjects to detect changes in their schedule from work to rest and back to work

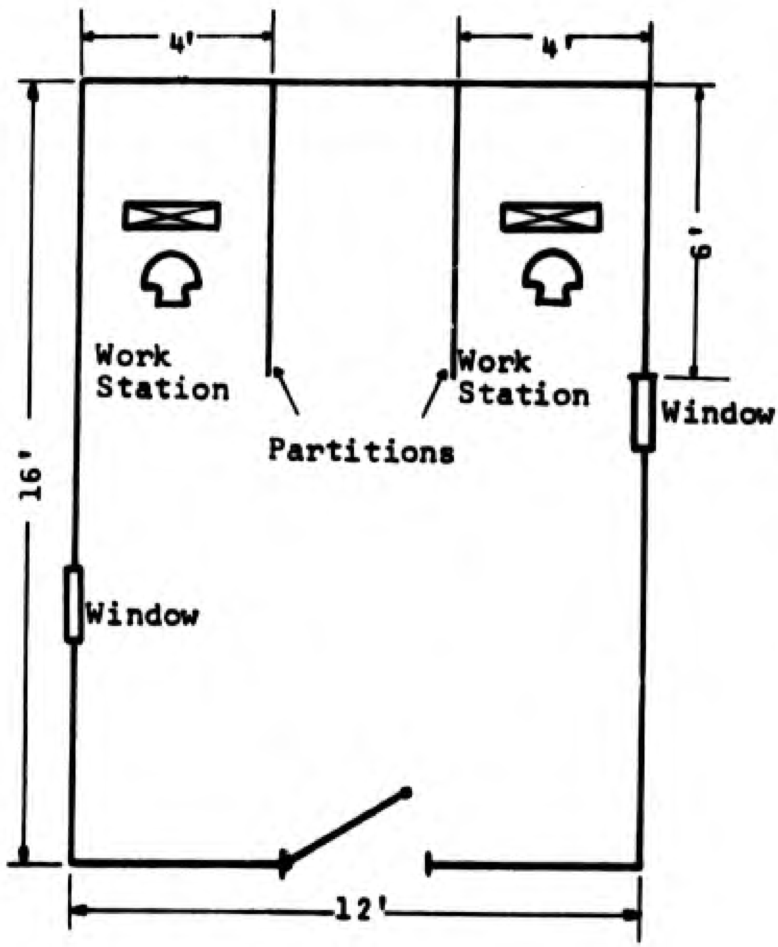

Fig. 1.--Layout of the environmental chamber

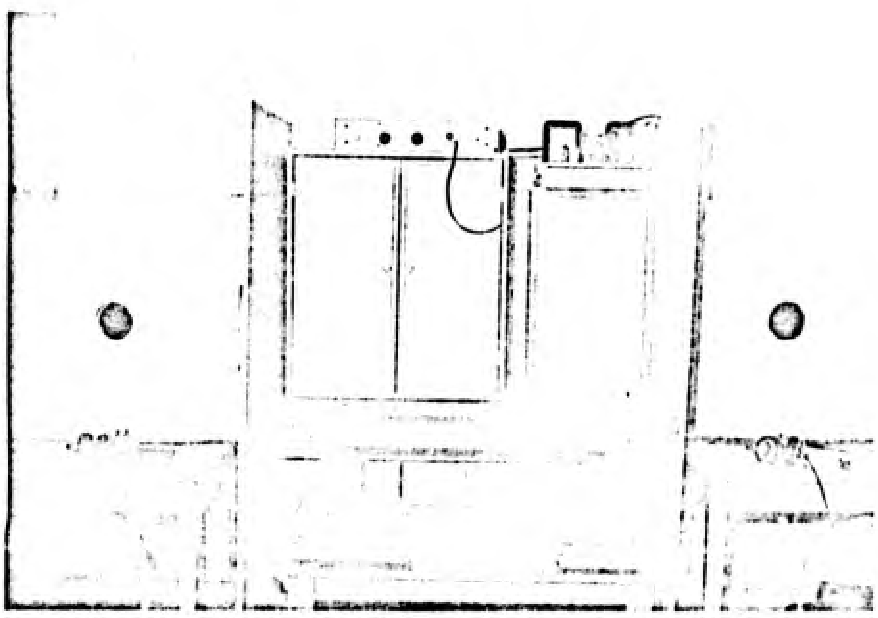

Fig. 2.--Work place layout

within a few seconds of their occurance, and in the same time did not interfere with their visual field during monitoring periods. The light switch is shown clearly in Figure 3.

Equipment for Producing the Experimental Task

The equipment used to produce the monitoring task consisted of a tape recorder, an A-D convertor, a potentiometer bridge and two cathode-ray oscilloscopes. The first three components are shown in Figure 4, and the latter in Figure 3. A schematic drawing of the four components and the connecting circuit is shown in Figure 5.

Tape Recorder

A Sony stereo tape recorder was used to record and later produce the required signal. Manufactured by Sony Corporation, Japan, the model TC-560 used, provided excellent sound quality on two channels. The tape was played at a speed of 3.75 inches per second which produced adequate sound quality. A Scotch brand magnetic tape model 290 was used for recording and playing back the signal. It provided low noise features even after long hours of usage. The right channel on tape was used in producing the signal and the left channel for auditory instructions during the period of instructions and practice.

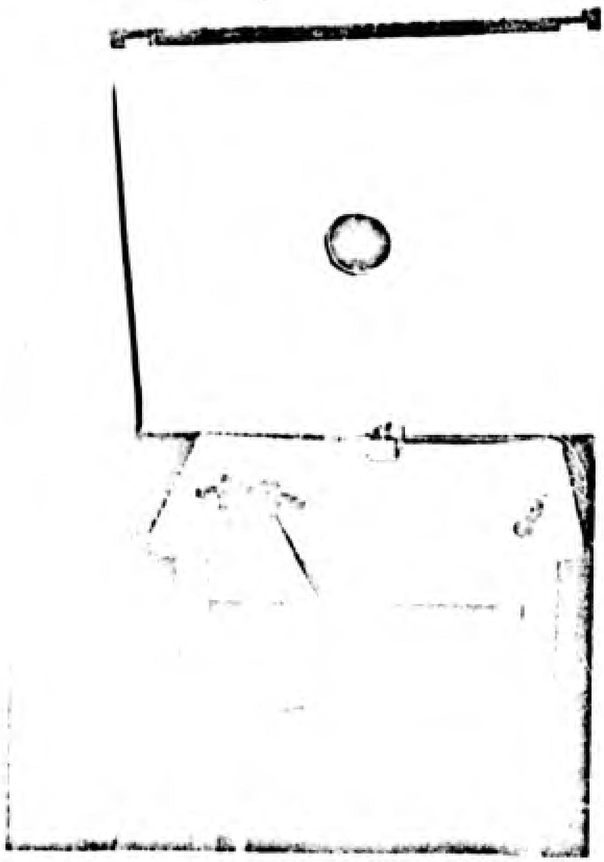

Fig. 3.--Work station

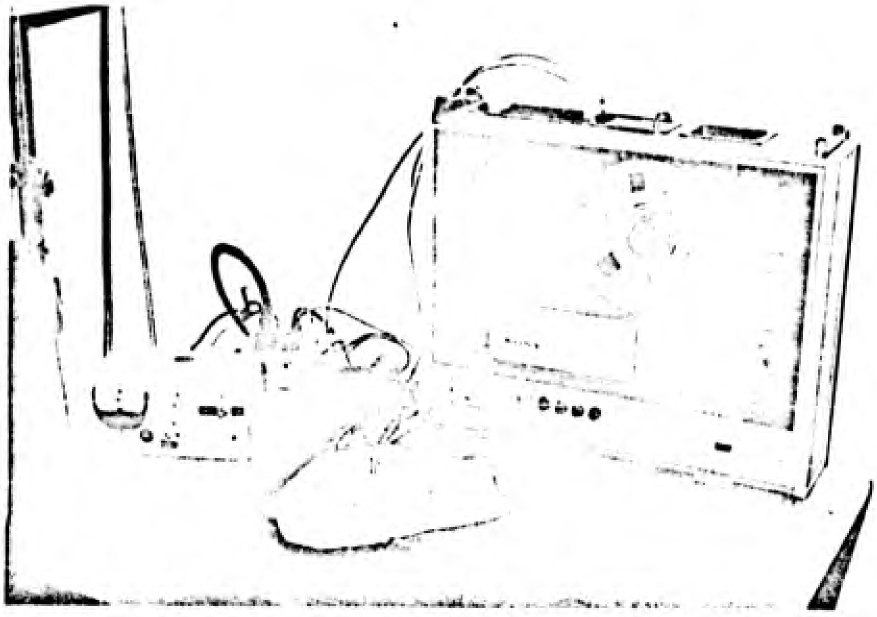

Fig. 4.--Converter, potentiometer and tape recorder

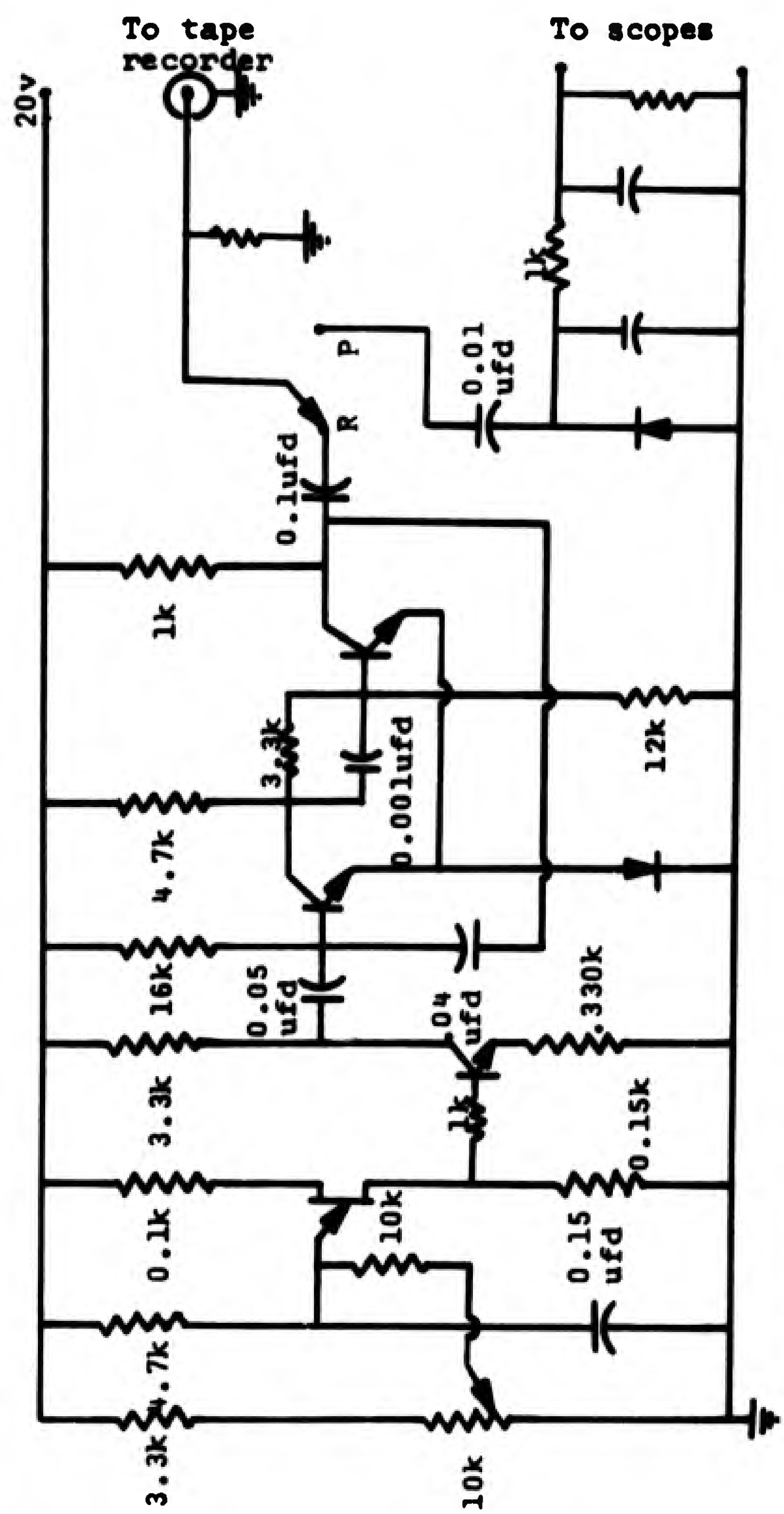

Fig. 5.--Connecting circuit for signal producing equipment

A-D Convertor

An A-D convertor was connected between the tape recorder and the oscilloscopes for the purpose of converting audio signals on tape to an electrical voltage input to the scope. It was also used in reverse function while making the signal tape, i.e. to change the voltage output from the potentiometer bridge to an audio signal recordable on tape. A toggle switch was used to adjust the convertor to either mode. A small dial showed the input voltage at all times.

Potentiometer Bridge Circuit

A potentiometer bridge was used to vary the input voltage to the tape during recording. Zero voltage, shown on the A-D convertor gauge, produced the background event. A small voltage change in the positive or the negative direction produced a small up or down signal, respectively. A large voltage change in either direction produced a large signal in the corresponding direction. The voltage changes were adjusted such that small and large signals occuring on the oscilloscopes were 1/4 and 1/2 inches respectively.

Cathode-Ray Oscilloscopes

Two cathode-ray oscilloscopes were used to display the signal. They were both manufactured by Tektronix, Inc., Portland, Oregon, model numbers 512 and 515A. The two models were slightly different but had the same size screen and operational characteristics. Since only the screens were visible to subjects, the two scopes were considered similar. They both had similar settings for focus, intensity, astigmatism, stability, input, vertical positioning, horizontal positioning and vertical deflection amplitude. Settings were adjusted such that small signals were 1/4 inch in length and large signals were 1/2 inch long.

Equipment for Recording and Measuring the Dependent Variables

The equipment used for recording and measuring the dependent variables consisted of two response buttons, one for each subject, and a physiograph recorder equiped with the required accessories.

Response Buttons

A handle grip type response button was attached to each subject's performance console. It allowed comfortable grip and pressing characteristics while the arm was in a relaxed position. A response button is shown in Figure 3.

Physiograph Recorder and Accessories

A physiograph Six recorder was used to record subjects' responses, signals produced, and subjects' heart rates and skin temperatures. It is manufactured by E & M Instrument Company, Houston, Texas, and has the ability to record on six analogue channels, plus time, event and optional servo channel. The time, event and optional servo channel was adjusted so as the pen deflection in one direction would indicate the time, and in the other direction would indicate one subject's response. Therefore, in effect, seven channels were used to record the measured and monitored variables. Figure 6 shows the physiograph recorder and accessories. A brief description of each channel and the accessories connected with it will follow and the seven channels are shown clearly in Figure 7.

Channel #3 and the optional servo channel were used to record responses of the right-hand and left-hand subjects, respectively. The input from the two response buttons was connected to a DC-AC preamplifier and a channel amplifier, respectively. Deflection of each pen indicated subjects' response corresponding to that channel.

Channel #4 was used to record the actual signal. The input signal from the tape recorder was connected to the channel through the A-D convertor, a DC-AC preamplifier and a channel amplifier. Having the signal on the recorder next to the responses allowed instantaneous judgement of subjects' response at the time of signal occurance.

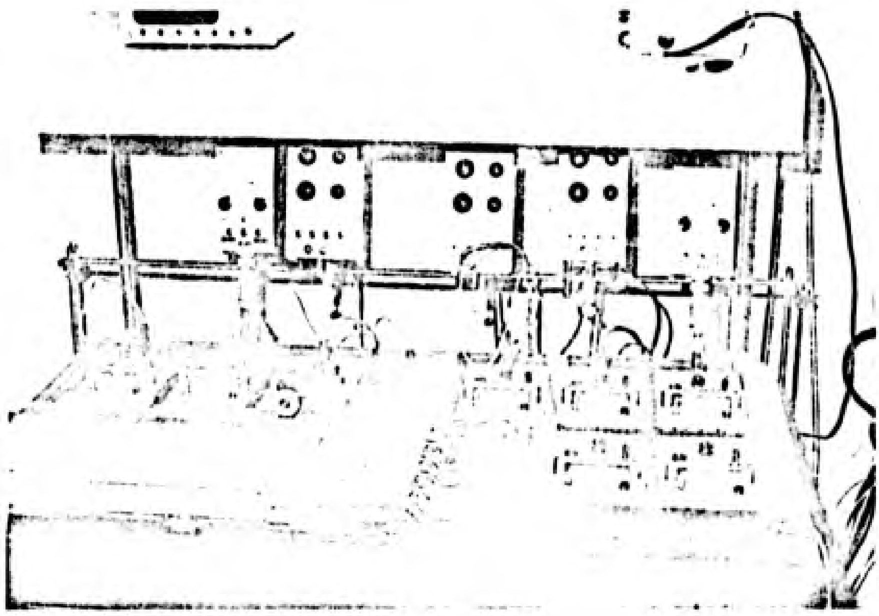

Fig. 6.--Physiograph recorder and accessories

Fig. 7.--A sample recording showing the seven physiograph channels

Channels #2 and #5 were used to monitor right-hand and left-hand subjects' under-arm skin temperatures. Temperature was measured by a disc type surface thermister connected to the recording channel amplifier through a thermistor bridge and a carrier preamplifier. Skin temperature was monitored as a safety precaution against undesirable temperature increases during the experimental run.

Channels #1 and #6 were used to monitor the subjects' heart rates. Surface electrodes were placed on the subjects' chest to transfer heart beats (EKG) to the channel amplifier through a DC-AC preamplifier. Heart rates were also monitored as a safety precaution against any undesirable effects due to high ambient temperatures.

Supporting Equipment

The supporting equipment consisted of a white noise circuit, two head-phones, and two performance consoles and chairs.

White Noise Circuit

In order to prevent any auditory distractions from affecting subjects' visual performance, white noise was generated and emmitted in the environmental chamber. The white noise level was adjusted to 85 decibels to insure masking all noises produced by the heating and cooling systems of the chamber. The noise circuit (Figure 8) consisted of three components: a generator, an amplifier and a speaker. A model 455C random-noise generator manufactured by Grason-Stadler, West Concord, Massachusetts was used to generate wide-band noise of uniform spectrum level. A Mackit 30 amplifier connected the generator to the speaker. It is manufactured by McIntosh Laboratory, Binghamton, New York and had a wide range of operating frequencies and intensities. The speaker used was model AX97596 manufactured by Acoustic Research, Inc., Cambridge, Massachusetts. It consistantly produced the required noise at varying degrees of temperature and humidity.

Head-Phones

Two Sony headphones model number DR-6C were used to transfer the instructions to the two subjects. They were used only during the instruction and practice period and were put aside during the remainder of the experiment.

Performance Consoles and Chairs

A horizontal table and a vertical white screen made of cardboard served as a performance console for each subject. The work/rest light switches were placed at the middle of the table and the headphones and response buttons were attached to the table in front of the cardboard screen.

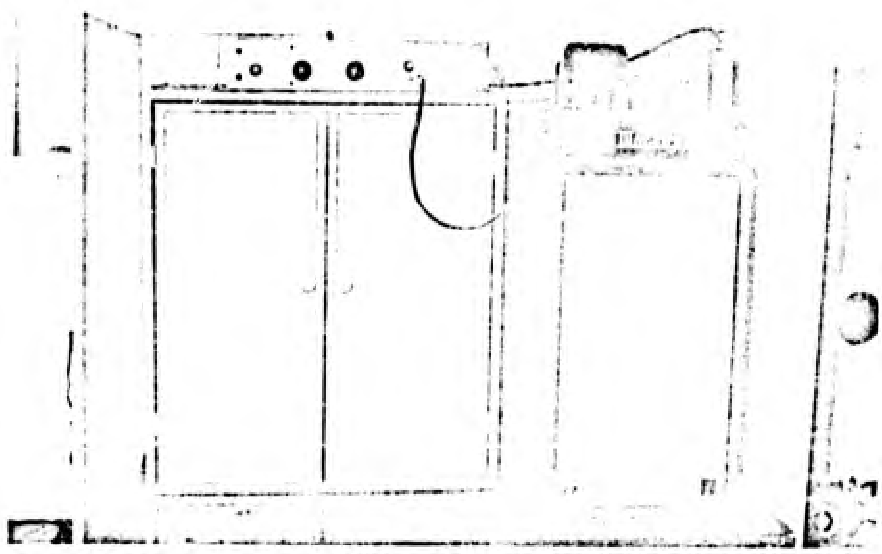

Fig. 8.--White noise equipment

The cardboard had a round opening in the middle equal in size to, and through which was visible, the oscilloscope screen. All electrical connections and the two oscilloscopes were hidden behind the cardboard and only the screens and light switches were visible to subjects. In front of each table a slightly padded chair was used by subjects. The chair allowed lateral movement of legs and slight changes in position to minimize boredom and fatigue. The performance console and chair are shown in Figure 3.

Measurements

Subjects' monitoring performance was the main measurement in this investigation. A vertical vigilance task was used as the performance criterion. A small dot of light displayed at the center of the oscilloscope screen served as the background event. Its movement, up or down, 1/4 or 1/2 an inch, produced the required signal. The subject's task was to detect the signal, whenever one occured, and to discriminate between short and long signals. The two measured performance parameters were percent correct detections and percent correct responses.

Percent correct detections were measured by the number of signals detected, regardless of identifying their magnitude correctly, during one performance period, divided by the total number of signals presented in such period and multiplied by one hundred. Each performance period was ten minutes in length during which four signals were presented.

Percent correct responses was measured by the number of signals detected and correctly identified in magnitude during each performance period, divided by the total number of signals presented in such period and multiplied by one hundred. Detecting a signal and failing to identify its magnitude correctly resulted in a miss when calculating percent correct responses. Meanwhile, it was considered a hit in calculating percent correct detections.

Subjects' heart rates and skin temperatures were monitored throughout the experiment as a safety precaution against any undesirable physiological changes due to high ambient temperatures.

CHAPTER III

EXPERIMENTAL DESIGN

This chapter is concerned with five aspects of the investigation: the task, the variables, the subjects, the statistical design of the experiment and the experimental routine. A separate section will be devoted to describe each of the above factors.

The Task

A one-dimensional vertical visual vigilance task was used to assess the effects of the independent variables on human performance. Visual vigilance behavior usually requires operators to monitor a display, detect and then report any changes in it. These changes are infrequent and are called signals. Signals may result from discreet stimulae which are added or taken away from the display or may appear as changes in a continuously presented background. Signals may also be transient or persistent: the former being a deflection which returns to its original position after a short period of time, and the latter being a permanent deflection which returns to its original position only when detected and reset by the observer. A transient type signals and a continuous background were adopted for the task used in this investigation.

The input to the task used consisted of an illuminated spot of light displayed at the center of a dark visual display (oscilloscope screen). This represented the continuous background event. Infrequently, at random intervals of time the light spot jumped up or down a certain distance for a very short period of time (0.5 second for small signals and 1 second for large signals), then went back to its original position. This movement represented a transient signal. The subjects' task was to detect and report a signal whenever one occured. Two different size signals were used: a small signal which corresponded to a 1/4" displacement of the light spot, and a large signal which corresponded to a 1/2" displacement of the light spot. Subjects were to distinguish between small and large signals and to respond accordingly. The correct response for a small signal was to press the response button and release it immediately, while the one required for a large signal was to press the response button and hold it down about five seconds before releasing it. A sample recording of the signal displayed, showing a small signal, a large signal and the background event, is shown in Figure 9.

Signals occured in a random manner with a mean interval between signals of 2.5 minutes, a minimum interval of 0.5 minutes and a maximum interval of 5 minutes. Signal

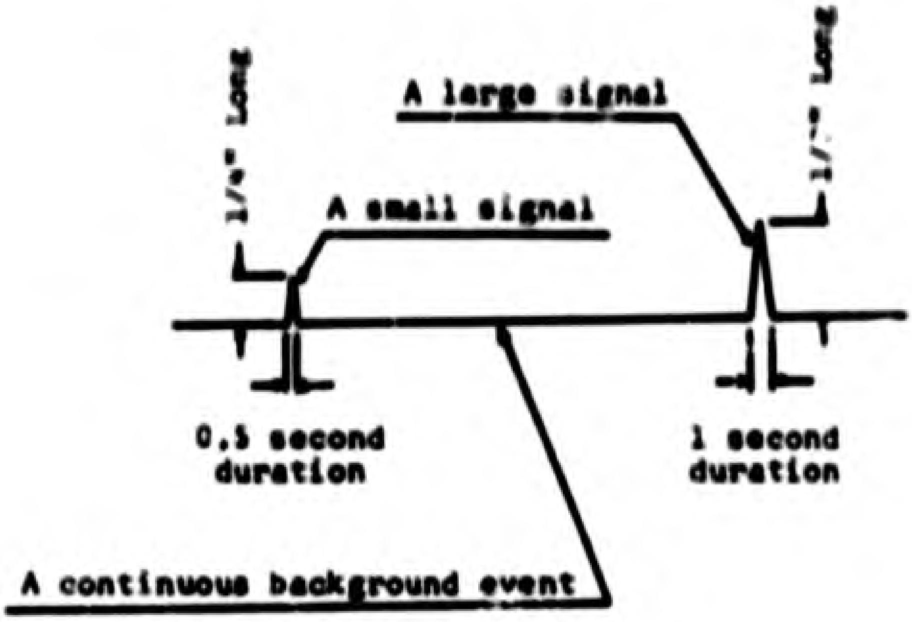

Fig. 9.--Sample recording of small and large signals

rate was fixed constant at 8 signals per 20 minutes, (4 signals per 10 minutes), four of which were small signals and four were large signals.

The choice of this specific task to represent a vigilance watch was promoted by several factors. Firstly, the task simulates many industrial and military situations where the operators' task is to monitor a screen looking for unusual signals. Secondly, this task, with the process of discrimination included, provided two levels of difficulty on which subjects' performance could be evaluated separately. Finally, the task was easily controlled and monitored by the experimental equipment available.

Subjects performed the vigilance task only during their work periods. During rest periods they were completely at ease. They were supplied with reading material and were allowed to do what they pleased except for three restrictions. They were not allowed to talk with each other, walk in the room or go to sleep at any time during the rest periods. The subjects' behavior inside the experimental chamber will be discussed in greater details in a later section describing the experimental procedure.

Interest in vigilance performance arose simultaneously in many fields. In industry, quality control people have been concerned about a sharp drop in detection flaws which was reported to occur in the first thirty to forty-five minutes of each work period. Since World War II, the military has been alarmed by the number of radar contacts being missed by radar operators and the sharp increase in misses with the elapse of time. Psychologists studying theoretical problems of human behavior have grown interested in vigilance as a factor interacting with such basic variables as motivation and decision-making. With the advancement of automation, man's primary task in many man-machine systems will be that of monitoring. The wide spread utilization of monitoring stations at present and the great potential associated with its use in the future has influenced the choice of a vigilance task as a criterion for performance evaluation in this investigation.

The Variables

Three major groups of variables will be discussed in this section: the independent variables, the dependent variables and the controlled variables. The first group represents those variables which were varied over different controlled levels so as to assess their effects on performance. The second group represents those variables which were affected by the first group and their variations provide a means of evaluating performance. The third group represents those variables which were controlled and maintained constant under all experimental conditions, in order to minimize their effects on the measured parameters.

The Independent Variables

Ambient Temperature.--This experiment was performed under three conditions of room temperatures, 74, 82 and 90°F on the effective temperature scale. Relative humidity was maintained constant at 50 percent and the average air velocity inside the experimental chamber was 80 feet per minute. The above mentioned effective temperatures were achieved by adjusting the dry-bulb and wet-bulb chamber controls to the following three combinations: 80/67, 92/76 and 102/86°F DB/WB, respectively.

The choice of effective temperature as an index of heat stress was affected by many factors. First the index is easy to use and is adequately controlled by the environmental chamber and equipment available. Although effective temperatures have shown to be an unreliable index of heat stress at extremely high temperatures and/or heavy physical activity, they have proved to possess good accuracy for the temperature range and the type of task used in this investigation (Lind, 1963). Finally, the index has been extensively used in evaluating performance under heat stress and its applicability was summarized by Teichner (1967), in a critical review of man's subjective responses to heat, in the following words:

> The effective temperature scale (ET), which uses environmental quantities, is the most widely employed, perhaps, because of its direct engineering potential.

The three levels of effective temperature investigated were chosen to satisfy many requirements. First, they all are very realistic temperatures which are found in many parts of the country. Secondly, the three temperatures are well within the tolerance limits set for 8 hours working-days (Lind, 1963; McCormick, 1957; Sells, 1967).

The lower temperature of 74°F (ET) represented control or normal conditions. It served as a base line for determining the optimum performance at pleasant room temperature, in order to provide a means of evaluating the heat effects on performance when subjected to the two higher temperatures. Similar or slightly different temperatures have been used before in investigations of basically the same nature and in most cases performance was found optimum at these conditions (Carlsson, 1961; Mackworth, 1964; Youngling, 1965). In no case a decrement in performance was reported as a result of heat stress at such temperatures.

The middle effective temperature of 82°F represented moderately hot conditions. Contradictory results have been reported in the literature regarding whether or not a decrement in performance does occur at this temperature. The slight differences in conditions and procedures of each investigation do not provide accurate bases of comparison. However, with some caution in mind, we could group previous research according to whether or not they have reported some decrement in the vicinity of 82°F (ET). The group which has reported some decrement of performance includes: Pepler, 1953; Provins et al., 1962; and Carpenter, 1946. The other group suggesting no decrement at this temperature includes: Fine et al., 1960; Chiles, 1957; and Mackworth, 1950. Such disagreement between researchers suggested further investigation of this temperature.

The high temperature of 90°F (ET) represented rather hot climatic conditions. However, it is well within the tolerance limits suggested for man, where no permanent undesirable effects are likely to occur. Decrement in performance has been reported to occur at this temperature in most of the studies reviewed (Pepler, 1953; Fraser and Jackson, 1955; Mackworth, 1950; Carpenter, 1946). Nevertheless, few studies have reported no such decrement (Loeb and Jeantheau, 1958; Chiles, 1957).

Work Period.--Work period is defined here as the on-watch time interval during one work/rest cycle or, the time interval between two successive rest periods. Three work periods were adopted: 20, 40 and 60 minutes. Each work period was repeated as many times as needed to reach a total work duration of 120 minutes (2 hours) per experimental session. Figure 10 shows the work period and work/rest ratio interactions adopted for this investigation.

Under normal environmental conditions vigilance performance has been known to decline significantly after the first 20 to 30 minutes of watch. If the watch continues, a more moderate decline in performance takes place and continues until the end of work. A typical vigilance decrement adapted from Mackworth, 1950, is shown in Figure 11. Often a sudden improvement in performance occurs during the last minutes of watch, regardless of the total length

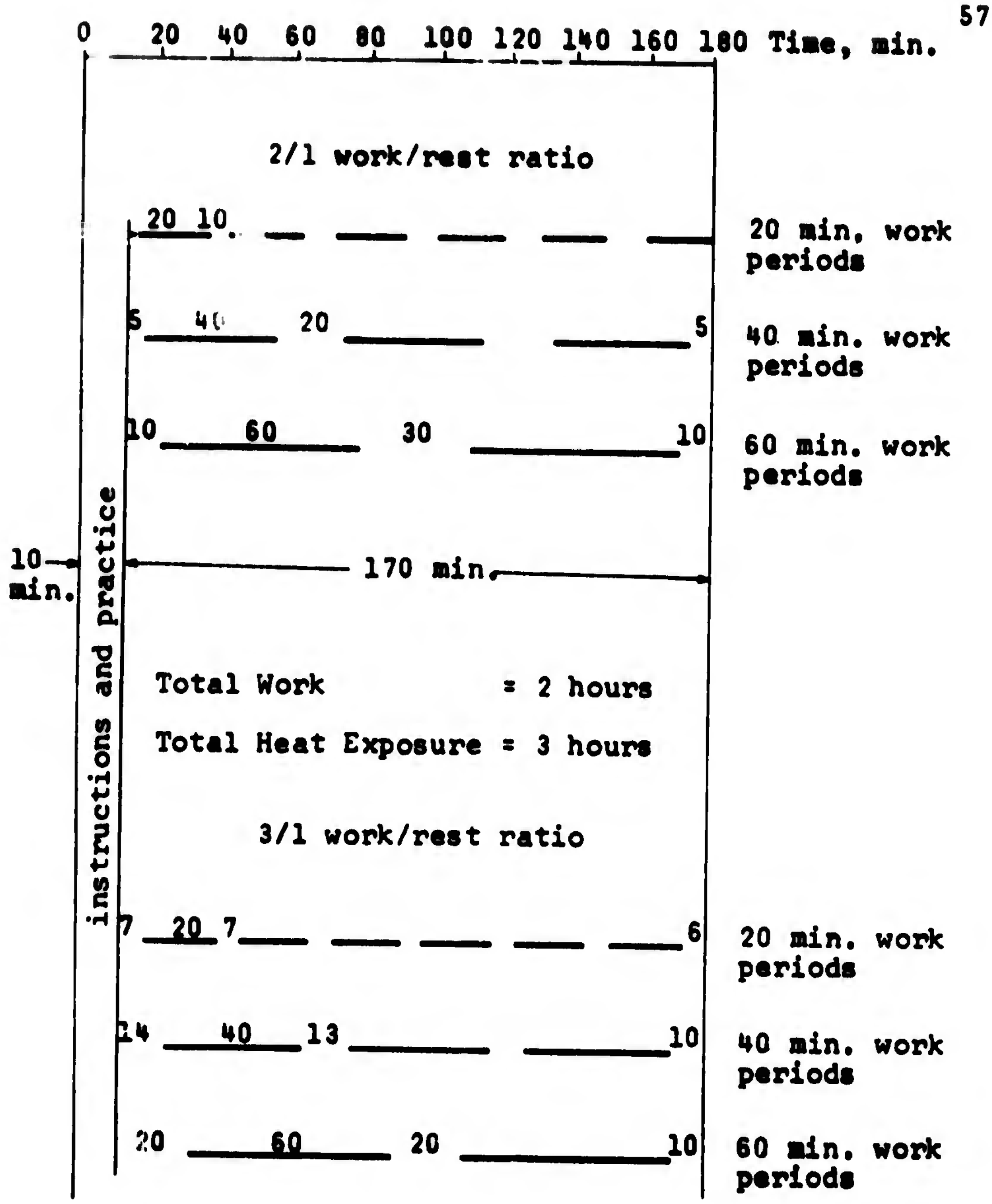

Fig. 10.--Work/rest schedules

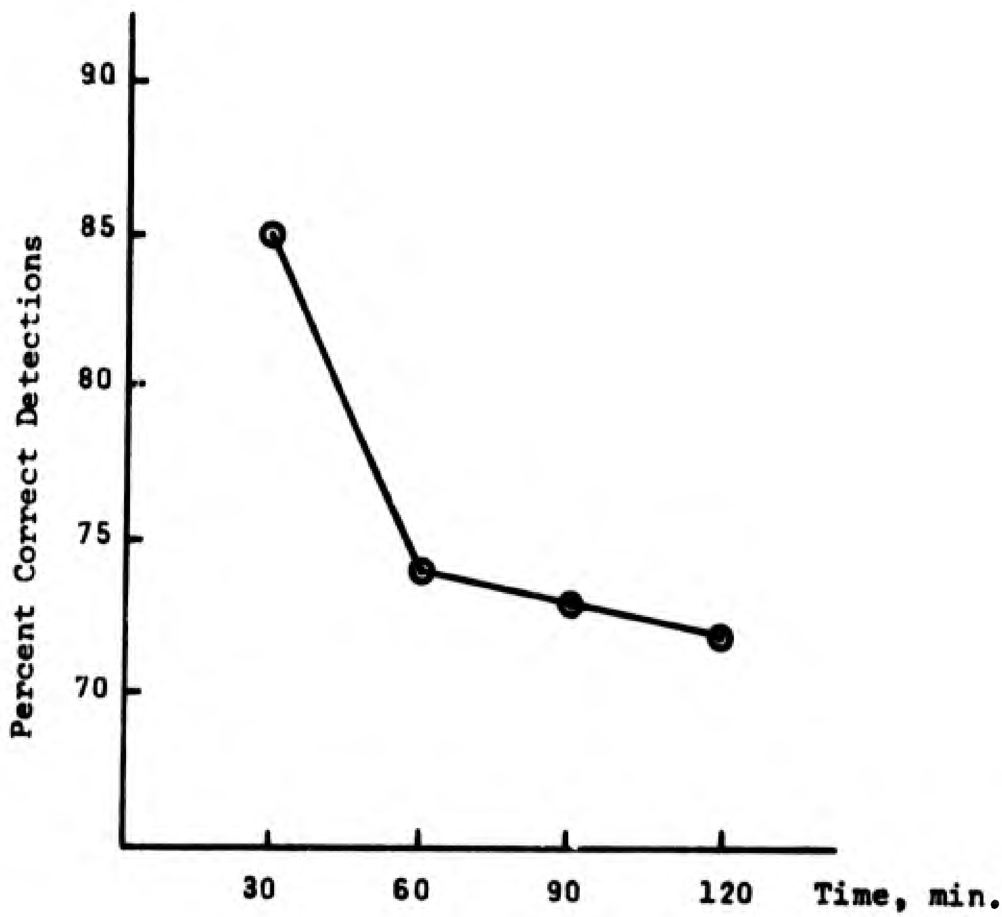

Fig. 11.--A typical vigilance decrement, adapted from Mackworth (1950)

of the watch period. This improvement is known as the end-spurt and depends mainly on the observer's knowledge of time during the watch (Bergum, 1963). If the observer has no means of knowing or estimating time, end-spurt is unlikely to occur.

Vigilance studies in hot climates have been reporting contradictory results, as has been discussed earlier. Nevertheless, some studies have reported detrimental effects on performance as a result of heat stress (Mackworth, 1946; Pepler, 1953; Frazer and Jackson, 1955). The nature of decrement in hot environments differed considerably from one investigation to the other and did not follow the same decrement pattern found under normal climatic conditions. To add to the complexity of the problem, those investigators who have found decrement in performance disagreed among themselves as to when, and at what temperatures, such decrement occurs. The time on watch, after which a significant impairment in performance takes place at various environmental temperatures, is still to be determined.

Most vigilance studies have used the first 20 minutes on watch to determine the observers' optimum performance, before any decrement takes place, then proceeded to evaluate performance decrement over time in 20 minutes increments. Some studies have used 30 minutes as their performance period. Mackworth (1951) evaluated subjects' performance every 30 minutes but presented the signals only during the first 20 minutes of each 30 minutes period. Twenty minutes on watch is widely acceptable as an adequate period with no impairment in performance. Nevertheless, a word of caution should be added here as to the a priori acceptance of the above, since most vigilance results depend primordially on various experimental and task variables.

Although performance is expected to decline after one half hour of watch, changing operators on monitoring tasks after such a short period was found too complicated in practice. Some industries, in a compromise effort, have tried one hour on-the-job for inspectors and monitoring operators. Also, one hour on duty was recommended by Mackworth (1961) for military purposes, and has been used extensively by him in vigilance studies.

The above discussion had a strong effect on the choice of 20 and 60 minutes as the shorter and longer work periods. It was felt that within such a range, which bridges between the theoretical findings in the laboratory and the convenient practices in real life, a better picture of performance changes could be achieved. The third time period tested (40 minutes) was chosen to represent the mean of the other two periods and to bridge the wide gap between them.

Work/Rest Ratio.--Work/rest ratio is the ratio between one work period and one rest period in any work/rest schedule. Two work/rest ratios were used in this research: 2/1 and 3/1. These two ratios represented the cases of two work stations three men crews and three work stations four men crews. The six work/rest schedules resulting from the interaction between work periods and work/rest ratios are shown in Figure 10.

The rest periods introduced relieved subjects only from the vigilance task. However, it did not affect the heat load imposed on them, since subjects were not allowed to leave the hot chamber at any time before the end of their experimental session. This is a realistic restriction since people working in hot environments can usually relieve themselves only from the work load by resting for a few minutes in the same hot environment where they are working.

The choice of the work/rest ratios used was affected by many factors. Practical considerations had some effect, since it is customary to have more than one work station in any monitoring facility. Two and three work stations are common and any conclusions reached from their study could be applied to 4, 6, 8, 9, ...etc. work stations (multiples of 2 or 3).

Research in the area of work/rest schedules has been concerned with work and rest periods longer than, and usually in multiple of, one hour (Adams and Chiles, 1960;

Chiles, Alluisi and Adams, 1968). The fewer studies investigating shorter periods centered around a 1/1 work/rest ratio (Mackworth, 1950). The short rest period in a typical work/rest scheme has not been investigated. The introduction of rest pauses or different ways of interrupting the vigilance watch has been known to improve performance (Bergum and Lehr, 1962; Mackworth, 1950). However, the problem of determining the length of the rest period needed to restore performance to its original level, is still under investigation.

Rest periods in hot environments present another problem. Their effect is no longer a simple one which depends mainly on one factor, but rather a complex effect which depends on several factors and their interactions. Assuming that rest pauses do enhance performance at normal environmental temperatures, similar effects at hot conditions are debatable. Any favorable effects on performance due to rest periods might be offset by increasing the duration of heat exposure, as a result of introducing such a rest. Other factors associated with rest pauses, like motivation, boredom, monotony, ...etc., might play a completely different role in hot environments.

The above discussion clearly illustrates the need for further investigation of the effects of rest periods on vigilance performance in the heat. The amount of rest needed at different work periods and various heat loads, represents an interesting point for investigation. The interaction between the three work periods and the two work/rest ratios used in this investigation yielded 6 different rest periods ranging from 7 to 30 minutes. Such a wide range was useful in accurately evaluating the length of the rest period needed to restore performance to its original level at different degrees of work and/or environmental temperature.

Time Interval.--As explained earlier, the three different work periods, 20, 40 and 60 minutes were repeated six, three and two times, respectively so that the total work duration per session would be 120 minutes. These 120 minutes were divided into twelve equal 10 minutes intervals (Figure 12). During each 10 minutes time interval performance was evaluated in order to assess the effects of time-on-task. Since the signal rate was fixed constant at 4 signals per 10 minutes, the number of hits during any time interval provided an accurate measure of performance during this interval. It was felt that breaking down the performance data to the minimum possible would allow better evaluation of the problem and better understanding of the role of time-on-task in a vigilance situation.

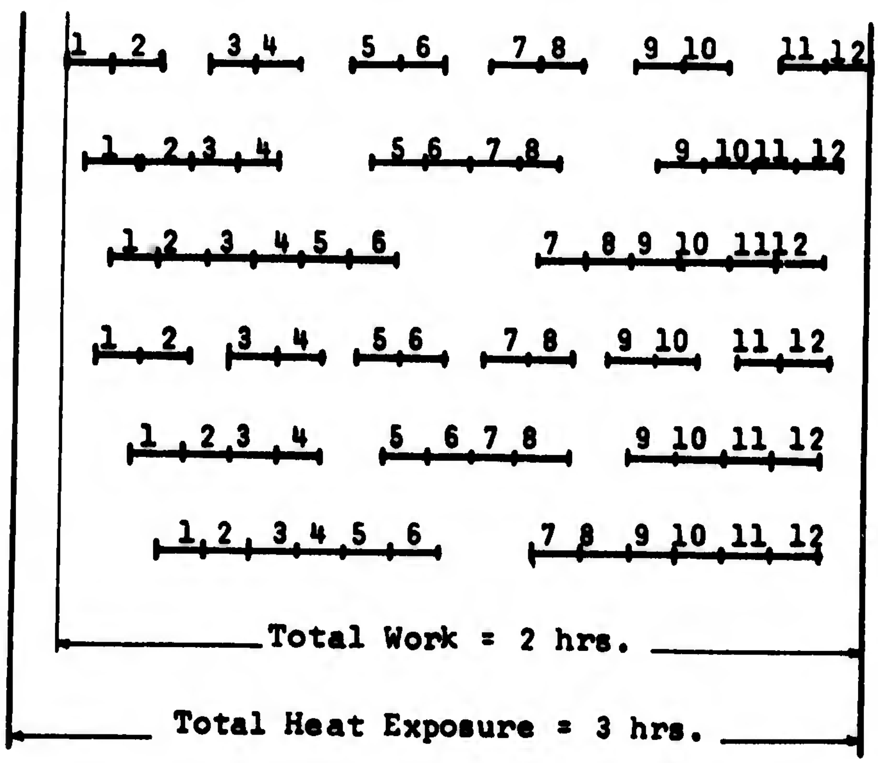

Fig. 12.--Time intervals for various work/rest schedules

The Dependent Variables

The primary variable of interest in this investigation was human performance. Two different parameters were used to assess such performance namely, percent correct detections and percent correct responses. Each of these parameters was analyzed separately as shown in the next chapter.

Percent Correct Detections.--Percent correct detections, often called probability of signal detection, is the number of signals detected in a time interval, divided by the number of signals presented in the same time interval, and multiplied by 100. Since the time intervals were kept constant at 10 minutes, and the signal rate was also constant at 4 signals per 10 minutes, the number of signals detected during any 10 minutes period provided an accurate assessment of performance during this period. Percent correct detections was chosen as a performance criterion because of its accuracy in representing vigilance behaviour. Despite the large number of performance measures, like reaction time, observing response, number of false alarms,... etc., percent correct detections is the most commonly used in vigilance research (Blackwell, 1970).

Percent Correct Responses.--Percent correct responses is defined as the number of signals detected and correctly identified in magnitude during one time interval (10 minutes), divided by the number of signals presented in the same interval (4 signals), and multiplied by 100. Here again, the number of signals detected and identified in any 10 minutes interval represented the ability of the observer to discriminate between small and large signals during this interval. The choice of this parameter as a performance criterion was governed by practical considerations, since operators on a monitoring task are usually expected to exert some sort of decision making and/or comparative judgement as to what kind of signals they have detected.

Any vigilance task usually requires five processes on the part of the observer: detection, interpretation, comparison, decision making and action. In the case of continuous background events and transient signals, like the task used for this investigation, only the processes of detection, interpretation and action are emphasized. The other two processes, namely comparison and decision making are not well represented. However, adding the discrimination phase to the task will provide equal emphasis to the five processes mentioned. It will also allow further grading of subjects' response beyond the detection stage.

The Controlled Variables

The controlled variables consist of all the variables which were maintained constant throughout the experiment. Variations among those variables have been shown to influence performance and to confound the effects of the independent variables if left uncontrolled. Therefore, they were controlled and kept constant in order to minimize their effects at various experimental conditions. These variables could be categorized in three different groups: the environmental controlled variables, the subject controlled variables and the task controlled variables.

The environmental controlled variables were: time of the experiment, acclimatization and noise. All experimental sessions were held in the afternoons between two and eight o'clock to minimize any effects arising from diurnal rhythms of subjects. All subjects were unacclimatized and were exposed to the heat only once to avoid any side effects due to acclimatization. The white noise level was maintained constant at 85 decibles to provide adequate masking of any extraneous noises during the experiment.

The subject controlled variables were: sex, health, age range, learning and motivation. All subjects were male undergraduate students, of good health and between 20 and 25 years of age. They had no previous experience with the vigilance task or the heat chamber. They were all allowed the same learning period during the instructions and practice period immediately preceding the actual experiment. Nevertheless, individuals usually differ as to their vigilance ability (Mackworth, 1951), as will be discussed in chapter IV. They were paid competitive student rates plus the possibility of winning the first or second prizes, as will be explained in the next section.

The task controlled variables were: type, rate and amplitude of signal. The signal presented was visual and consisted of a small spot of light of constant illumination centered in the middle of a dark screen. Signal rate was fixed at 4 signals per 10 minutes. Small and large signals were constant at one quarter and one half of an inch in length respectively. Fixing the signal characteristics insured no effects on performance as a result of signal variability.

Subjects

One hundred and eight male students served as subjects in this investigation. They were all volunteer undergraduates and were paid appropriate student rates for the time spent on the experiment. In addition they were announced a bonus of $50 and $20 to be given away to the best and second best performer, respectively. Such a positive incentive was hoped to increase subjects' motivation and keep them alert throughout the watch.

All prospective subjects were required to fill out a questionaire containing information pertinent to this investigation. They were then screened according to their age, health and medical history. Those selected to participate in the experiment were between 20 and 25 years of age, of good health and having no ailments that might interfere with the task variables. They were instructed to eat no food and participate in no heavy physical activity at least one hour before their scheduled experimental run. They were also advised to get their normal amount of sleep the night prior to their run.

Subjects were randomly assigned to the eighteen experimental conditions, with a total of six subjects per cell. Each subject performed the experiment only once, with no previous training on the task except a few minutes of practice during the instructions and practice period, immediately preceding the actual run.

Using subjects in this framework has the advantages of minimizing any misleading effects on performance due to individual differences between subjects, motivation, learning, training, heat acclimatization and diurnal rhythms. The large sample of subjects used increased the power of the statistical testing and allowed better accuracy in projecting the results to a larger population.

Statistical Design of the Experiment

The four independent variables, ambient temperature, work period, work/rest ratio and time interval, were analyzed to determine their effect on performance. A separate, but similar analysis was run for each of the two dependent variables, percent correct detections and percent correct responses. A complete randomized factorial design with six replications was used and the factors involved are shown in Table 1.

The model for the randomized factorial design is (Hicks, 1966):

$$X_{ijkln} = U + A_i + B_j + AB_{ij} + C_k + AC_{ik} + BC_{jk} + ABC_{ijk} + D_l + AD_{il} + BD_{jl} + ABD_{ijl} + CD_{kl} + ACD_{ikl} + BCD_{jkl} + ABCD_{ijkl} + R_n + E_{ijkln}$$

where:

X_{ijkln} = dependent variable observed at i, j, k, l and n of their respective treatments

U = common effect for the whole experiment

A_i = ambient temperature effect, $i=1,2,3$

B_j = work period effect, $j=1,2,3$,

C_k = work/rest ratio effect, $k=1,2$

D_l = time interval effect, $l=1,2,\ldots\ldots,12$

R_n = replication effect, $n=1,2,\ldots,6$ for all i, j,k and l

E_{ijkln} = random error

Table 2 shows the estimated mean squares and the ratios required for the F-statistics.

TABLE 1

EXPERIMENTAL DESIGN

Factor	Label	Level	Type Effect
1. Ambient Temperature	A	1. 74°F (ET) 2. 82°F (ET) 3. 90°F (ET)	Fixed
2. Work Period	B	1. 20 minutes 2. 40 minutes 3. 60 minutes	Fixed
3. Work/Rest Ratio	C	1. 2/1 ratio 2. 3/1 ratio	Fixed
4. Time Interval	D	1. 1st 10 min. 2. 2nd 10 min. 3. 3rd 10 min. 4. 4th 10 min. 5. 5th 10 min. 6. 6th 10 min. 7. 7th 10 min. 8. 8th 10 min. 9. 9th 10 min. 10. 10th 10 min. 11. 11th 10 min. 12. 12th 10 min.	Fixed
5. Replication	R	1 2 3 4 5 6	Random

TABLE 2

ESTIMATED MEAN SQUARES

Model	d.f.	EMS	F test
A_i	2	$\sigma_e^2 + 432\ \sigma_a^2$	A/E
B_j	2	$\sigma_e^2 + 432\ \sigma_b^2$	B/E
AB_{ij}	4	$\sigma_e^2 + 144\ \sigma_{ab}^2$	AB/E
C_k	1	$\sigma_e^2 + 648\ \sigma_c^2$	C/E
AC_{ik}	2	$\sigma_e^2 + 216\ \sigma_{ac}^2$	AC/E
BC_{jk}	2	$\sigma_e^2 + 216\ \sigma_{bc}^2$	BC/E
ABC_{ijk}	4	$\sigma_e^2 + 72\ \sigma_{abc}^2$	ABC/E
D_l	11	$\sigma_e^2 + 108\ \sigma_d^2$	D/E
AD_{il}	22	$\sigma_e^2 + 36\ \sigma_{ad}^2$	AD/E
BD_{jl}	22	$\sigma_e^2 + 36\ \sigma_{bd}^2$	BD/E
ABD_{ijl}	44	$\sigma_e^2 + 12\ \sigma_{abd}^2$	ABD/E
CD_{kl}	11	$\sigma_e^2 + 54\ \sigma_{cd}^2$	CD/E
ACD_{ikl}	22	$\sigma_e^2 + 18\ \sigma_{acd}^2$	ACD/E
BCD_{jkl}	22	$\sigma_e^2 + 18\ \sigma_{bcd}^2$	BCD/E
$ABCD_{ijkl}$	44	$\sigma_e^2 + 6\ \sigma_{abcd}^2$	ABCD/E
R_n	5	$\sigma_e^2 + 216\ \sigma_r^2$	R/E
E_{ijkln}	1075	σ_e^2	
	1295		

Experimental Routine

The experiment was conducted in the environmental laboratory located in the Industrial Engineering Building, room 104. A floor plan of the laboratory is shown in Figure 13. The environmental chamber occupies a large space of the laboratory. The two small rooms on its sides are used as viewing areas and for experimental equipment.

Only the two subjects, the two stations and the equipment required for producing white noise were placed inside the environmental chamber as shown in Figure 14. The experimenter and all the other equipment were placed in the north room as shown in Figure 15.

Two hours before any scheduled run, all the equipment was turned on. This provided an adequate warm-up period for the electrical equipment. It also allowed enough time for the environmental chamber to reach the required levels of dry-bulb and wet-bulb temperatures and to stabilize there. After all the settings and controls were checked and adjusted, the equipment was ready for experimentation.

Subjects performed the experiment in pairs. However, each subject was visually isolated from the other and they were instructed not to talk to each other at any time. They were all dressed in long sleeve shirts, trousers and shoes. Upon arrival for the experimental session, subjects were asked to leave their watches and belongings outside the

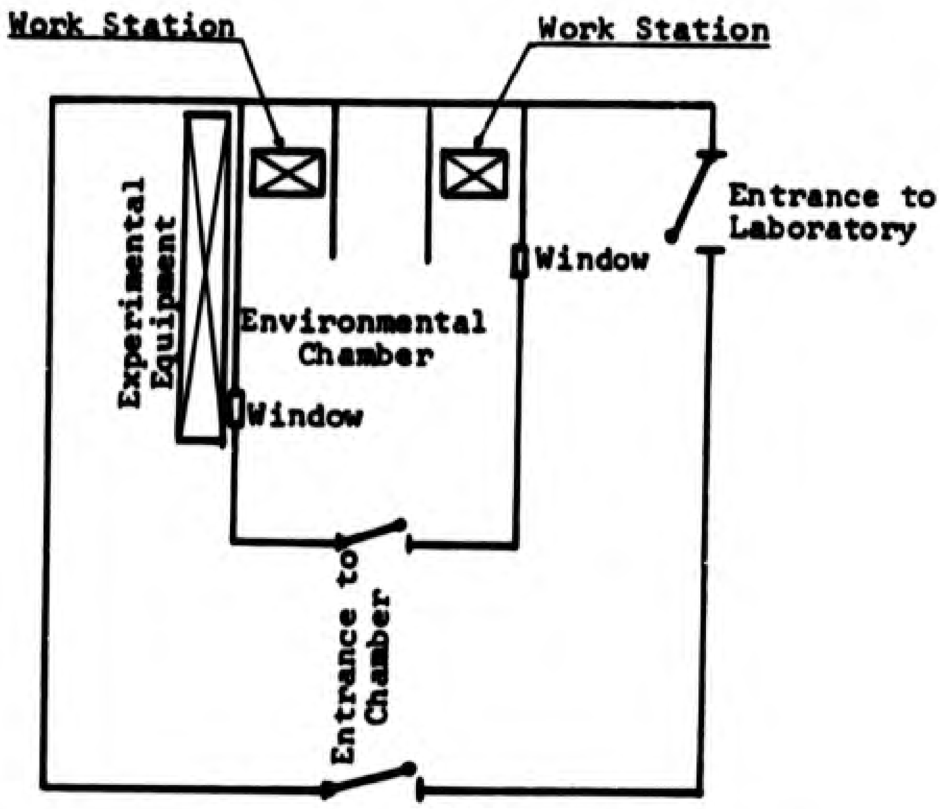

Fig. 13.--Floor plan of the environmental laboratory

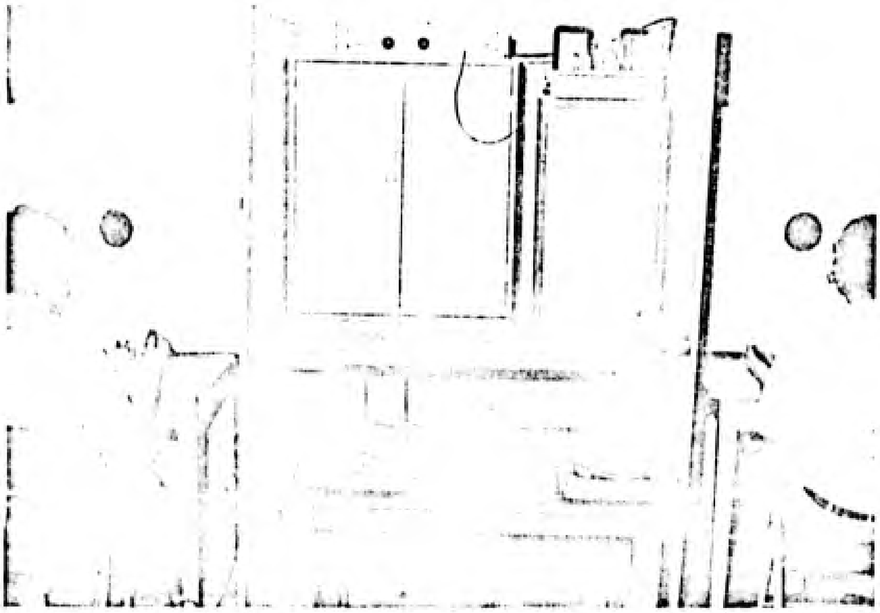

Fig. 14.--Subjects at their work stations

Fig. 15.--Experimenter and equipment outside the environmental chamber

environmental chamber. They were then led inside the chamber by the experimenter. The three hours exposure to heat started at this moment.

Inside the chamber, heart rate electrodes and temperature thermistors were placed on subjects' chest and skin, respectively. Subjects were then seated in their work stations and were asked to position their headphones and get ready to listen to the instructions. The experimenter then left the chamber and the instructions were played on the tape recorder.

The purpose of the instructions was to introduce subjects to the experiment and the task as illustrated in the Appendix. To achieve consistancy of the instructions they were recorded earlier on magnetic tape and were played back each time prior to the experiment. Sample signals were shown along with the appropriate responses. Work and rest periods were explained together with the subjects' expected behavior during each period. A practice period was included to clarify the subjects' understanding of their task.

At the end of the instructions and practice period, the subjects were asked to remove their headphones and get ready for the experiment to start. The experimenter went inside the chamber to answer any questions the subjects might have. He then turned the white noise generator and speaker on and left the chamber. The vigilance watch started at this point and lasted for a total of 170 minutes, during which subjects worked and rested according to a specific work/rest schedule. Adding the 10 minutes of subjects' preparation, instructions and practice, their total exposure to heat was three hours. The duration of the experiment was selected to be three hours to provide accurate balancing of various work/rest schedules under investigation and to generate a total of two hours of work in each. It also allowed better bases of comparison with other studies since most of the ones conducted in hot climates lasted between two and four hours.

Subjects' performance, temperatures and heart rates were recorded on the physiograph recorder placed outside the chamber. This allowed minute by minute inspection of these variables. Occasionally, subjects were viewed from the one-way windows to insure proper performance of the task. At the end of the three hours exposure, the experimenter went inside the chamber. He took off the electrodes and thermistors from the subjects' skin. Subjects were then allowed to go and all the equipment was turned off. This signaled the termination of one experimental run.

CHAPTER IV

FINDINGS AND INTERPRETATIONS

This chapter is devoted to the results of the investigation. The significant effects of the independent variables on the dependent variables as determined by statistical techniques will be presented and discussed.

The significant effects were determined by a statistical analysis of variance. A complete randomized factorial design was used to test the significance of the independent variables. A computer program-QAD TANOVA-written by Charles Burdsal and provided by the Texas Tech Computer Center, was used for statistical testing on an IBM-360 computer. The program yielded the following information:

1. source table for each dependent variable,
2. F-ratio for all main effects and interactions,
3. probability of occurance by chance for all main effects and interactions,
4. cell means and standard deviations for all main effects and interactions.

A summary of the significant effects for all dependent variables is shown in Table 3 for comparison purposes. However, each of the two dependent variables, namely percent correct detections and percent correct responses will be discussed in a separate section. An analysis of variance table will be presented for each variable along with graphs and discussions of each of the significant effects.

TABLE 3

SUMMARY OF SIGNIFICANT EFFECTS

Source of Variation	Percent Correct Detections	Percent Correct Responses
Ambient Temperature, A_i	.01	.01
Work Period, B_j	.01	.05
Work/Rest Ratio, C_k		.05
Time Interval, D_l	.01	.01
Replication, R_n	.05	.01
AB_{ij}	.01	
AC_{ik}	.05	
BC_{jk}	.05	.01
ABC_{ijk}	.01	.05

Percent Correct Detections

The analysis of variance for the percent correct detections is shown in Table 4. The significant effects will be discussed in the same order they appear in that table.

Ambient temperature was found to have a highly significant effect (.01 level) on percent correct detections. A decrement in performance occured when effective temperature was increased from 74 to 82°F or from 82 to 90°F. A plot of percent correct detections versus ambient effective temperature is shown in Figure 16. A Duncan Multiple Range test for treatment means indicated a significant difference in percent correct detections between the three effective temperatures under investigation, 74, 82 and 90°F.

As explained earlier, measures of performance in heat tend to be specific to a particular set of experimental conditions (Pepler, 1961). Taking this into consideration, we will proceed to discuss the results obtained here and their relation to previous research.

High ambient temperatures have been shown to produce a decrement in vigilance performance (Bursill, 1958; Mackworth, 1951; Pepler, 1953; Frazer and Jackson, 1955). Mackworth used artificially acclimatized subjects and reported 83 to 87.5°F (ET) to be the critical zone where an

TABLE 4

ANALYSIS OF VARIANCE FOR PERCENT CORRECT DETECTIONS

Source of Variation	DF	Sum of Squares	Mean Squares	F Ratio
Ambient Temperature, A	2	109.46	54.73	33.16 *
Work Period, B	2	22.94	11.47	6.95 *
AB	4	25.75	6.44	3.90 *
Work/Rest Ratio, C	1	5.25	5.25	3.18
AC	2	12.36	6.18	3.74 **
BC	2	15.20	7.60	4.60 **
ABC	4	42.24	10.56	6.40 *
Time Interval, D	11	120.50	10.95	6.64 *
AD	22	45.17	2.05	1.24
BD	22	35.85	1.59	0.99
ABD	44	63.72	1.45	0.88
CD	11	17.03	1.55	0.94
ACD	22	33.25	1.51	0.92
BCD	22	40.13	1.82	1.11
ABCD	44	56.94	1.29	0.78
Replication, R	5	24.46	4.89	2.96 **
Error, E	1075	1774.49	1.65	
Total	1295	2444.74		

* Significant at .01 level.
**Significant at .05 level.

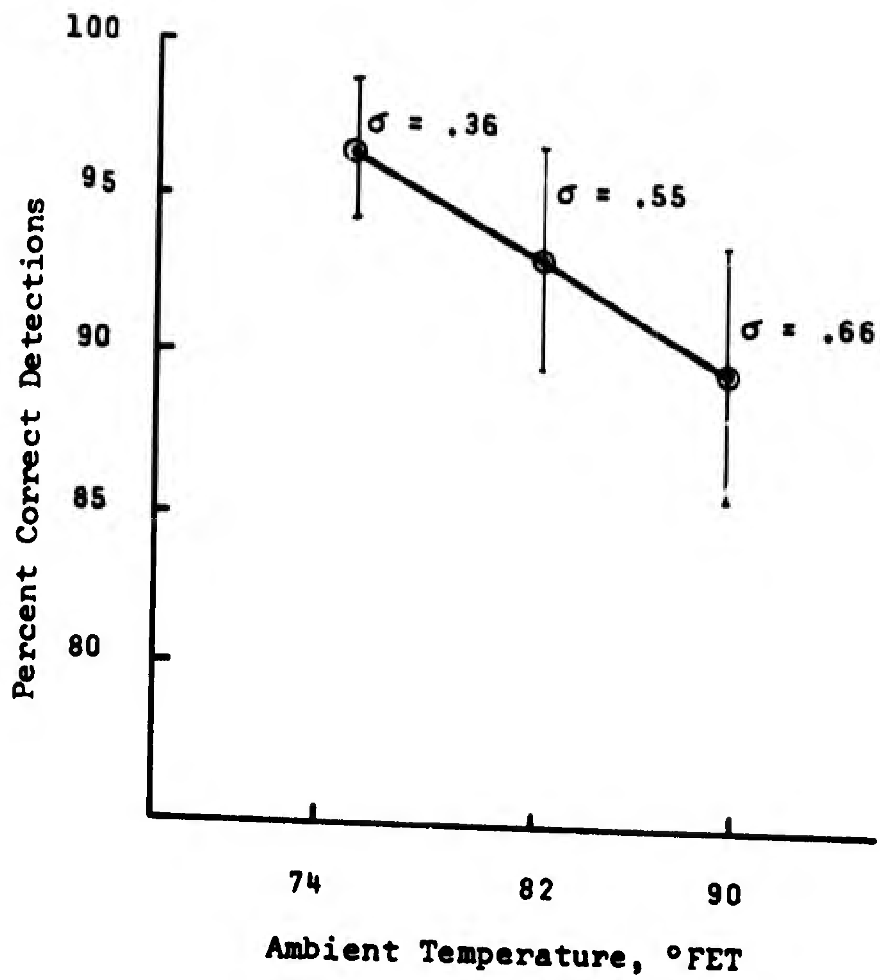

Fig. 16.--Percent correct detections for ambient temperature

impairment in performance is expected. Pepler, on the other hand, suggested a critical zone between 81 and 86°F (ET) for naturally acclimatized men. Since a facilitation in performance usually occurs with acclimatization,unacclimatized subjects are expected to show a decrement at temperatures slightly lower than those reported above. The significant decline in performance found in this investigation at 82°F seems to agree with the above discussion.

The fact that further decrement occured at 90°F (ET) agrees with previous studies where performance constantly deteriorated with the increase in temperature. The high level of performance exhibited at 74°F (ET) is also consistant with various studies which have reported optimum performance in the vicinity of this temperature (Mackworth, 1951; Pepler, 1961).

Another interesting observation on Figure 16 is the variability of performance at different temperatures as represented by the standard deviation. Increasing temperature from 74 to 82 and to 90°F (ET) resulted in larger variances every time. The higher variability at hot temperatures could be attributed to the differences in skill between individuals and its relation to heat. Mackworth (1951) and Pepler (1961) have reported that skilled subjects are generally less affected by heat compared to non-skilled ones. Since subjects participating in this investigation were chosen at random, they varied as to their ability to perform vigilance tasks. Such variation could have caused the larger variances at high temperatures.

Work period was found to have a highly significant effect (.01 level) on percent correct detections. A higher decrement in performance was found at longer work periods as shown in Figure 17. Increasing the work period from 20 to 40 minutes or from 40 to 60 minutes resulted in a deterioration in performance. However, a Duncan Multiple Range test concluded no significant differences in treatment means between the 20 minutes and the 40 minutes work periods. Only the 60 minutes condition was significantly different from the other two.

The non-significant difference in detection performance between the 20 minutes and the 40 minutes conditions seems to contradict previous studies where a significant decrement in performance has been observed after 20 to 30 minutes of watch. However, two factors might be responsible for these differences. First, the difficulty of the vigilance task has a strong effect on the rate of performance deterioration over time. Therefore, it is rather difficult to compare the quantitative results of various studies unless they have used primarily identical tasks. Secondly, the significant decrement after 20 to 30 minutes, has been reported on continuous tasks, not involving any work/rest

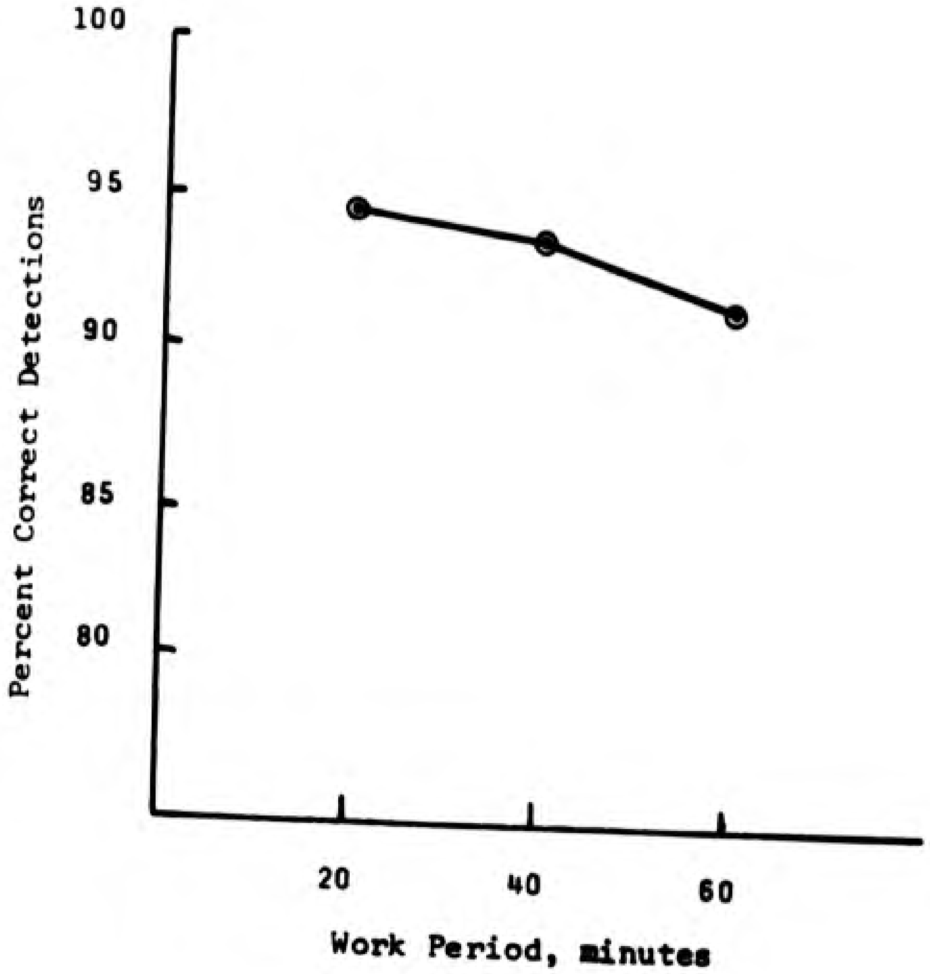

Fig. 17.--Percent correct detections for work period

schemes. The introduction of rest periods might have affected performance differently. A possible effect could be the occurance of an end-spurt near the completion of the 40 minutes period, where subjects' expectancy of a rest interval to occur is high, thus resulting in a better than expected performance average over the entire 40 minutes. For the 60 minutes period this expectancy occured either too early and faded away or too late, and in both cases it did not stay long enough to affect the mean performance over the 60 minutes of work. Similar improvements in performance over the first 30 minutes of watch have been reported by Colquhoun (1959). Subjects who were promised and given a 5 minutes rest half-way through a one hour watch, have performed significantly better during the first 30 minutes than those neither given nor promised any rest.

Performance at the 60 minutes work period was found significantly worse compared to the other two conditions. This result agrees with earlier research in vigilance and advocates the introduction of rest periods during such long watches. It should be mentioned at this point that 60 minutes on watch is often used as the shortest watch period in practice.

The interaction between ambient temperature and work period was found to have a highly significant effect (.01 level) on percent correct detections. Figure 18

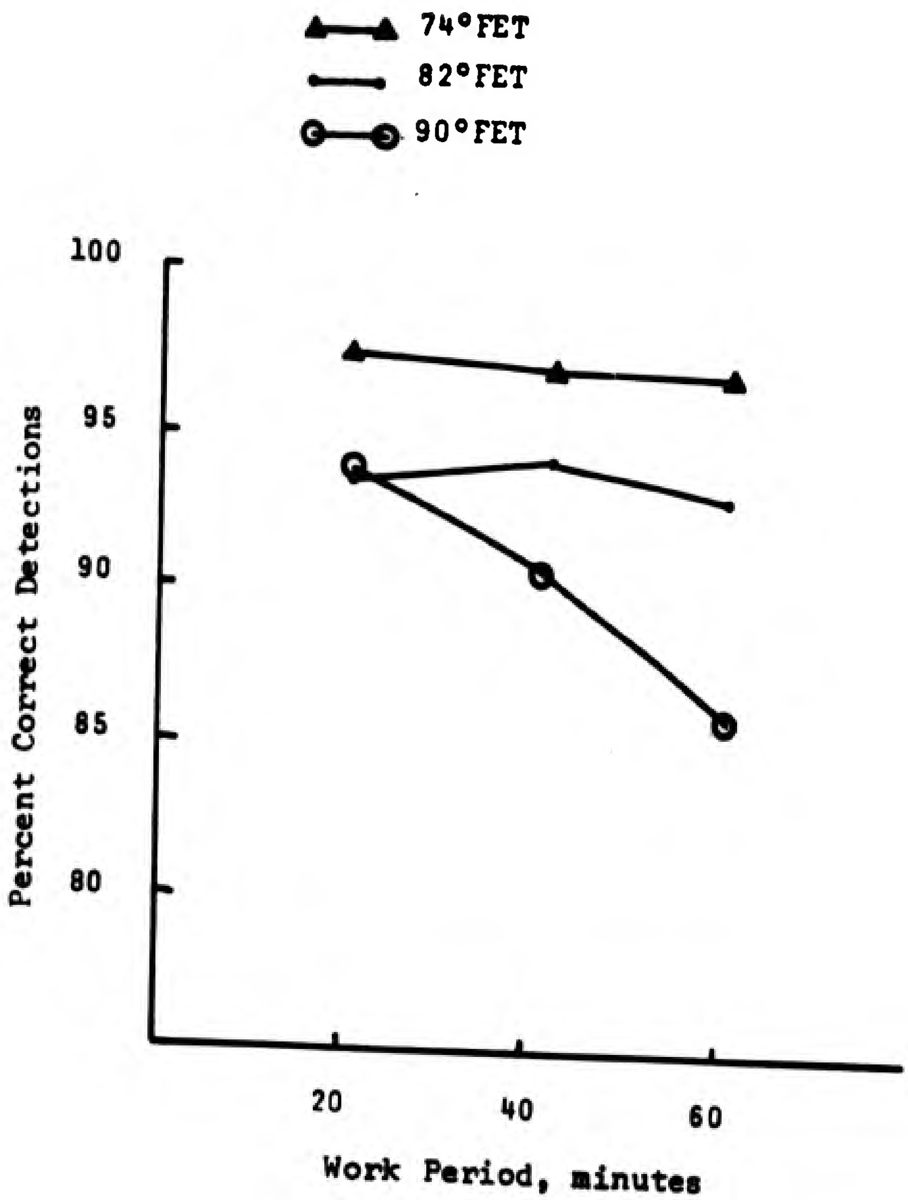

Fig. 18.--Percent correct detections for ambient temperature by work period interaction

illustrates the performance means for various ambient temperature and work period combinations. Although the overall effect was significant, the Duncan test proved no significant differences between the three work periods means at either 74°F (ET) or 82°F (ET). The only significantly different means were recorded at the high temperature (90°FET) between 20 and 60 minutes work periods and between 40 and 60 minutes work periods.

The fact that performance declined with the increase in temperature at the three work periods tested, except from 82 to 90°F (ET) at 20 minutes, is in agreement with the earlier discussion about the effects of ambient temperature on detection. However, the non-significant differences between the three work periods at either 74 or 82°F (ET) is surprising. Ideally some decrement would have been expected there. Nevertheless, various experimental conditions might have influenced performance in the directions reported. Possible experimental factors involved include rest periods, task difficulty and incentives. Rest periods and their favorable effects on performance have been discussed earlier. The detection task might have been too simple to generate any decrement in performance during long work periods at normal and slightly hot conditions (74 and 82°FET). However, with the added load of high heat at 90°F (ET), a progressive decrement in performance occured as a result of longer work periods. The monetary rewards promised to the two best performers represented a high level of incentives to the experimental subjects. Operators have been known to maintain their level of performance for long periods when various incentives are introduced (Davies and Tune, 1969). However, the effect of incentives at high temperatures is greatly questionable (Mackworth, 1951 and Pepler, 1961). The above discussion provides possible explanations to the experimental findings.

Although the work/rest ratio effect on percent correct detections was found to be not significant at the conventional 5 percent level, it will be discussed briefly here for several reasons. First, the power of the statistical test was calculated to be 0.46, which does not provide any conclusive evidence in support of a nonsignificant effect decision. Second, the work/rest ratio effect was found significant at 10 percent which is accepted by many as a sufficiently accurate level for statistical testing. Finally, its effect on percent correct responses was significant at 5 percent; therefore discussing its effect on percent correct detections will provide better means of comparison between the two parameters. A plot of percent correct detections versus work/rest ratio is shown in Figure 19. Performance at the 2/1 work/rest ratio was found to be slightly better than that at the 3/1 ratio. This result

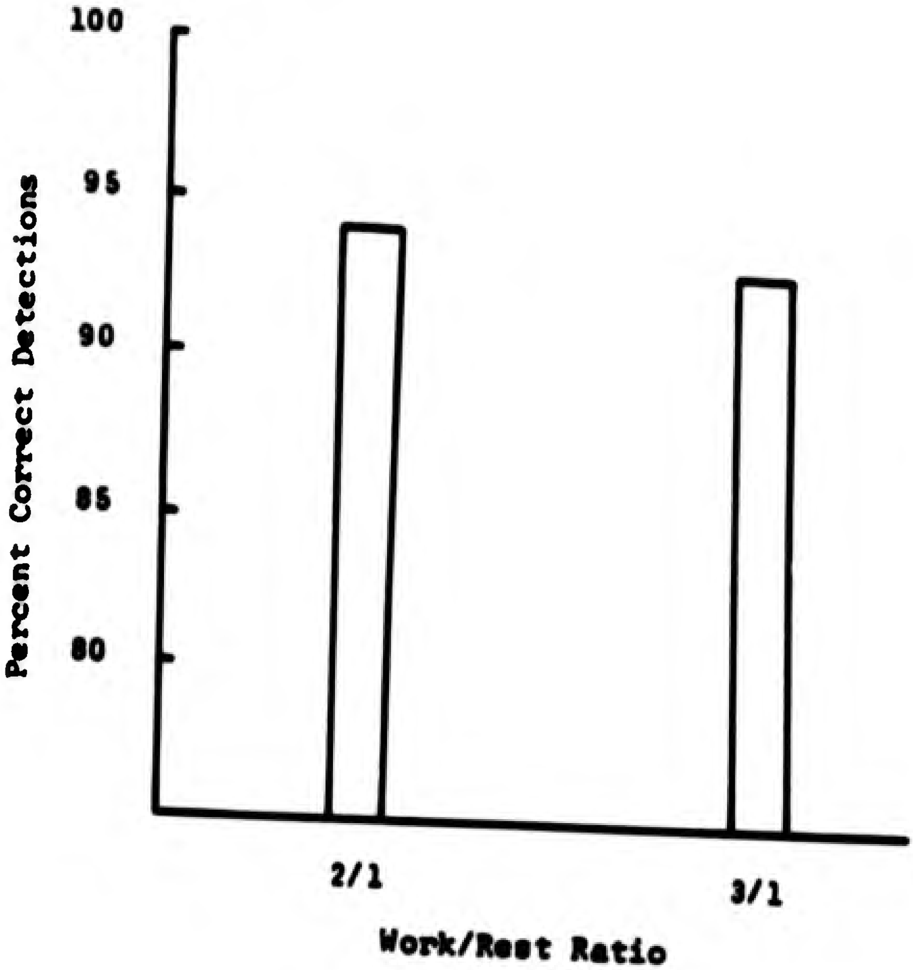

Fig. 19.--Percent correct detections for work/rest ratio

supports the argument that the greater the period of rest allowed to recover from the effects of work, the higher the performance level thereafter (Davies and Tune, 1969). The 2/1 ratio involved longer rest between any two work periods, compared to the 3/1 ratio, thus allowing performance to stay at a slightly higher level.

The interaction between ambient temperature and work/rest ratio was found to have a significant effect (.05 level) on percent correct detections. A plot of performance means for the interaction effect is shown in Figure 20. Percent correct detections decreased with the increase in temperature at both work/rest ratios. The Duncan test indicated no significant differences between the 2/1 and the 3/1 work/rest ratios at either 74°F (ET) or 82°F (ET). However, a significant difference between the two work/rest ratios was detected at 90°F (ET). There was also a significant difference in performance between the three temperatures at either 2/1 or 3/1 ratio.

The differences between temperatures at any one work/rest ratio supports the earlier findings about the effect of temperature as a main effect. Introducing a rest period did not interfere with that effect. It might have improved the average performance level at each temperature but it did not offset the differences between various temperatures. However, the differences in performance

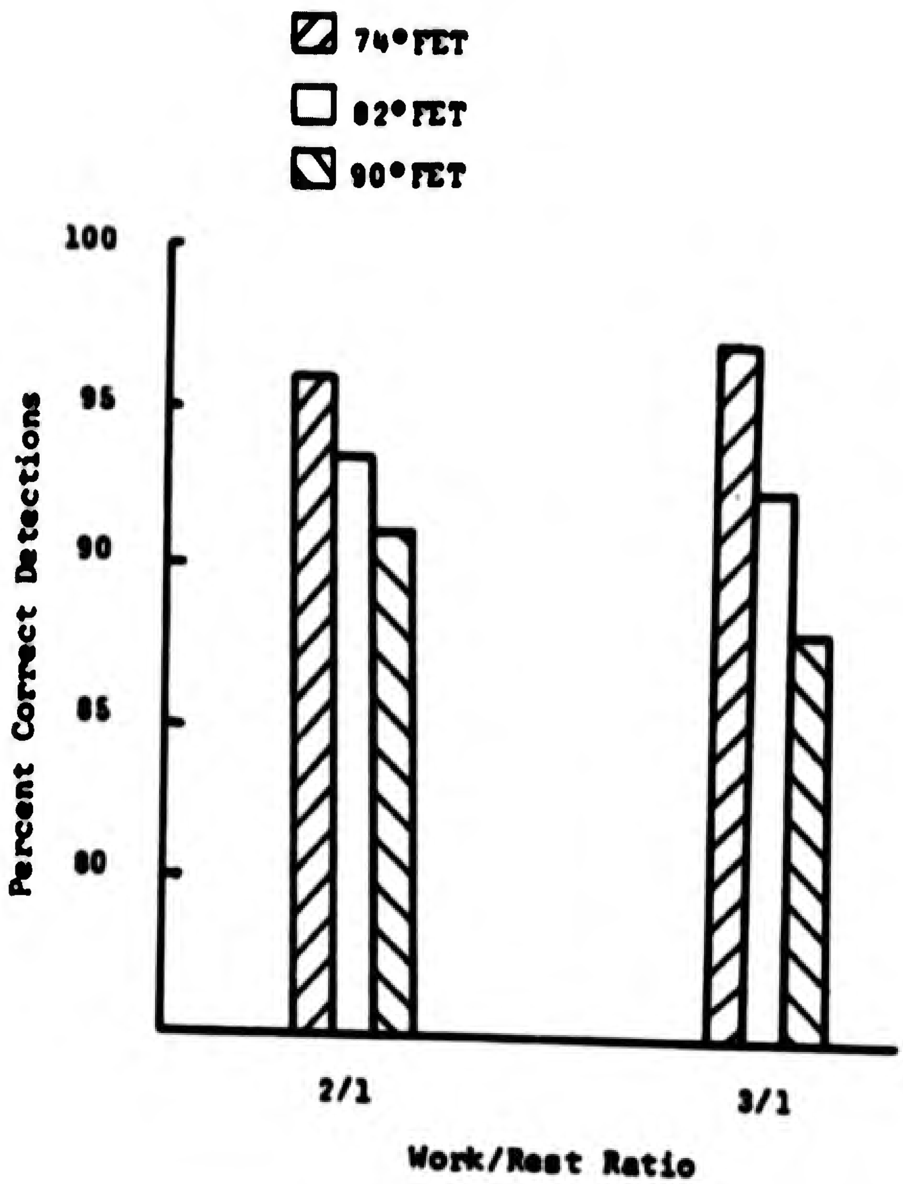

Fig. 20.--Percent correct detections for ambient temperature by work/rest ratio interaction

between the three temperatures at the 2/1 ratio were considerably smaller compared to those at the 3/1 ratio. This could be attributed to the effect of the longer rest intervals at the 2/1 work/rest ratio. They could have been long enough to enhance performance to a relatively high level, even at hot environmental conditions.

The fact that only at 90°F (ET) there was a significant difference in performance between the two work/rest ratios could also be attributed to the length of rest provided by each ratio. At either 74 or 82°F (ET) the heat load was not severe enough to require long rest periods for recovery. Consequently, the amount of rest did not seem to matter at these two temperatures. Furthermore, at 74°F (ET) the unnecessary long rest periods provided by the 2/1 ratio might have caused the slight decrement in performance found at this ratio compared to the 3/1 ratio. However, at 90°F (ET) subjects apparently needed all the rest they could get. Therefore, when the rest periods were shorter at the 3/1 ratio, their performance did not recover completely, and was significantly lower than the performance of the subjects given longer rests at the 2/1 ratio.

The work period by work/rest ratio interactions was found to have a significant effect (.05 level) on percent correct detections. Figure 21 illustrates the means for all combinations of work period and work/rest ratio. It is

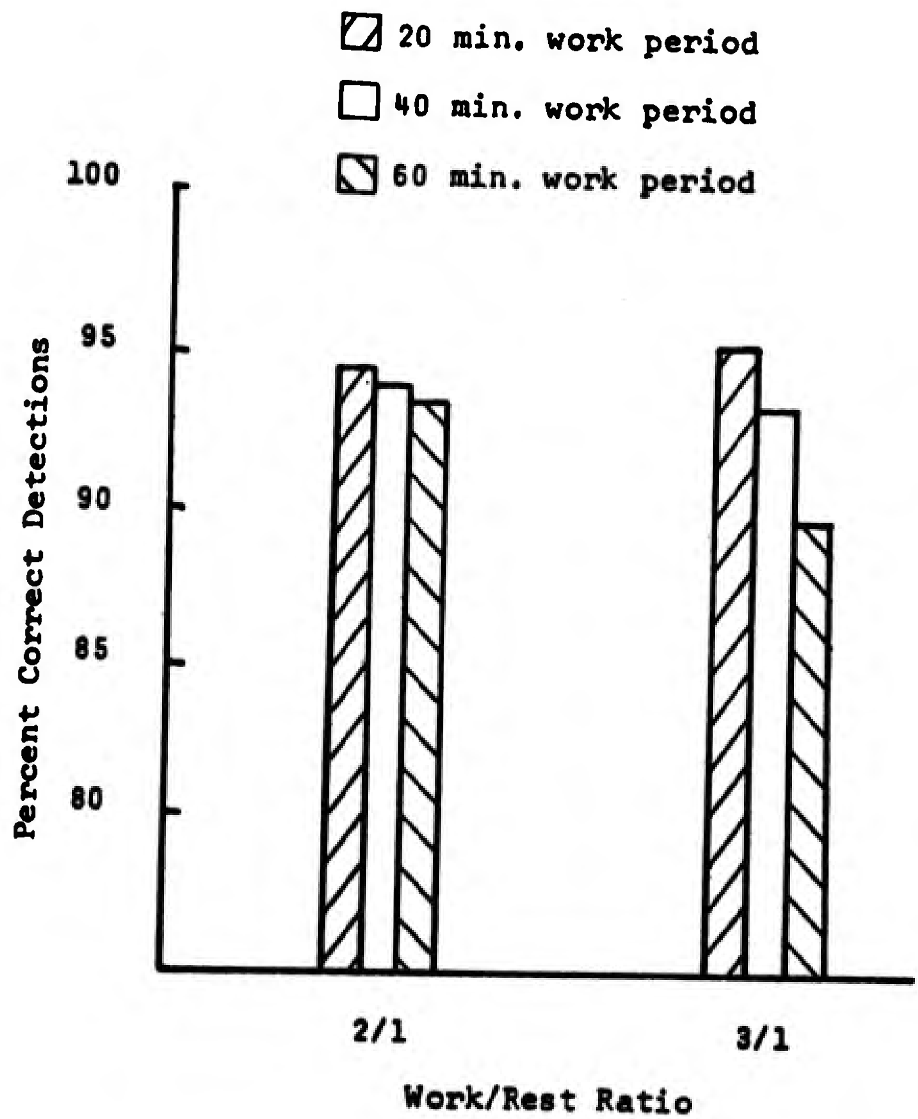

Fig. 21.--Percent correct detections for work period by work/rest ratio interaction

obvious from the graph that performance means suffered a decline at longer work periods. The Duncan Multiple Range test indicated no statistical difference between the means of the two work/rest ratios at the two shorter work periods (20 and 40 minutes). However, a significant difference was found between the 2/1 and the 3/1 ratios at the 60 minutes work period.

The above findings reflect the adequacy of either work/rest ratios at 20 and 40 minutes of work. However, at the 60 minutes work period the length of rest intervals given had a major effect. Longer rests resulted in higher performance. In other words, the length of the rest period had an effect on performance only when the task was more demanding (60 minutes on watch). Similar results have been reported in previous research (Davies and Tune, 1969).

The second order interaction of ambient temperature by work period by work/rest ratio was found to have highly significant effect (.01 level) on percent correct detections. Performance means for this interaction are shown in Figure 22.

It is difficult to explain every point in this graph. However, general trends could be detected which summarize the effects of temperature, work period and work/rest ratio on detection performance. Firstly, a decline in performance with the increase in temperature, especially at 90°F (ET).

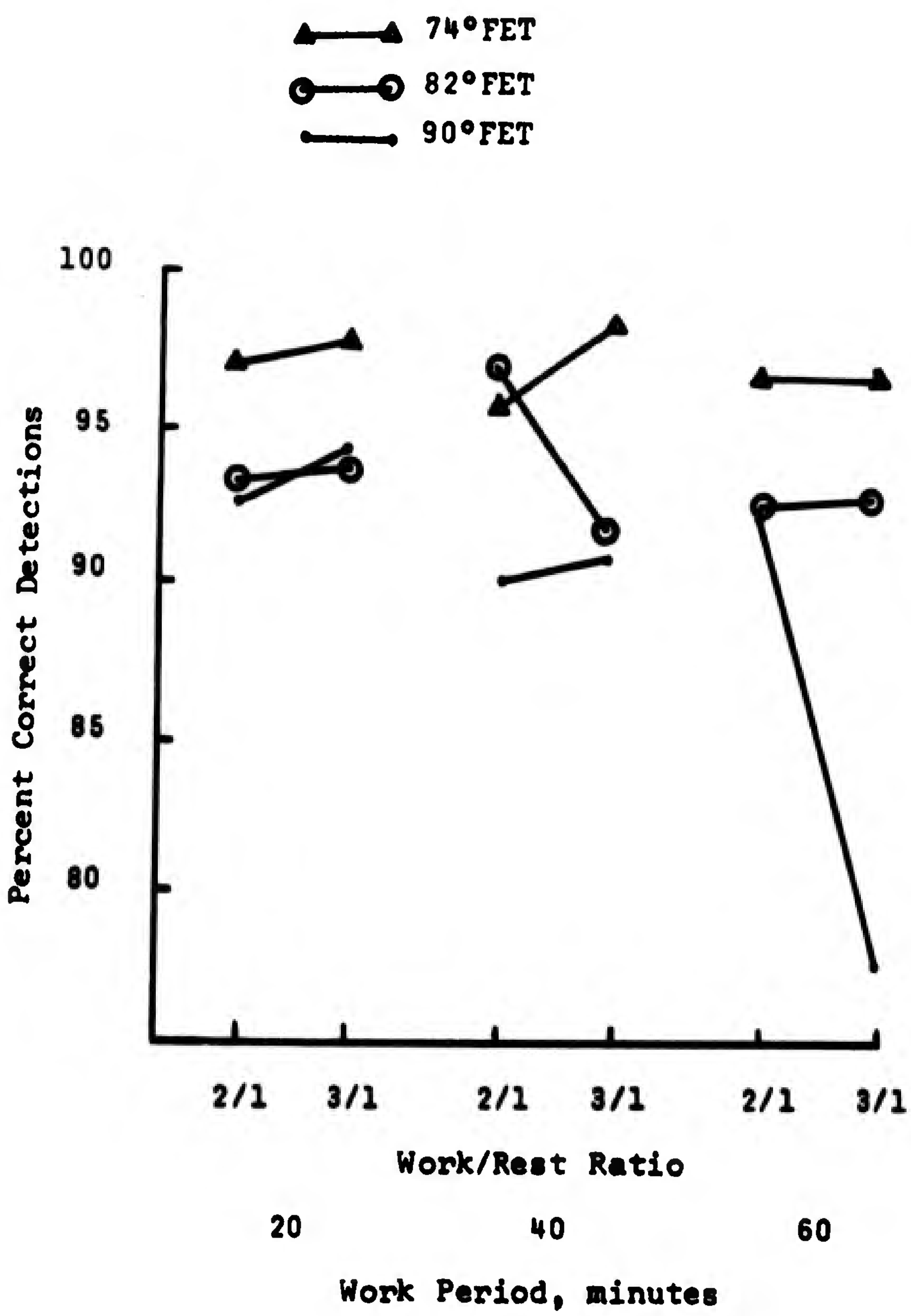

Fig. 22.--Percent correct detections for ambient temperature by work period by work/rest ratio interaction

Secondly, a decline in performance with the increase in the length of the work period, especially at 60 minutes of work. Finally, no appreciable changes in performance between various work/rest ratios except at severe conditions (60 minutes of work at 90°FET).

Time interval was found to have a highly significant effect (.01 level) on percent correct detections. Figure 23 shows performance means for the 12 time intervals studied. The changes in detection performance over time proved to be highly irregular and certainly very different from a typical vigilance decrement. Several factors could have caused this discrepancy.

First, the two hours of watch were not continuous but rather, interrupted by one or more rest periods depending on the subject's work/rest schedule. Therefore, the effect of this work/rest schedule is confounded with the effect of the time spent on watch. However, three time intervals are worth discussion in conjunction with this point, the first, the seventh and the ninth time intervals. At the first interval, all subjects were starting the watch. At the seventh and ninth intervals, two thirds of the subjects were starting the task fresh after a rest period and one third had been on the watch only for 20 minutes. Therefore, performance during these three intervals is expected to be highest. The results of this investigation confirmed

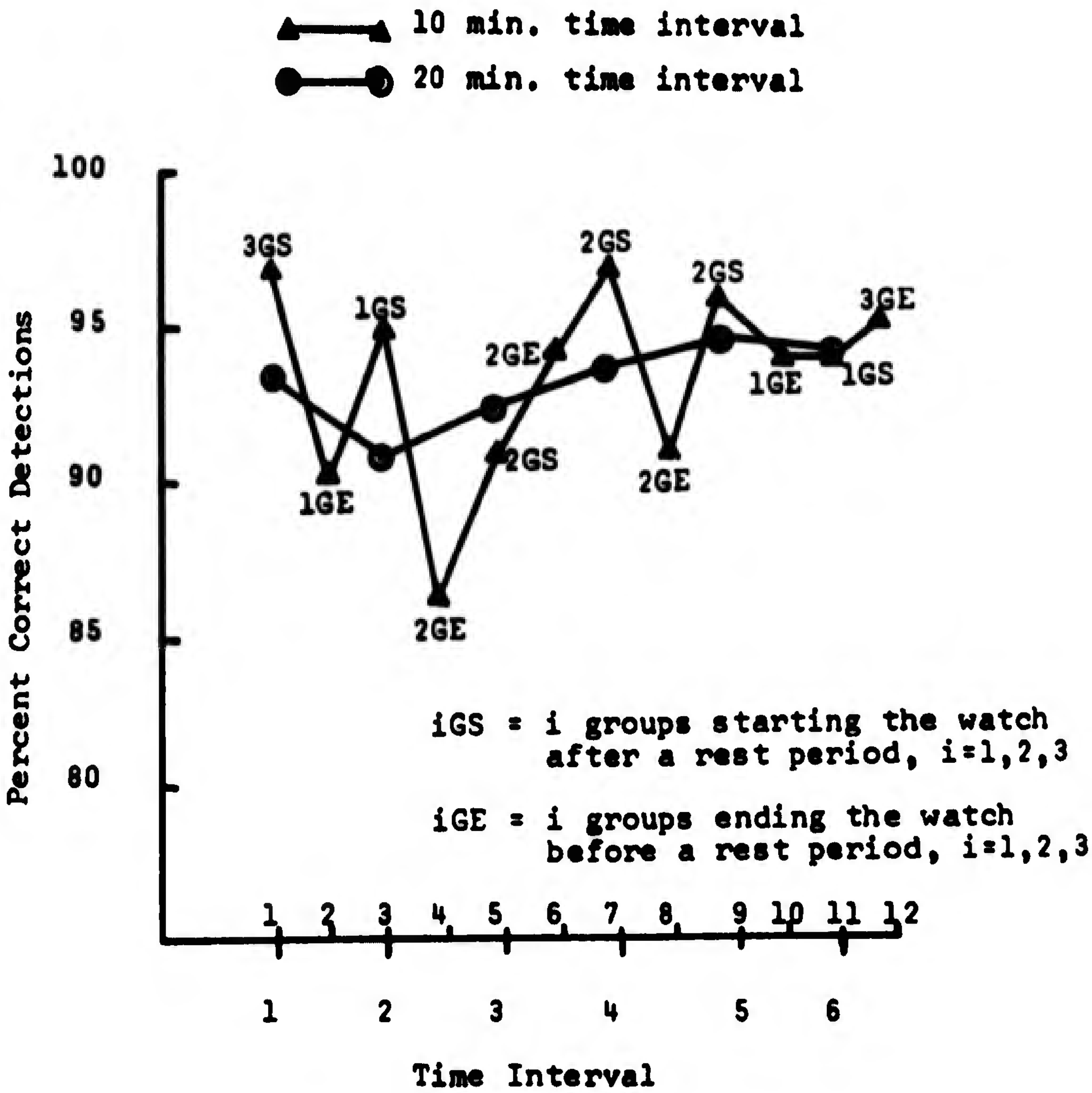

Fig. 23.--Percent correct detections for time interval

this point.

Secondly, a 10 minutes time interval might have been too short a period to assess performance characteristics over time. Dividing the total work duration into six time intervals instead of twelve will result in intervals 20 minutes long. Performance during these new intervals is more stable and consistant as shown in Figure 23. Improvements in performance over the second hour of work suggests possible effects due to heat acclimatization and training on the task. These two factors have been known to induce favorable effects on performance with the elapse of time.

The effect of replications on percent correct detections was found significant. This result was expected since individuals differ considerably as to their vigilance ability and their ability to perform in hot climatic conditions (Mackworth, 1951).

Percent Correct Responses

Percent correct responses, as a variable, is related to and dependent on percent correct detections. Therefore, the two performance parameters reacted in a somewhat similar manner to various experimental conditions. The analysis of variance for the percent correct responses is shown in Table 5. Following is a discussion of all the significant effects found in that table.

TABLE 5

ANALYSIS OF VARIANCE FOR PERCENT CORRECT RESPONSES

Source of Variation	DF	Sum of Squares	Mean Squares	F Ratio
Ambient Temperature, A	2	162.46	81.23	24.02 *
Work Period, B	2	25.24	12.62	3.73 **
AB	4	30.49	7.62	2.25
Work/Rest Ratio, C	1	14.59	14.59	4.31 **
AC	2	19.51	9.76	2.89
BC	2	33.46	16.73	4.95 *
ABC	4	43.86	10.96	3.24 **
Time Interval, D	11	178.99	16.27	4.81 *
AD	22	68.80	3.13	0.93
BD	22	78.23	3.56	1.05
ABD	44	131.66	2.99	0.89
CD	11	46.12	4.19	1.24
ACD	22	65.44	2.97	0.88
BCD	22	71.63	3.26	0.96
ABCD	44	125.71	2.86	0.85
Replication, R	5	93.26	18.65	5.52 *
Error, E	1075	3634.87	3.38	
Total	1295	4824.32		

* Significant at .01 level.
**Significant at .05 level

Ambient temperature was found to have a highly significant effect (.01 level) on percent correct responses. Performance declined considerably as a result of high temperature as shown in Figure 24. However, a Duncan test indicated a significant decrement in performance only when temperature was increased from 74 to either 82 or 90°F (ET). Increasing temperature from 82 to 90°F (ET) produced a slight but not a significant impairment in percent correct responses.

The highest percent correct responses was recorded at 74°F (ET). This result was expected since most studies have reported optimum performance in the neighborhood of this temperature (Mackworth, 1951; Pepler, 1951). Furthermore, this temperature was mainly tested to determine subjects' normal performance under pleasant atmospheric conditions. Comparing this performance with the one at high temperatures provided adequate means of evaluating the effects of heat stress.

The impairment in performance at high temperatures has been reported by various investigators. However, the conflicting point is at which temperature a significant decrement occurs. The significant drop in performance at 82°F (ET) found in this investigation supports earlier findings by Pepler (1961), Mackworth (1951) and others. Although the test conditions differ slightly between

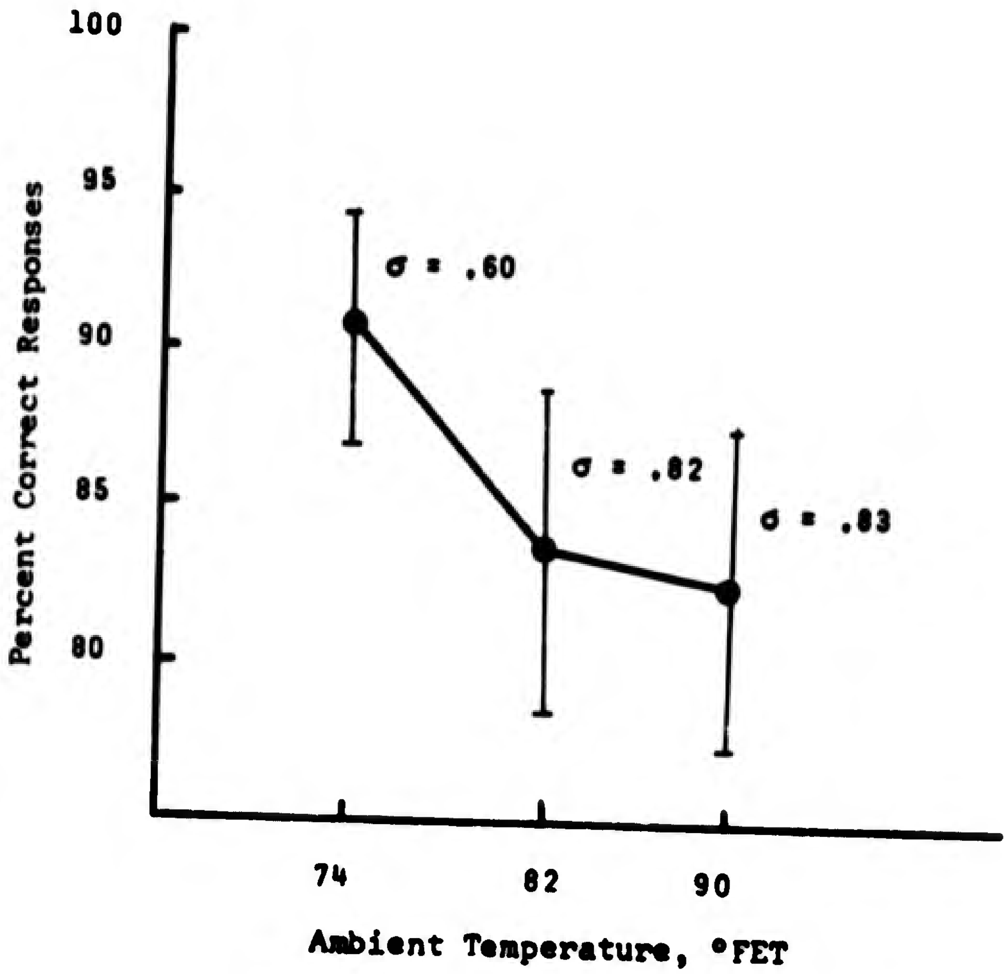

Fig. 24.--Percent correct responses for ambient temperature

various studies, the results could be considered comparable.

The further decrement at 90°F (ET) agrees with the hypothesis that performance is affected by the intensity of heat. As a result, the poorest performance was recorded at the highest temperature tested. Similar results have been reported by Frazer and Jackson (1955), Mackworth (1951) and Pepler (1961).

The fast decrement in percent correct responses at 82°F (ET) and then the moderate decline from 82 to 90°F (ET) needs further consideration. It differs slightly from the decrement found for percent correct detections where an even decline in performance was observed each time. Since the main difference between the two parameters is the discrimination process added to the former, this process could be responsible for the variation. Discrimination is a decision making process which requires more complex faculties than those normally required in a simple detection task. It seems to have been greatly affected by heat at 82°F (ET). Further heating to 90°F (ET) affected discrimination but the change was less drastic compared to the change from 74 to 82°F (ET).

The increase in performance variability at higher temperatures is indicated by the changes in standard deviation as shown in Figure 24. Again this variability could be attributed to the differences in skill between subjects and the degree to which their performance was impaired by heat, as explained earlier.

The effect of the work period on the percent correct responses was found to be significant at 5 percent. The plot of means in Figure 25 shows a decline in performance associated with the longer work periods. However, a Duncan Multiple Range test showed a significant difference only between the means of the 20 and 60 minutes work periods. The 40 minutes work period showed no significant differences when compared to either the 20 minutes or the 60 minutes work periods.

The progressive decrement of this parameter at longer work periods differs slightly from that found for detection performance. Here, increasing the work period length 20 minutes, either from 20 to 40 or from 40 to 60, produced no significant effect. A possible explanation lies in the complex effect of two factors; training on the discrimination task and time on the vigilance watch. The former has been known to improve performance (Sheldon, 1962; Adams, 1963), and the latter has been known to impair it. The combined effects of these two factors might have caused the slight decrement mentioned above. However, the difference in length between the 20 minutes and the 60 minutes work periods is long enough to assure a predominant effect due to the time spent on the watch (Davies and Tune, 1969).

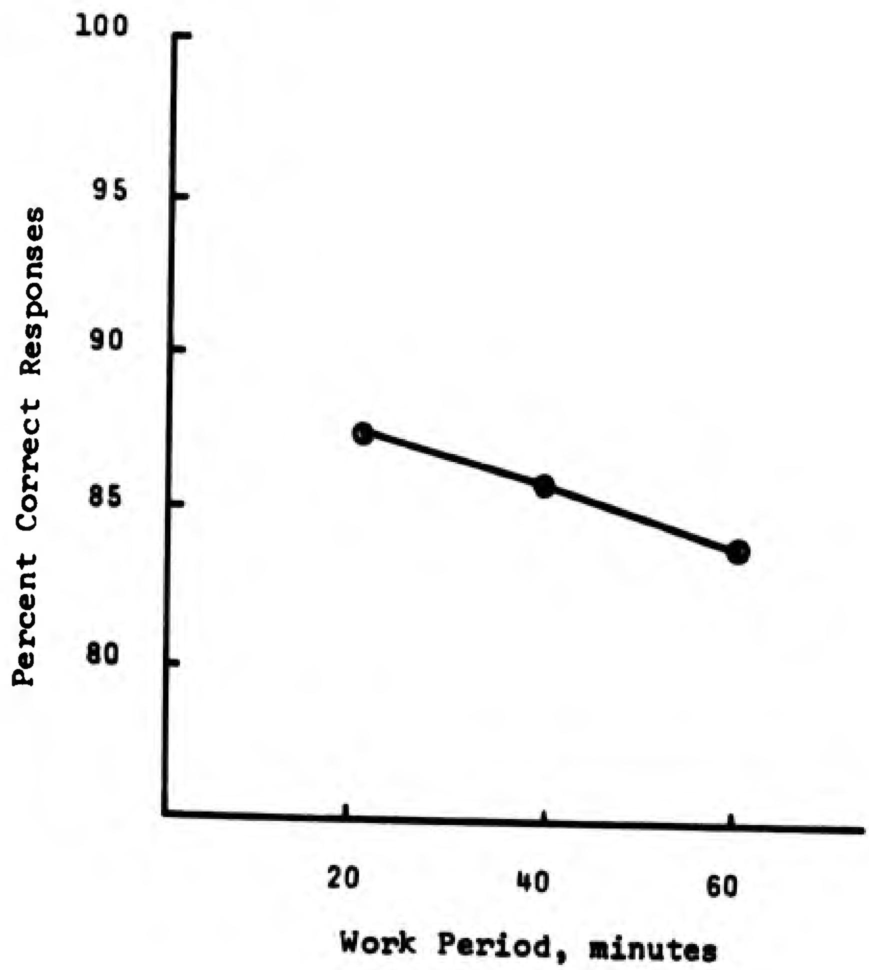

Fig. 25.--Percent correct responses for work period

Consequently, a significant difference in performance occured between these two work periods.

The interaction between ambient temperature and work period was found to have a nonsignificant effect on percent correct responses at 5 percent. However, its effect was significant at 10 percent, and will be discussed briefly here to provide means of comparison with its effect on percent correct detections, which was significant at 1 percent. A plot for the interaction means is shown in Figure 26. The Duncan test indicated no significant differences between the three work periods means at either 74 or 82°F (ET). However, at the hot condition of 90°F (ET) the 20 and 60 minutes work periods were significantly different, but not the 40 minutes work period when compared to either the 20 minutes or the 60 minutes. Furthermore, performance during any work periods at 74°F (ET) was significantly different from that at the other two temperatures.

The differences in performance between 74°F (ET) and either 82 or 90°F (ET), and the similarities between the last two have been explained in details earlier when discussing temperature effects. Similarly, the changes in percent correct responses between various work periods within any one single temperature is best explained by the discussion presented in an earlier section dealing with the effects of temperature by work period interaction

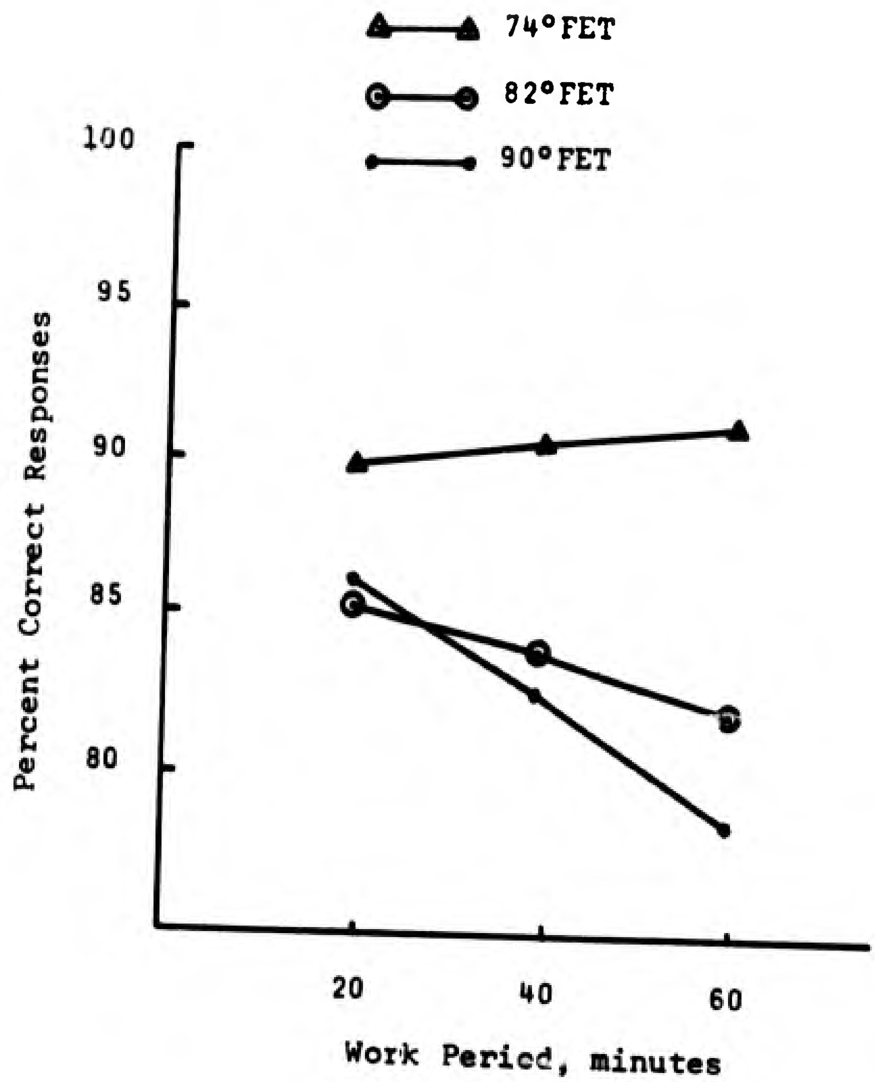

Fig. 26.--Percent correct responses for ambient temperature by work period interaction

on percent correct detections. The only major difference is the added difficulty to the task discussed here and its effect on performance. Increasing the task load, by adding the discrimination process, is possibly responsible for the low level of performance at 82°F (ET).

Work/rest ratio was found to have a significant effect (.05 level) on percent correct responses. Performance at the 2/1 ratio proved to be superior to that at the 3/1 ratio as shown in Figure 27. Here again, the longer rests associated with the 2/1 work/rest ratio enhanced performance to a considerably higher level compared to the effect of the shorter rests provided by the 3/1 ratio. Since the discrimination process involved here is considerably more demanding than simply detection, the effect of longer rests was more apparent. As a result the difference in performance between the two work/rest ratios was significant and in favor of the 2/1 ratio.

Similar to the ambient temperature by work period interaction, the temperature by work/rest ratio interaction effect was found significant at 10 percent and not at 5 percent. It will be presented here to allow comparison with its effect on percent correct detections, which was found significant at 5 percent. The increase in temperature caused a decline in performance at both work/rest ratios as shown in Figure 28. However, within each temperature,

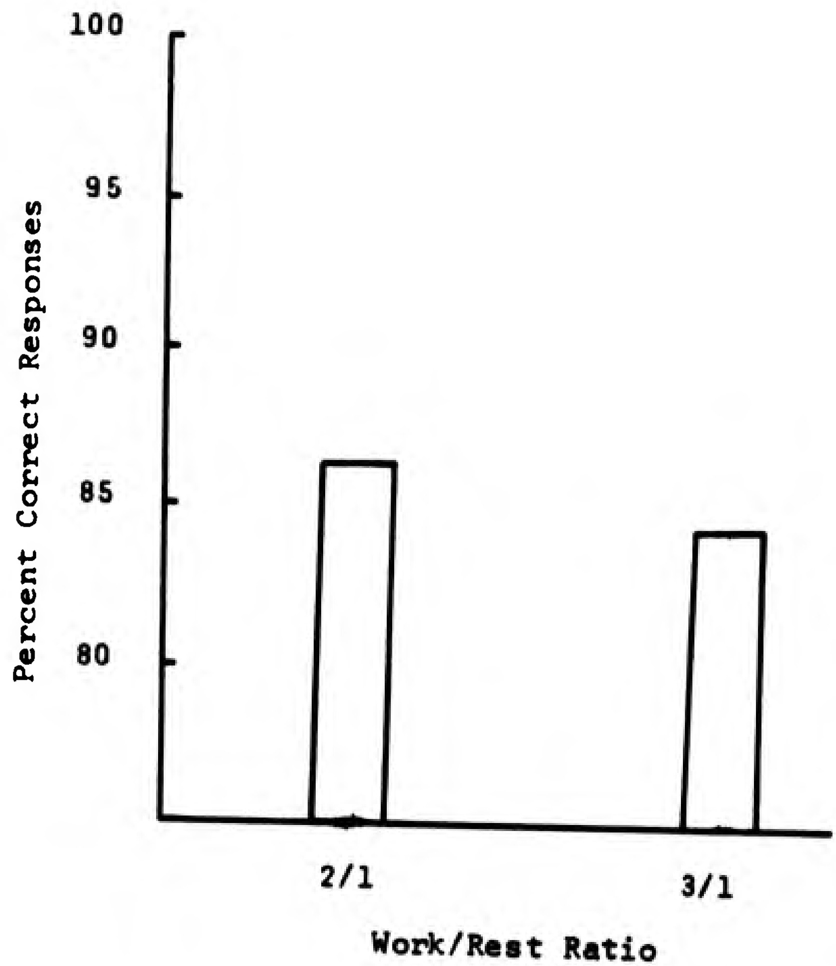

Fig. 27.--Percent correct responses for work/rest ratio

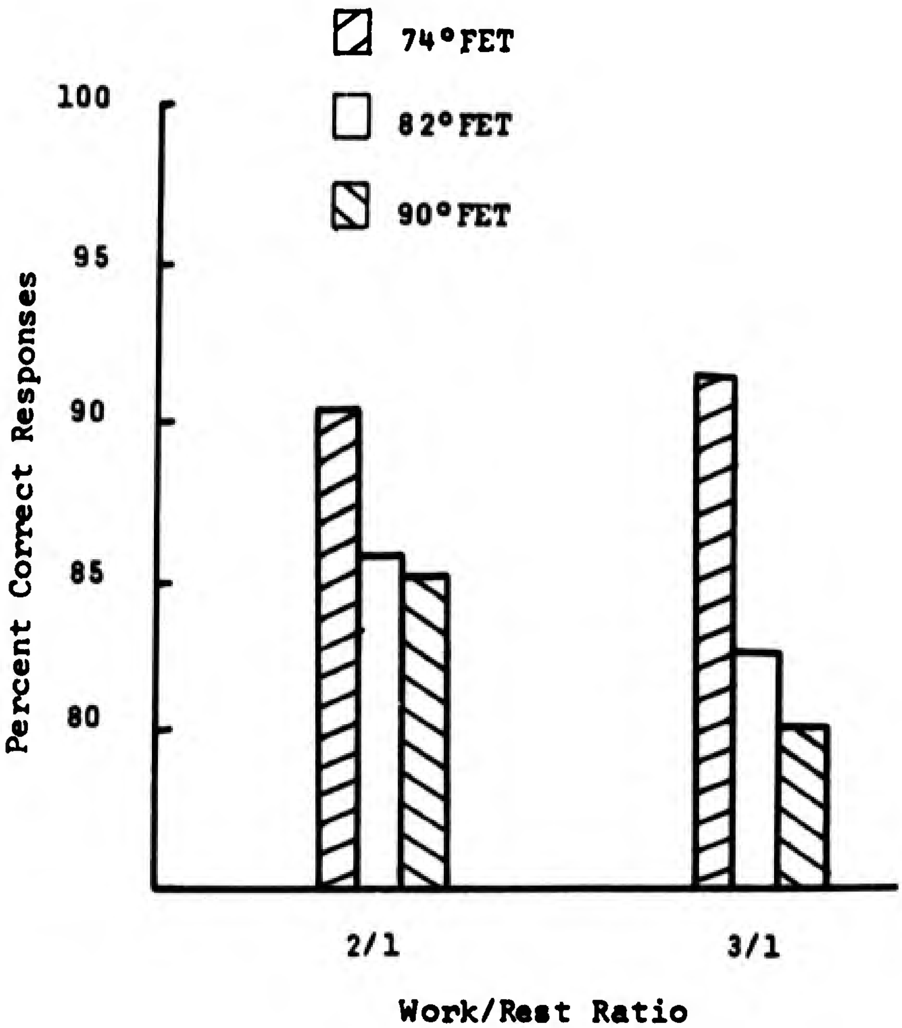

Fig. 28.--Percent correct responses for ambient temperature by work/rest ratio interaction

there was no significant difference between the two ratios except at 90°F (ET) where percent correct responses was significantly superior at the 2/1 ratio when compared to the 3/1 ratio. There was also a significant difference in performance at either 2/1 or 3/1 ratios, between 74°F (ET) and either 82 or 90°F (ET), but not between the latter two temperatures.

Here again, the non-significant differences between 82 and 90°F (ET) agree with the effects of temperature, as a main effect, on percent correct responses. Also in agreement are the significant differences between 74°F (ET) and any of the other two temperatures. The above similarities might have been responsible for the non-significancy of this interaction. The length of rest intervals provided by each work/rest ratio had an effect on percent correct responses very similar to that on percent correct detections. The latter was discussed earlier in greater details.

The interaction between work period and work/rest ratio had a highly significant effect (.01 level) on percent correct responses. A plot of the interaction means is shown in Figure 29. Further tests on the means of each cell indicated a significant difference between the two ratios only at the 60 minutes work period, but not at either the 20 minutes or the 40 minutes work periods. These findings for percent correct responses are identical to those for

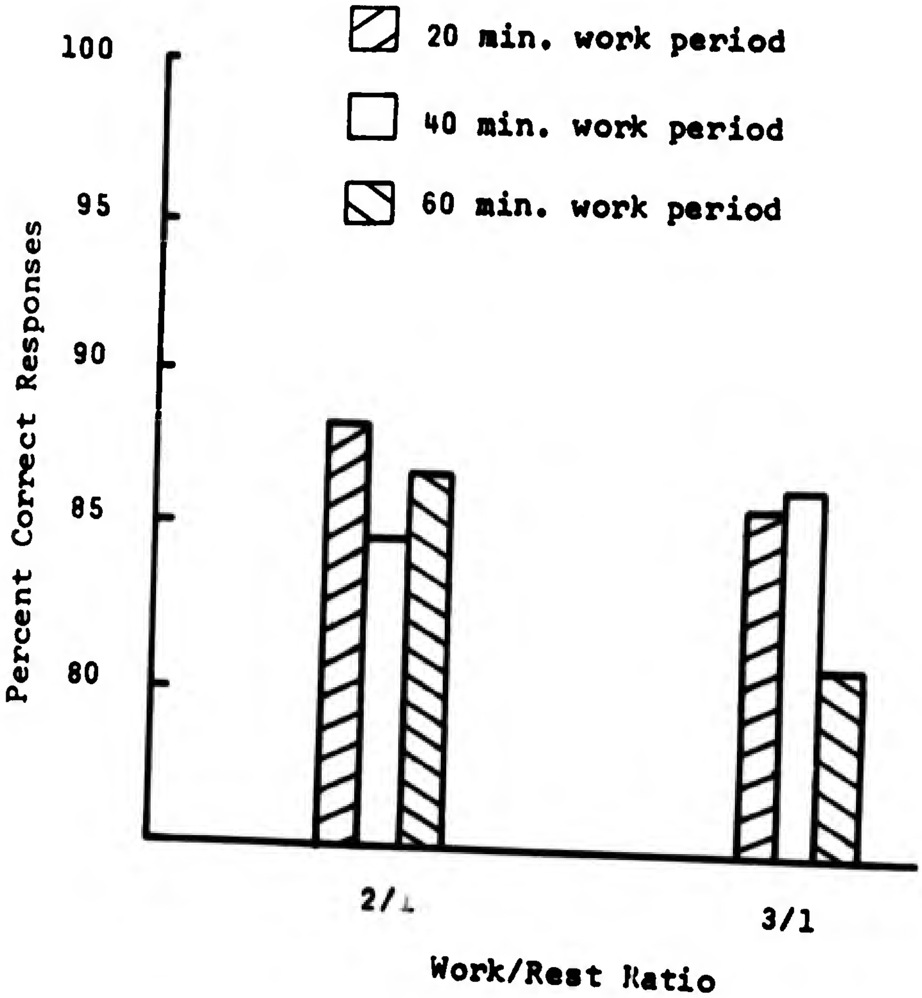

Fig. 29.--Percent correct responses for work period by work/rest ratio interaction

percent correct detections. The explanation provided for the latter in an earlier section could be applied here.

The second order interaction of ambient temperature by work period by work/rest ratio was found to have a significant effect (.05 level) on percent correct responses. A plot of performance means is shown in Figure 30.

Some general trends could be summarized from this graph regarding the effects of temperature, work period and work/rest ratio on correct responses. Firstly, a decline in performance with the increase in temperature especially at 82 and 90°F (ET). Performance at these two temperatures was relatively close. Secondly, a decrement associated with increasing the length of the work period, especially at 60 minutes of work. Finally, a decline in performance at the higher work/rest ratio, especially at the more severe conditions (longer work periods and/or high temperatures).

Time interval was found to have a highly significant effect (.01 level) on percent correct responses. Figure 31 shows performance means for various time intervals. As explained in an earlier section a better picture of the changes in performance over time was obtained when the length of the time interval was changed from 10 to 20 minutes.

A definite learning effect was detected for this task. It seems that subjects' ability to discriminate between small and large signals improved continuously with

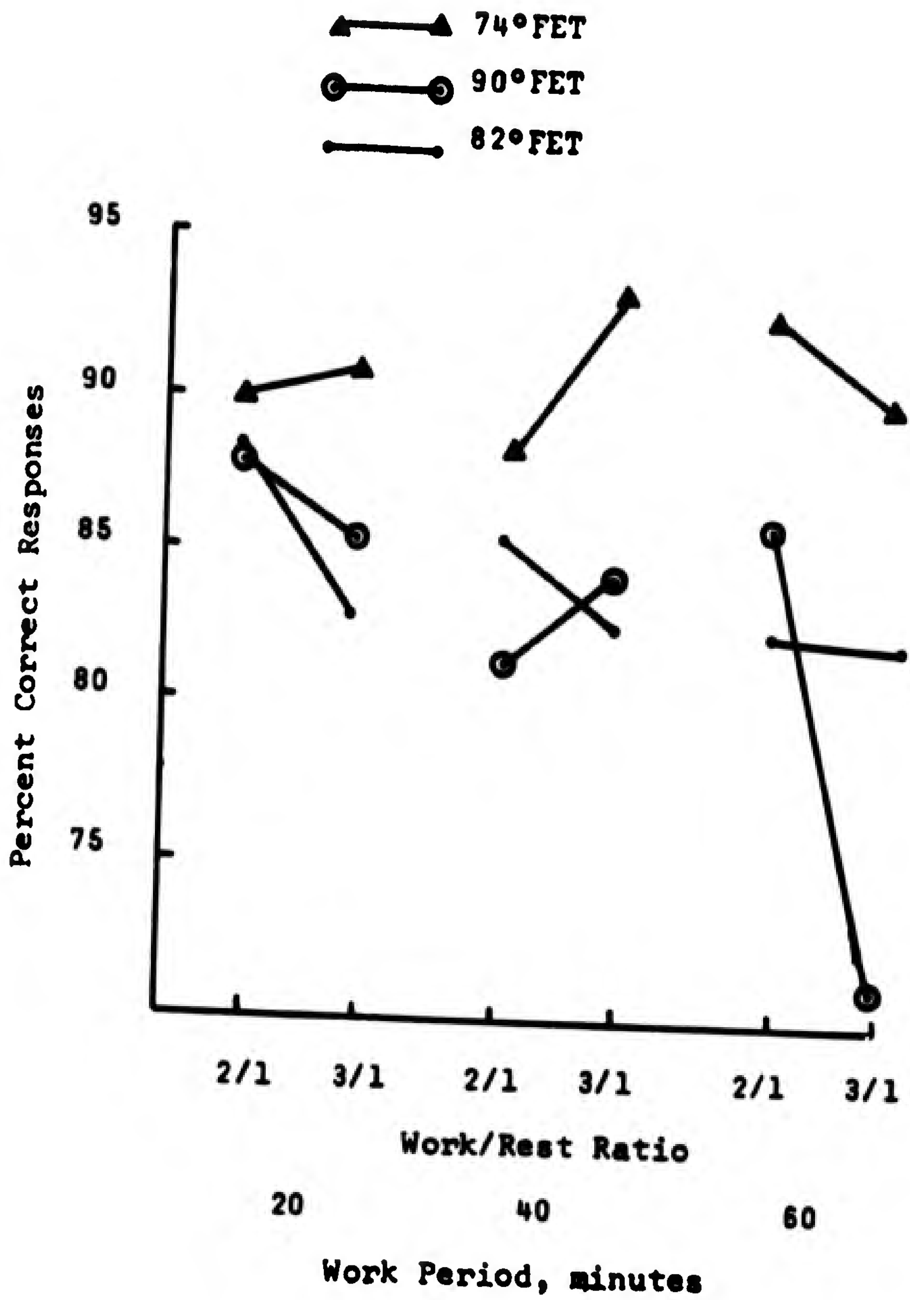

Fig. 30.--Percent correct responses for ambient temperature by work period by work/rest ratio interaction

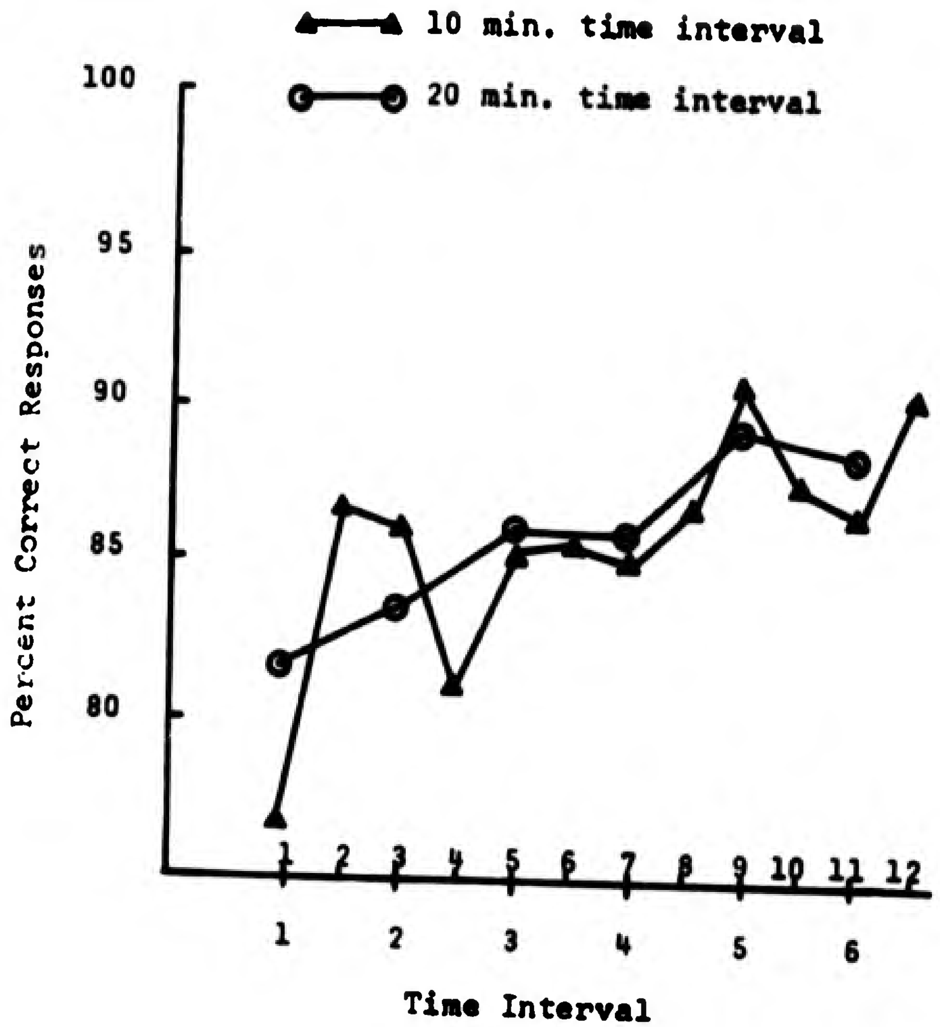

Fig. 31.--Percent correct responses for time interval

the time spent on the task. Discrimination is a complex process which is usually enhanced as a result of learning and practice. Increasing the number of signals presented, improved subjects' judgement of their size. Similar results have been reported in literature (Colquhoun, 1952; Mackworth, 1951).

To support the above argument about the effects of learning on discrimination, any effects due to changes in subjects' detection ability had to be isolated. This was achieved by defining a new variable, percent correct discriminations, as: the number of signals detected and correctly identified in magnitude during one time interval, divided by the number of signals detected in the same time interval and multiplied by one hundred. A plot of the changes in percent correct discriminations over time is shown in Figure 32. Here again, 20 minutes time intervals were a better indicator of the changes in this parameter. The graph shows a continuous improvement in discrimination performance over the first hour of watch. A slight drop was detected at the begining of the second hour, followed by a continuous improvement until the end of watch. The slight drop in discrimination ability at the start of the second hour could be attributed to the rest periods introduced at this point. One third of the subjects were given 20 or 30 minutes of rest between the first and second hours

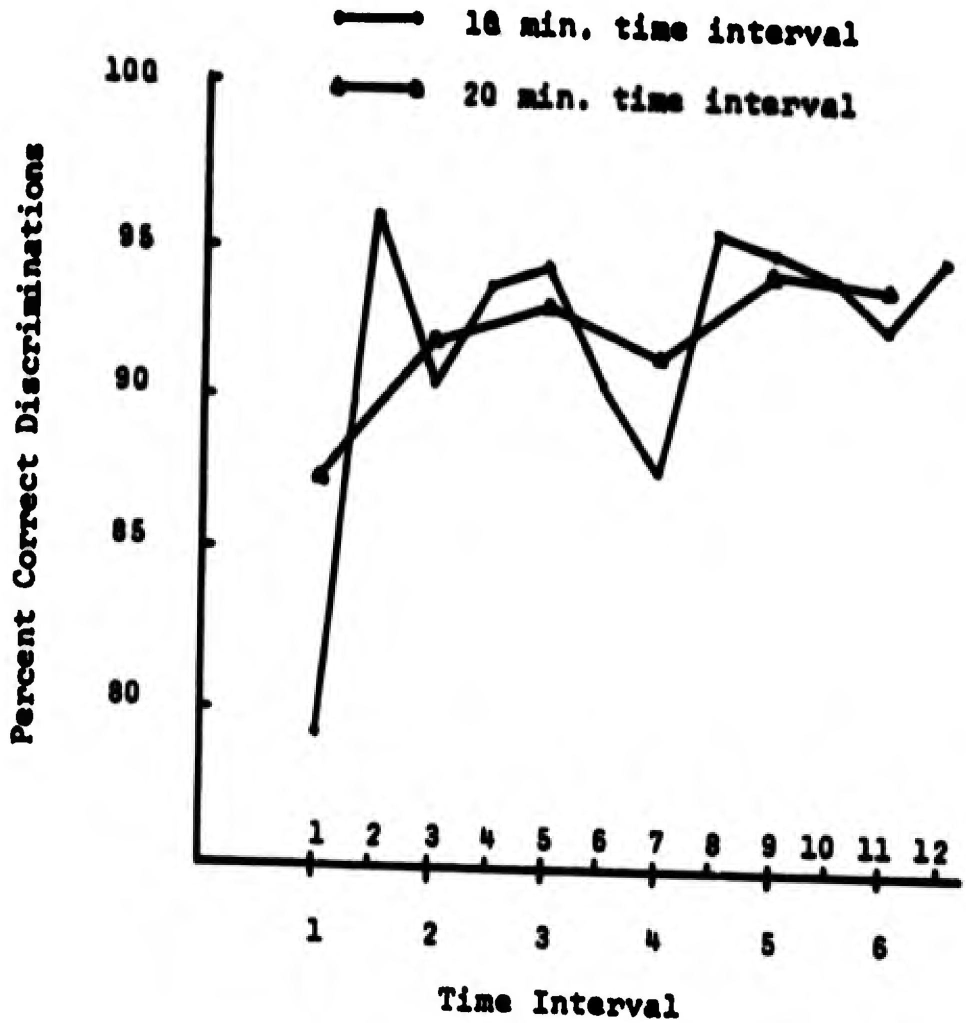

Fig. 32.--Percent Correct Discriminations for time interval

of watch. This long off-watch period could have interrupted temporarily the subjects' learning process. However, once the subjects were back on-watch their performance improved continuously. The above discussion clearly illustrates the favorable effects of learning on subjects' discrimination ability.

The effect of replications on percent correct responses was found significant primarily as a result of the individual differences between subjects. These differences are usually found in similar task and test conditions.

The significant findings of this investigation have been presented and discussed in this chapter. The following chapter will be comprised of conclusions drawn from this study and possible areas for future research.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This investigation has attempted to evaluate the effects of ambient temperatures and work/rest schedules on vigilance performance. The various experimental findings were discussed earlier. Appropriate conclusions based on these findings and recommendations for further research will be presented in this chapter.

Conclusions

A general conclusion could be drawn in regard to the relation between the two performance parameters, namely percent correct detections and percent correct responses. The latter was constantly and consistantly poorer than the former. The differences between the two parameters were slight at moderate conditions. However, they grew larger as the conditions deteriorated (long work periods, high work/rest ratios and/or high ambient temperatures). Since the only difference between the two parameters was the discrimination process added to the task requirements for the percent correct responses, we can draw conclusions in regard to the difficulty of the task and the nature of discrimination. Within the scope of this investigation it was thus concluded that complexity of the task had a strong effect on vigilance performance. Simple tasks produce high levels of performance when compared to complex tasks of basically the same nature. This conclusion agrees with previous research in the area of vigilance. Furthermore, it could be concluded that the detrimental effects of severe experimental conditions were stronger on discrimination than on detection. This conclusion reflects the sensitivity of percent correct responses as a measure of vigilance performance.

In reviewing the significant findings presented in Chapter IV, certain conclusions could be drawn about the effects of ambient temperature, work period, work/rest ratio and time interval on vigilance performance. Conclusions related to each of these areas will be presented in a separate section.

Ambient Temperature

Within the scope of this investigation it was concluded that ambient effective temperature had a strong effect on vigilance performance. Increasing ambient temperature caused a decline in performance.

It could also be concluded that the two performance parameters reacted in a similar fashion to the changes in ambient temperature. Nevertheless, there was a quantitative difference in their response to heat. Percent correct detections deteriorated at a near constant rate with the increase in temperature. On the other hand, the rate of deterioration of percent correct responses was high at first between 74 and 82°F (ET), then declined at further elevation of temperature to 90°F (ET). These differences between the two parameters resulted from the different task requirements of each.

It was also concluded that other experimental conditions had an influence on the changes in performance as a result of heat. Severe conditions (long work periods and/or high work/rest ratios) intensified the detrimental effects of heat, particularly at high temperatures (90°FET).

It is therefore recommended that performing similar tasks at temperatures of, or in excess of 82°F (ET) should be avoided, if possible. Other experimental conditions should also be kept within acceptable limits to insure efficient and satisfactory levels of monitoring performance.

<u>Work Period</u>

The length of the work period, as a main effect, was found to have an effect on vigilance performance, especially at 60 minutes of work. However, further evaluation of the interactions effects indicated a significant decrement in performance at the 60 minutes work period only at 90°F (ET) ambient temperature and 3/1 work/rest ratio. At all other experimental conditions there was no significant impairment in performance as a result of the 60 minutes work period. It was therefore concluded that long work periods (60 minutes) had detrimental effects on vigilance performance only at severe experimental conditions (90°FET and 3/1 work/rest ratio). These conditions added to the burden imposed on the subjects by the long work period and strengthened the undesirable effects of the latter.

It could be concluded that both performance parameters, percent correct detections and percent correct responses, reacted identically to the changes in the length of the work period. The latter was always at a lower level compared to the former, as explained earlier.

Therefore, it is recommended that at severe working conditions (high temperatures and short rest periods) serious consideration should be given to the detrimental effects of work periods in excess of 40 minutes in length. Various other environmental and task conditions must also be considered in relation to the length of the recommended work period.

Work/Rest Ratio

The work/rest ratio, as a main effect, was found to have an effect on performance. However, further evaluation of the interaction effects indicated a significant decrement in performance at the 3/1 ratio only at 90°F (ET) ambient temperature and 60 minutes work period. At all other experimental conditions there was no significant impairment in performance as a result of either work/rest ratios. It could therefore be concluded that the 3/1 work/rest ratio, which provided shorter rest periods, had detrimental effects on vigilance performance only at severe experimental conditions (90°FET and 60 minutes of work).

Another related conclusion might be drawn regarding the two performance parameters under investigation. Percent correct responses, which is associated with more difficult task requirements, was impaired by shorter rest periods to a higher degree than percent correct detections. Nevertheless, both parameters responded unfavorably to shorter rests, i.e. higher work/rest ratios, especially at severe experimental conditions.

It is therefore suggested that longer rest periods, as provided by the 3/1 work/rest ratio, should be allowed at severe environmental and task conditions (high temperatures and long work periods). However, at comfortable conditions caution should be exerted in regard to the possibly undesirable effects of the unnecessary long rest periods.

Time Interval

Within the scope of this study it was concluded that the time spent on the task had an effect on vigilance performance. There was some evidence that subjects starting fresh at the begining of the watch or after a rest period performed at the highest level on the detection task. However, no conclusions could be drawn in regard to the effects of time, as a main variable, on performance, mainly because of the confounding effects imposed on the problem as a result of the work/rest schedules under consideration. Nevertheless, the fact that no vigilance decrement was found over time advocates the use of work/rest schedules as a means of overcoming such a decrement.

The changes over time of the two performance parameters differed considerably. Percent correct detections showed a marked improvement during the second hour of watch, while percent correct responses showed a progressive improvement over the full two hours. It appears that percent correct detections, which corresponds to simple task requirements, was affected by acclimatization to heat and/or familiarization with the task. On the other hand, percent correct responses seemed to have been considerably enhanced by learning and slightly improved by acclimatization. The process of discrimination involved in one parameter and not the other might have been responsible for these differences.

Summary

This research has attempted to evaluate the effects of work/rest schedules on monitoring performance in hot environments. Its results contribute to the better understanding of human performance in the heat. However, such performance is usually affected by many factors which can only be evaluated and clarified by continuous and systematic research. Therefore, the results of this investigation must be interpreted in conjunction with related results of other researchers in order to fully comprehend the different characteristics of human performance in the heat.

The significant conclusions drawn from this investigation are:

1. High ambient temperature (82 and 90°FET) had a significantly detrimental effect on vigilance performance.
2. Long work periods (60 minutes) caused a significant deterioration in performance only at 90 °F (ET) ambient temperature and 3/1 work/rest ratio (shorter rest periods).
3. Similarly, high work/rest ratios (3/1) produced a significant decrement in performance only at 90°F (ET) ambient temperature and 60 minutes work period.
4. The combined effects of high temperatures (90°FET), long work periods (60 minutes) and high work/rest ratios (3/1) had a strongly

detrimental effect on vigilance performance.

5. There was a significant difference in subjective reactions to various experimental conditions, especially at high heat.
6. Performance showed a slight improvement over time. No vigilance decrement was detected possibly due to the effects of work/rest schedules, learning and heat acclimatization.
7. Discrimination, which adds to the complexity of the vigilance task, was strongly impaired by severe experimental conditions. Detection was also impaired but to a lesser degree.

Recommendations for Future Research

The findings of this investigation and the analysis presented for each of them pointed out several related areas which are worthy of consideration. Further research in these areas would ultimately aid the purpose of this investigation and would clarify any points that this study has failed to consider.

The vigilance task adopted represents one area worth studying. It has been pointed out earlier that most of the previous research in heat is task specific. This restriction imposes extreme difficulties in comparing the results of various studies. There is a definite need for one or more standard tasks that every researcher in the area can use.

The requirements for each standard task should be selected to accurately represent one of the various tasks that are commonly used in practice. This will not only provide better means for comparing various studies but also bridge the gap between vigilance research in the laboratory and monitoring tasks in actual life.

Further studies are needed in the area of heat especially in the range of effective temperatures from 74 to 82°F. Somewhere in this range lies a critical point where a considerable decrement in performance takes place. No one study has attempted to evaluate each single temperature in this range. With the variety of tasks in use the results of such a study would have been very limited. However, with a set of standard tasks a critical temperature could be determined for each task, along with the rate of performance deterioration beyond that temperature.

In the area of work/rest scheduling, 20 to 30 minutes work periods proved to be adequate to maintain a high level of performance. However, there is a definite interaction effect between the length of the work period and both the intensity of heat and the length of the rest period. Adequate work periods for various degrees of heat stress need to be determined. Similarly, the length of the rest period required to restore performance to it's original level at various temperatures and/or work periods needs further consideration.

Eight hours exposure to heat should be investigated. This will allow more frequent work/rest cycles and consequently better assessment of their effect. It will also provide better means of evaluating the changes in performance over time in relation to the work/rest schedules.

Another area for future research is that of secondary tasks. Vigilance research in normal environmental temperatures has indicated an enhancement in performance by introducing various secondary tasks in place of interpolated rests. A question remains to be answered. Would secondary tasks have the same effect in hot conditions? Or would the secondary task add to the burden imposed on the subject by heat? This represents an interesting problem which certainly is worthy of consideration.

A related problem is that of allowing individuals to rest in a cool environment instead of the same hot one. Would that provide faster recovery? And what are its effects on any partial acclimatization acquired by the subject? Would switching back and forth between warm and cold environments have a detrimental effect on various body functions? These questions and various related ones also need to be investigated.

Subjective comments of the individuals tested need further consideration. How well can an individual determine the degree of heat stress imposed on him? Furthermore, how well can he, under these hot conditions, predict his performance and the amount of decrement it suffers, if any?

If we broaden our search to the general area of performance under heat stress, we will find several problems of interest for future researchers. First, the similarities and differences in the effects of heat on various perceptual, intellectual and sensorimotor performances need further investigation. What aspects or specific functions of each task are most susceptible to heat decrements? How can we preserve these functions from deterioration in heat? A second relevant problem pertains to the effects of localized cooling of various parts of the body during heat exposure. Can we prevent performance deterioration on various tasks by cooling the most relevant body segments? To what extent would this technique be effective, if at all? Finally, the problem of individual differences needs further consideration. How are individual differences in performance decrement in heat correlated with skill variables? To what extent are these differences affected by heat acclimatization and learning?

The last problem that will be mentioned here concerns the type and number of subjects observed. Most of the previous data on the effects of heat on performance have been obtained from experiments on highly restrictive populations (healthy young men, pilots and astronauts, male students and the like). Research should be extended to include the young and the old, males and females, the fit and the unfit and the average man or woman. Such generalization of the subjects' population will eventually lead to better understanding of the effects of heat on human performance.

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APPENDIX

INSTRUCTIONS PLAYED FOR THE SUBJECTS PRIOR TO EXPERIMENTATION

The instructions were played during the instructions and practice period immediately preceding every experimental session. They were as follows:

> The experiment you are about to participate in is concerned with monitoring performance, which is the ability to stay alert for long periods of time. During the experiment your task will be as follows: on the radar type screen directly in front of you will appear a small dot of light.

The dot of light representing the continuous background event was introduced at this point, and the instructions continued.

> The dot of light will normally be seen at the center of the screen with little or no movement. However, at various times the dot of light will make an appreciable movement up or down. When such a movement occurs you are to press the response button with your thumb as quickly as possible. The dot of light will make one of two types of movements. It is going to move either up or down a small distance of about 1/4 inch like this,

The dot of light moved up a distance of 1/4 inch to illustrate a small signal.

> or it will make a longer movement of about 1/2 inch like this.

Again the dot of light moved up, but a distance of 1/2 inch this time, to illustrate a large signal.

> If the light movement is small you are to press the response button and immediately release it.

> If the movement is large, press the button and hold it down for about five seconds before releasing it. During the experiment you will experience some slight variations in temperature. These variations will be within the normal range experienced in your daily activities. There will also be a steady background noise during the experiment. Although the noise level will seem high, it will not be injurious. The experiment will last about three hours during which you will be allowed a number of rest periods. A rest period will start when the red light on the table in front of you goes on and will last as long as the red light stays on. The disappearance of the red light will signal the end of the rest period and you are to go back to the monitoring task immediately. During the rest period you can relax in place and do whatever you please. Reading material is provided for you convenience. However, you are urged to stay awake and not to talk to the other subject or walk in the room. Now we will have a short practice period. You should respond by pressing the button and releasing it immediately.

A small signal was presented and subjects' responses were checked to insure proper understanding of their task.

> You will now see a large signal: you should press the button and hold it down for about five seconds before releasing it.

A large signal was presented and subjects' responses were checked again.

> Ignore any vibrations of the light dot. Watch the screen for further signals and make the appropriate responses.

The practice period started at this point and lasted for three minutes during which subjects were presented with eight signals. Signals varied from small to large and from up to down. Subjects' response to each signal was checked carefully to make sure it is the appropriate one. Failure to understand the task resulted in subject's elimination (only two subjects were eliminated). At the end of the practice period, the following instructions were played:

> The practice period is over. You will experience the same type of signals during the next three hours. However, signals will occur at a much slower rate. Relax in place, stay quiet and don't make any disturbing noises during the experiment. Take your headphones off and watch for the experiment to start in about one minute.

The instructions ended at this point and the experiment continued as described earlier.