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THE EFFECTS OF ENVIRONMENTAL TEMPERATURE AND ALERTING STIMULI ON PROLONGED SEARCH

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The Effects of Environmental Temperature and
Alerting Stimuli on Prolonged Search

by

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Introduction

A vigilance task is a situation in which a human operator maintains a watch, over a relatively long period of time, for infrequently appearing targets. Such tasks may be created in the laboratory or they may exist in highly complex operating conditions, for example, monitoring a radar scope for the arrival of airplanes. Because of its continuing importance as a human task in man-machine systems, vigilance has been given a considerable amount of research attention.

The prototype vigilance experiment designed by Mackworth (1950), used a large circular disk with an indicator extending from the center of the disk to the outer edge. The normal movement of the indicator was a "jump" or step equal to a 3-degree angle with the center of the disk. The subject (S) was required to respond to the indicator when it jumped, at unpredictable times, through a distance of twice its normal movement. Mackworth found that detection of the target event, that is, of the double jump, decreased rapidly as a function of time so that most of the loss which was observed during a 1-2 hr. session, occurred during the first 20-30 min. of the experimental session.

Recent studies of vigilance (Adams, Stenson and Humes 1961; Scott, 1957; and Teichner, 1962a) have placed considerable emphasis on an interpretation of the vigilance effect in terms of a neurological activating hypothesis. This hypothesis, as developed by Hebb, (1955), Lindsley, (1957) and Malmo, (1959), states that a stimulus input travels along two major systems, the primary sensory system and the reticular activating system. The primary sensory system conducts the nerve impulse initiated by the incoming stimulus, from the sensory organ to discrete sensory areas of the cortex (cue function), while the reticular activating system conducts the nerve impulse along multisynaptic pathways to various parts of the cortex. It is the reticular activating system that is associated with the arousal effect. Sensory input from varied stimuli results in greater activation to the cortex, which implies a greater alertness on the part of S to the stimulus. If the sensory input is from uniform stimuli, the human operator undergoes a period of "sensory habituation" to the arousal properties of the stimuli (Scott, 1957). Under exposure to repetitive tasks, a gradual loss of alertness develops, and therefore, a greater deterioration of performance.

Several behavioral studies lend some support to the activation approach. Adams, Stenson and Humes (1961) have reported no loss in deterioration with complex targets

as opposed to the usual results with simple targets. They have interpreted this to mean that the greater stimulation afforded by the more complex target tends to maintain the activation level. Teichner (1962a) has shown with simple targets, that if the intensity of the target, defined as per cent of targets detected under alerted pre-vigilance conditions is controlled, response (R) speed remains constant for those targets which are detected, even though the per cent of detected targets decreases. Teichner pointed out that this can also be interpreted within the activation framework. That is, although the S may become less aroused during the session and so miss more targets, those targets which are detected tend to produce an immediate re-activation. In support of this explanation, Teichner (1962a) noted that the speed of nerve conduction involved is negligible compared to the reaction time produced by the mechanical elements of the human body and consequently, ordinary R-speed measures may not vary with the state of activation in the vigilance task.

Another critical factor shown to influence target detection in a vigilance task is the signal rate. Thus, it has been shown repeatedly (Deese and Ormond, 1953; Jenkins, 1958; Kappauf and Powe, 1959; Nicely and Miller, 1958; Pollack and Knaff, 1958, and Wiener, 1962), that for a variety of kinds of signal, target detection is related

directly to the rate of signal presentation. In general, the proportion of targets detected increases up to a signal rate of approximately 60 signals/hr., after which target detection remains constant. This general finding is also consistent with the activation concept since the rate of neural stimulation can be expected to increase with increasing stimulus rate.

Mackworth (1950) extended his studies to include the effects of various air temperatures on performance in vigilance situations. Using the same task, he exposed his Ss to temperatures of 70°, 79°, 87.5°, and 97° F. E. T.* He found maximum performance for Ss exposed to 79° F. E. T. Pepler (1958), also studying the effects of vigilance performance under various temperature exposures of 75°/65°, 90°/80° and 120°/85° DB/WB**, found maximum performance for Ss exposed to 90°/80° F. DB/WB. These experiments suggest that as air temperature increases from cool to hot,

* F. E. T. Farenheit Effective Temperature. Effective temperature is an empirical sensory index which expresses the combined effect of air temperature, humidity, and air movement in terms of the subjective feeling of warmth. In an environment where the air is completely saturated (relative humidity = 100%) and air velocity is zero, E. T. is defined arbitrarily as the value of the air temperature. Combinations of temperature, humidity and air velocity which produce the same subjective feeling of warmth are assigned to E. T. value (Houghton and Yagloglou, 1923).

** Dry bulb/wet bulb.

there results first an activating and then a de-activating effect. The effect of low temperature on vigilance performance has not been studied and therefore generalization of the apparent de-activating phenomenon cannot be made to the cold. In view of the current importance of prolonged tasks involving target detection and of environmental control in applied contexts, for example, the aerospace field, low temperature effects must be given importance.

The more usual operating situation is not characterized by a passive operator who waits for a signal coming from a fixed location, but rather, by an operator who must scan the area of a display, for example, a radar screen, the sea and sky etc., in order to detect a presented signal. Therefore, the operator not only cannot predict when a target will appear, he cannot predict where it will appear. Such scanning tasks have not been studied in relation to temperature or other assumed activating conditions. It appears then, that there is a practical need for such information. The major purpose of this investigation therefore, was to provide a first step in this direction.

For the activation concept to have experimental meaning, it would be desirable to demonstrate that target detection depends on states of a physiological activating mechanism which in turn depend upon independently varied stimulus conditions. Not only has this not been done for

the neurological activating concept in regard to the present context, but the possibility of doing it with human Ss in a vigilance task appears remote. However, if it could be done, the linkage between activation and performance would still be incomplete, that is, knowledge of the intervening mechanics of the physiological system would still be limited.

Recently, Teichner (1963) has proposed an intervening physiological mechanism with activating or arousing properties. His theoretical approach has particular relevance to the present interest in thermal environments because it uses the thermal regulatory system of the body as an arousal mechanism. Before discussing the thermal arousal concept as proposed by Teichner, a brief review of the thermal regulatory system may be of value and will be presented.

The maintenance of body heat balance is accomplished functionally by a feedback system in which the anterior hypothalamus is thought to act as a controlling center. In this capacity, the hypothalamus regulates (a) the internal heat-producing metabolic activities and (b) the external heat loss by variation of the surface blood circulation through control of the sweat glands. Heat produced internally is transferred to the body surface mainly by convection through the blood stream, and then

transferred to the environment. If the body is in heat balance, the amount of heat transferred from the "core" to the surface equals that transferred from the surface to the environment.

Of the many ways to induce thermal imbalance, exposure to temperature has received the greatest research attention. Winslow, Herrington and Gagge (1937) have shown that thermal balance exists for a nude resting S at approximately 85°-88° F. If the ambient temperature is decreased, there occurs quickly both an increase in metabolic rate and a peripheral vasoconstriction. Down to perhaps 65°-70° F. for the nude S thermal balance may be recovered eventually although the balance may be achieved at different steady state levels of internal heat production and external heat loss. However, with continued exposure to still lower temperatures, the surface heat loss may exceed the internal heat production producing a decreasing internal body temperature.

The reverse phenomenon occurs when the ambient temperature is increased above about 85° F., that is, metabolic rate is decreased and vasodilitation occurs. This decreased heat production and increased surface heat loss will also come into balance in time. However for continued exposure to temperatures above about 100° F., the internal heat production may exceed the surface heat

loss thus producing an undesirable internal heat load.

The basic heat balance equation as described by Burton (1934) is:

$$M \pm S = H$$

where M = rate of metabolic heat production, S = rate of body heat storage (or loss), and H = rate of heat exchange via radiation, convection, evaporation or conduction. This equation expresses heat balance in terms of rate of heat transfer.

The thermal circulation index also proposed by Burton (1934) is:

$$\frac{T_R - T_S}{T_S - T_A} (K)\ I_A$$

where T_R = average core temperature, T_S = average skin temperature, T_A = average air temperature, K is a constant which corrects for differences in evaporative heat exchange and I_A is the insulation of the air. This equation expresses heat balance in terms of temperature gradients. The numerator, representing the gradient between average internal and average surface measures, is a physiological thermal gradient; the denominator, representing the gradient between average skin and average air measures, is a physical thermal gradient. Under conditions of thermal balance, the thermal circulation index is the temperature equivalent of

$$\frac{M \pm S}{H}$$

That is, when the body is in heat balance,

$$T_R - T_S = T_S - T_A$$

With T_A held constant, any change in either T_R or T_S represents a change in heat balance. The steeper the gradient between $T_R - T_S$, the greater the heat production relative to heat loss and the greater the thermal stress being placed on the body.

The state of thermal balance is dependent on most conditions to which the body is exposed, e.g., amount, kind, and time of food intake, exercise, sleep, rest and exposure to various environmental energies. Teichner (1963) noting that the R-measures of behavioral studies also depend on these same stimulus factors has proposed that the thermal regulatory mechanism acts as a general physiological arousing system. According to his view, R-strength first increases with increasing "thermal arousal" up to a point, after which, any further increases in thermal arousal results in a decrease in R-strength; the general function resembles an inverted U-shaped curve. The model is comparable in its behavioral relationships to certain aspects of Hull's (1943) generalized drive state and to the arousal concepts of Hebb (1955) and Malmo (1958). In addition to noting the physiological linkage between thermal regulation and the neurological activating concepts of Lindsley (1957) and Scott (1957)

via the anterior hypothalamus, Teichner also has gathered considerable evidence which provides support for this approach.

Among the thermal regulatory measures exploited by the theory is the physiological thermal gradient, $T_R - T_S$. Since, as thermal balance is altered and therefore $T_R - T_S$ changes, the changes in T_R are small relative to changes in T_S. This measure is an index of the general state of peripheral vasoconstriction. Within the context of Teichner's theory in relation to the present problem, target detection would be expected to be an inverted U-shaped function of the value of the gradient and this should be true regardless whether the gradient was altered by exposure to temperature variations or by other means. This approach is of particular interest in the present investigation since it suggests appropriate physiological measures and provides a basis for prediction.

One consequence of the theory is the desirability of taking individual differences in heat production into account. Since as noted, thermal balance can be achieved at different levels of heat production and heat loss, the same numerical value of the physiological thermal gradient may represent varying individual levels of thermal arousal. Thus, unless individuals are known to have the same basal

heat production, the theory requires that predictions be made on an individual basis.

In reviewing the behavioral literature regarding exposure to environmental temperatures, few studies have been found in which appropriate physiological measures were recorded. In the ones that have, (Pepler, 1958, 1959; Teichner, 1962b), only rectal or skin temperatures were recorded. No estimation of either the thermal circulation index or the thermal gradient was made. Teichner (1962b) found that individuals with a tendency toward persistent vasoconstriction, that is, those tending to maintain a heat load under local cold stress showed behavioral over-arousal effects. Teichner and Youngling (1962), found that rats exposed continuously to low ambient temperatures, showed both an increased metabolic rate and an increase in R-strength relative to performance in optimal thermal conditions. Although the physiological thermal gradient was not obtained for these Ss, it can be inferred that an increased gradient did exist.

A similar interpretation can be given to the studies of Mackworth (1950) and Pepler (1958), cited above. Throughout the ranges investigated (approximately 65° to 95° F. E. T.), both studies found performance to

be optimum at approximately 80° F. E. T. Although neither investigator computed the thermal circulation index or the thermal gradient for their Ss, it can be assumed that as air temperatures were varied, the expected variations in $T_R - T_S$ occurred. Thus, although speculative, these results tend to support the expecta- of an inverted U-shaped function.

On the other hand, according to Teichner, since the data of Mackworth (1950) and Pepler (1958) are averages of Ss, either all Ss used in either experiment must have had comparable heat productions or the range of basal heat productions must have been truncated. For example, Ss with low heat production would not be expected to have a maximum of the function at the same value of $T_R - T_S$, as Ss with high heat production. Therefore, an experiment which averaged the performance of both kinds of S might not show any relation between target detection and air temperature. Interpreted in this manner, the optimum value suggested by Mackworth and Pepler must be viewed as an important confounding of air temperature with classes of individual differences. That this is possible is suggested by the results of Payne (1959) in which human performance in a perceptual motor task was found to be optimum at 55° F. and a similar kind of study by Teichner and Wehrkamp (1954) in which optimum performance was found at 70° F. Even allowing for some differences

in the nature of the tasks, both of these optima are well below that reported by Mackworth and Pepler. Further, if task differences are not allowed, the differences between the optima obtained by Payne (1959) and Teichner and Wehrkamp (1954) represent a large variation which might be due to the S-confounding. There is a need therefore for an investigation of the relationship between target detection and appropriate physiological measures of thermal states in various air temperatures. The obtained data should be analyzed both with the average of Ss and individual S performance. The present experiment attempted to meet this need using the thermal gradient $T_R - T_S$.

There is a considerable accumulation of evidence (reviewed by Ackner, 1956) that sudden unexpected stimuli induce peripheral vasoconstriction. Since the result of a peripheral vasoconstriction is an increase of the physiological thermal gradient, such stimuli theoretically should act as alerting signals and as such might have value as a means for offsetting temperature-produced vigilance decrements. A second major concern of the present investigation was to study this expectation.

Since the major variables of interest were air temperature and alerting by sudden stimulation, it was desirable to minimize, as much as possible, the effect

of other stimulus factors which influence target detection. This was accomplished by using a very high rate of signal presentation and a complex task which demanded continuous scanning behavior on the part of the S as noted above. Both of these conditions would be expected to result in a constant level of vigilance performance throughout the experimental session.

Statement of the Problem

The purpose of the investigation was to evaluate the effects of air temperature and sudden unexpected, "alerting" signals on target detection in a prolonged search task and to evaluate the results in terms of their relations to the physiological thermal gradient. The following predictions were made:

1. The apparent results will depend on whether the data are averaged over Ss or related to individual differences in Ss. On the basis of individual S analyses, some classes of Ss will show their best performance at low temperature and others at higher temperature. These effects may be lost by the averaging process.

2. Target detection will be related to $T_R - T_S$ by an inverted U-shaped function. The specific function and its maximum will vary within individuals.

3. The effect of unexpected alerting signals will be an increase in $T_R - T_S$ and the targets detected.

4. Changes in the number of targets detected during the vigilance session will be correlated with changes in $T_R - T_S$ during that session.

Method

Apparatus

The S performed in a controlled temperature chamber at different times under three thermal environments, a "cold" condition of 55° F., a "comfortable" condition of 75° F., and a "warm" condition of 105° F., all at 40% relative humidity. The normal effective temperatures were 53.5°, 66.5° and 89° F. E. T. respectively.

The stimuli consisted of 15 flashlight bulbs on the wall of the chamber arranged in 5 columns with 3 lights in each column. The columns were 4 feet apart and the distance between each row was 3 feet. The S was seated in a standard barber's chair 7 feet from the panel, directly in front of the third column. The stimuli were programmed automatically by a Western Union tape transmitter located outside the temperature chamber, and appeared in random order with a varied interval schedule ranging from 2.5 to 27.5 sec. with an average of one light every 15 sec. During each 15-min. period, each light appeared 4 times. The pattern was repeated every 15 min. or 4 times in the 60-min. experimental session. Each light remained on for 0.10 sec. The voltage to the lights was reduced to produce an intensity below the

peripheral, but above the central visual threshold. The S reported detected lights by pressing a hand-held button-type switch. Both S's responses and target occurrences were recorded on an Esterline-Angus event recorder located outside the temperature chamber.

The alerting stimulus was white noise presented to certain groups for 1-min. periods through earphones from a Grason-Stadler white noise generator located outside the temperature chamber. The audio output was 100 db. re 0.0002 dyne/cm.^{2} as measured at the earphones by a sound level meter.

The e.m.f. of two 26 gauge, copper-constantan thermocouples was recorded on a Minneapolis-Honeywell multi-point Electronik recorder located outside the temperature chamber. One of these thermocouples provided measures of S's left inner medial thigh. These measures were used as single-point estimates of mean body surface area-weighted temperature (Teichner, 1958). The other thermocouple provided measures of air temperature where S was seated. A Yellow Springs rectal thermistor probe was used as the transducer for rectal temperature. This was recorded on a pre-calibrated Esterline-Angus strip chart recorder.

Subjects

Twenty-four male Ss volunteered from the undergraduate student body at the University of Massachusetts. They were paid $12.00 for their services. The only requirement for the choice of Ss was that they had never served in any previous vigilance, temperature or noise experiments and that, to their knowledge, they had normal vision and hearing.

Procedures

A summary of the procedures and experimental design is presented in Table 1. The Ss were divided randomly into 4 groups of 6, each of which was presented the alerting stimulus at a different time. One group was presented 1-min. of white noise at the end of 30-min. of the experimental session. During this period, no targets were presented and the group was permitted to rest. Another 1-min. rest period was given at the end of 45 min. of the experimental session, only this time, no alerting stimulus was presented to this group. The other groups were permitted the same rest periods but differed only in the presentation pattern of the alerting stimulus. A second group received the alerting stimulus only during the second rest period, i.e., at the end of 45 min., while a third group received the 1-min. alerting stimulus, during both rest periods. The control group which received no alerting

Table 1

Summary of the experimental design

Days

Ss	1	2	3
2	55*	75	105
2	75	105	55
2	105	55	75

* Degrees Farenheit

Each of the 4 alerting-signal groups was exposed to this latin square arrangement.

stimulus during the rest periods, also wore earphones throughout each experimental session.

Each group experienced each temperature condition, one per day, on three consecutive days. The temperature conditions were presented to each group in a latin square arrangement forming a 3 x 3 matrix with 2 Ss in each group undergoing each sequence at each arrangement of the alerting stimulus. The Ss served individually. The search session was 1-hr. long and was preceded by a 20-min. equilibration period. The S had no time piece available while in the chamber.

The S was instructed to search the target area systematically. The actual instructions read to each S at the start of the experiment, are presented in Appendix A. On each of the remaining 2 days of the experiment, the S was reminded briefly of the nature of his task. After S was instructed, thermocouples were attached to his body, he was seated and told to rest. No activity was permitted during this period. The experimenter left the chamber during this equilibration period. An inter-com was used to notify S to start the search task. Each S was observed continuously by the experimenter through a one way window during each experimental session.

Results

Analysis of Grouped Data

The dependent behavioral measures were the proportion of targets detected in each of the 4 successive 15-min. repetitions of the signal presentation pattern. Table 2 presents the summary of an analysis of variance of the arc sine transformation of these measures. As this table shows, none of the conditions of the experiment significantly influenced the mean proportion of target detection.

To analyze the possible effect of the alerting stimuli further, the average thermal gradient of each S was plotted for the 2-min. periods preceding and following the occurrence of the signal. Inspection of these data did not suggest any systematic relationship between the value of the gradient and the presentation conditions of the signal.

Table 3 presents the summary of an analysis of variance performed on the quantity $T_R - T_S$. The dependent measure used was the difference between T_R and T_S recorded for each S at the end of each 15-min. period. The significant effects of temperature ($p < 0.01$) and temperature x time ($p < 0.01$) suggest that the physiological thermal gradient depended on both temperature

Table 2

Analysis of variance of the proportion of targets detected

Source of Variance	Sums of Squares	Degrees of freedom	Mean Square	F ratio
Total SS	28,222.05	287		
Between Ss Total	6,295.69	23		
Alerting Condition (A)	1,279.02	3	426.34	2.10
Pooled Sequences (Seq.) plus A x Seq.	2,582.87	8	322.86	1.59
Ss/A x Seq.[a]	2,433.80	12	202.82	
Within Ss Total	13,211.60	48		
Temperature (L)	124.92	2	62.46	0.36
Days (D)	97.83	2	48.91	0.28
A x D	5,594.88	6	932.48	2.69
A x L	470.78	6	78.46	0.22
Pooled Square Uniqueness (Sq. U.) plus A x Sq. U.	2,770.20	8	346.27	2.00
Ss x D/A x Seq.[b]	4,152.98	24	173.04	
Within Ss Residual Cells	8,714.76	216		
Exposure Time (T)	50.54	3	16.84	0.23
A x T	360.15	9	40.01	0.54
Seq. x T	79.03	6	13.17	0.18
D x T	297.44	6	49.57	0.97
L x T	170.82	6	28.47	0.56
A x Seq. x T	216.87	18	12.05	0.16

a Error term for A, Pooled Seq. plus A x Seq.
b Error term for L, D, A x D, A x L, pooled Sq. U. plus A x Sq. U.

Table 2 (continued)

Source of Variance	Sums of Squares	Degrees of freedom	Mean Square	F ratio
A x D x T	315.34	18	17.52	0.34
A x L x T	416.58	18	26.09	0.51
Pooled Sq. U. x T plus A x Sq. U. x T	422.74	24	17.61	0.34
Ss x T/A x Seq.[c]	2,642.52	36	73.40	
Ss x L x T/A x Seq.[d]	3,689.74	72	51.25	

c Error term for T, A x T, Seq. x T, A x Seq. x T.
d Error term for D x T, L x T, A x D x T, A x L x T, pooled Sq. U. x T plus A x Sq. U. x T.

Table 3

Analysis of variance of the physiological thermal gradient (T_R - T_S).

Source of Variance	Sums of Squares	Degrees of freedom	Mean Square	F ratio
Total SS	3,116.03	287		
Between Ss Total	165.24	23		
Alerting Condition (A)	28.34	3	9.45	1.12
Pooled Sequences (Seq.) plus A x Seq.	35.45	8	4.43	0.52
Ss/A x Seq.[a]	101.45	12	8.45	
Within Ss Total	2,882.75	48		
Temperature (L)	2,690.72	2	1,345.36	283.23**
Days (D)	3.18	2	1.59	0.33
A x D	21.14	6	3.52	0.74
A x L	27.63	6	4.61	0.97
Pooled Square Uniqueness (Sq. U.) plus A x Sq. U.	25.95	8	3.24	0.68
Ss x D/A x Seq.[b]	114.13	24	4.75	
Within Ss Residual Cells	68.05	216		
Exposure Time (T)	1.01	3	0.34	1.17
A x T	1.63	9	0.18	0.62
Seq. x T	0.66	6	0.11	0.38
D x T	1.02	6	0.17	0.52
L x T	9.67	6	1.61	4.88**
A x Seq. x T	4.18	18	0.23	0.79

a Error term for A, Pooled Seq. plus A x Seq.
b Error term for L, D, A x D, A x L, pooled Sq. U. plus A x Sq. U.
** $p < 0.01$

Table 3 (continued)

Source of Variance	Sums of Squares	Degrees of freedom	Mean Square	F ratio
A x D x T	3.08	18	0.17	0.52
A x L x T	6.87	18	0.38	1.15
Pooled Sq. U. x T plus A x Sq. U. x T	5.79	24	0.24	0.72
Ss x T/A x Seq.[c]	10.51	36	0.29	
Ss x L x T/A x Seq.[d]	23.63	72	0.33	

c Error term for T, A x T, Seq. x T, A x Seq. x T.
d Error term for D x T, L x T, A x D x T, A x L x T, pooled Sq. U. x T plus A x Sq. U. x T.

and its interaction with exposure time. None of the other experimental conditions were found to have had a significant effect.

Figure 1 shows the physiological thermal gradient at various search periods for each of the temperature conditions. It is evident that the size of the thermal gradient was inversely related to air temperature. In 55° F., the thermal gradient increased somewhat up to 45-min. and then showed a slight decrease during the final 15-min. of the experimental session. In 75° F. the thermal gradient was essentially constant throughout the experimental session. In 105° F., the figure suggests a slight decrease. The total range variation at 105° F. was approximately 0.25° C. and at 75° F., it was approximately 0.10° C. Since this range of variation is of the order of the sensitivity of the temperature-measuring equipment (0.20° C.), it cannot be given serious consideration. Similarly, the range of 0.70° C. in $T_R - T_S$ at 55° F., although presumably the source of the significant temperature x time interaction, cannot be given serious consideration as a source of differences in the temperature means. Thus, the most reasonable conclusion apparent from these results is that only temperature provided an important effect on the gradient.

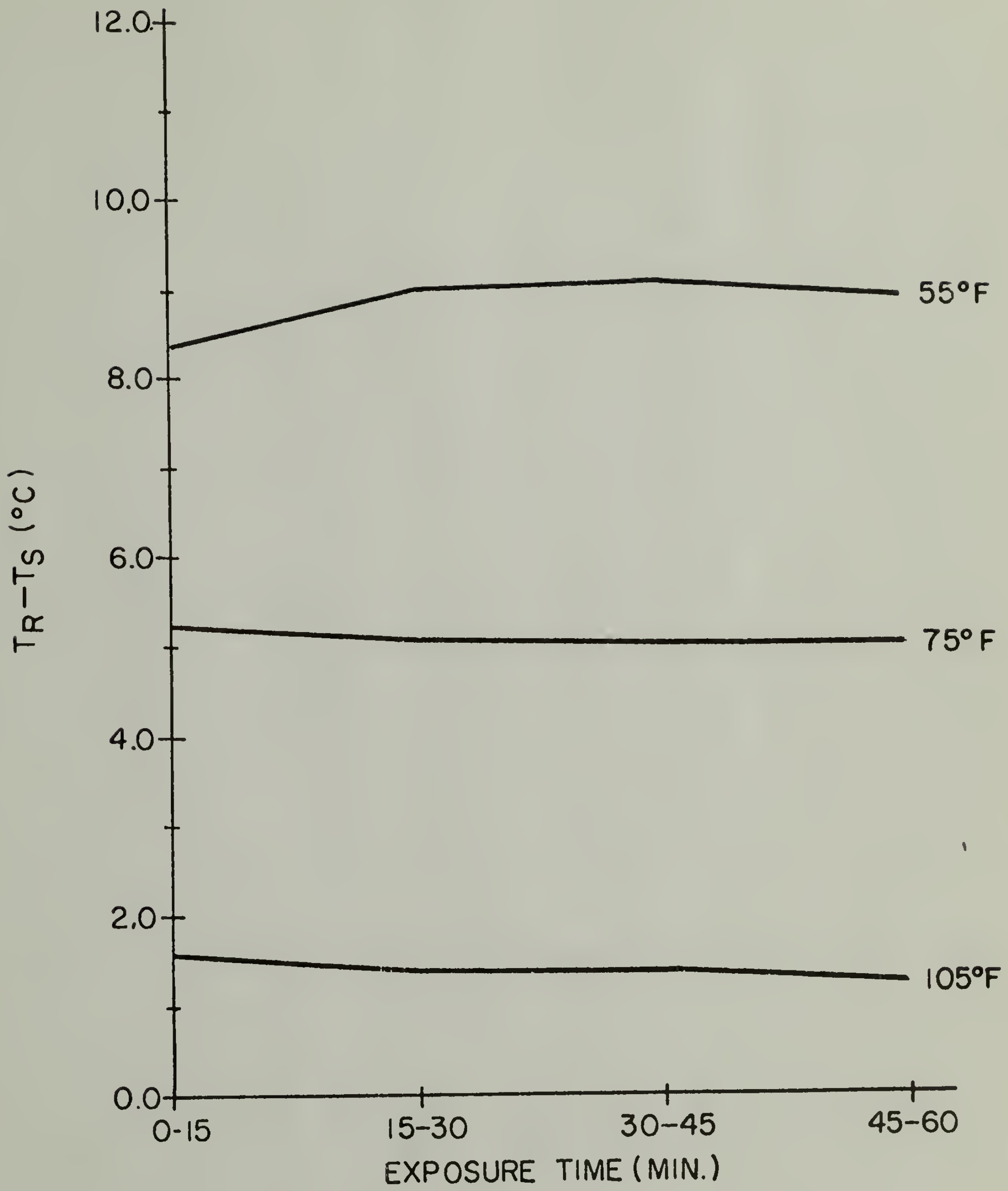

FIGURE 1. MEAN DAILY PHYSIOLOGICAL THERMAL GRADIENT (T_R-T_S) ON GROUPED DATA FOR EACH TEMPERATURE VS EXPOSURE TIME.

Analysis of Individual Data

Since target detection was found to be independent of the various experimental conditions, it was possible to analyze the data with respect to individual differences in target detection. To do this, each 15-min. period was treated as a random sample from the same population of performance measures for each S. This provided 12 measures of target detection for each S (four 15-min. periods within an experimental session and 3 replications represented by the 3 temperature conditions).

Following Walker and Lev (1953), an F-test of non-linear trend at the 0.05 level of risk was computed for each S on the relationship between $T_R - T_S$ and the proportion of targets detected. According to the results of these tests, the Rho coefficient was used to express linear correlations and the Eta coefficient to express non-linear ones. Table 4 presents a summary of the trends and correlations obtained. Of the 24 tests, 18 were linear and 6 curvilinear. Table 4 shows that of the 18 linear correlations, 10 were significant at $p < 0.05$ or less. Similarly, 5 of the 6 curvilinear correlations were significant; of these, 4 at $p < 0.01$. Also, it may be seen that 5 of the 10 significant linear correlations were negative. The binomial probability of obtaining 15

Table 4

Summary of correlations on individual Ss between target detection and the physiological thermal gradient ($T_R - T_S$).

Alerting Condition	Ss	Linear Correlations (Rho)	Non-linear Correlations (Eta)
	1	- 0.19	
	2	- 0.39	
Control	3	0.19	
	4	0.13	
	5		0.98**
	6	- 0.29	
	1	- 0.52*	
	2	0.74**	
30 min.	3	0.37	
	4	0.89**	
	5		0.95*
	6	- 0.58*	
	1	- 0.56*	
	2		0.92
45 min.	3		0.86**
	4		0.95*
	5	0.87**	
	6	0.16	
	1	0.59*	
30 and 45	2	- 0.62*	
	3		1.00**
	4	0.84**	
	5	- 0.64*	
	6	0.08	

* $p < 0.05$
** $p < 0.01$

significant correlations out of 24 occurring by chance at the 0.05 level of risk is $p < 0.0001$.

Figure 2 presents the significant linear and curvilinear correlations. With the exception of S-11, the range of the thermal gradient was approximately equal for all Ss. All curvilinear functions, including that of S-11 may be seen to display an inverted U-shaped function with a maximum target detection performance at a gradient value of approximately 6° C. S-11's data suggest a negatively accelerated increasing function not unlike one arm of the inverted U-shaped curve.

Figure 3 presents the relation between targets detected and exposure time with air temperature as a parameter for the 15 Ss shown in the previous figure. With the exception of the Ss who demonstrated a significant negative relation between target detection and $T_R - T_S$, no consistent relationship was evident for any given temperature condition as a function of exposure time. However, the trends obtained from 4 of those 5 Ss suggest a decreasing time function under exposure to 75° F. To evaluate this, using all 5 Ss, an analysis of variance was performed on the arc sine transformation of the proportion of targets detected under 75° F. As shown in Table 5, exposure time was significant ($p < 0.05$) which provides some support for the suggested trend.

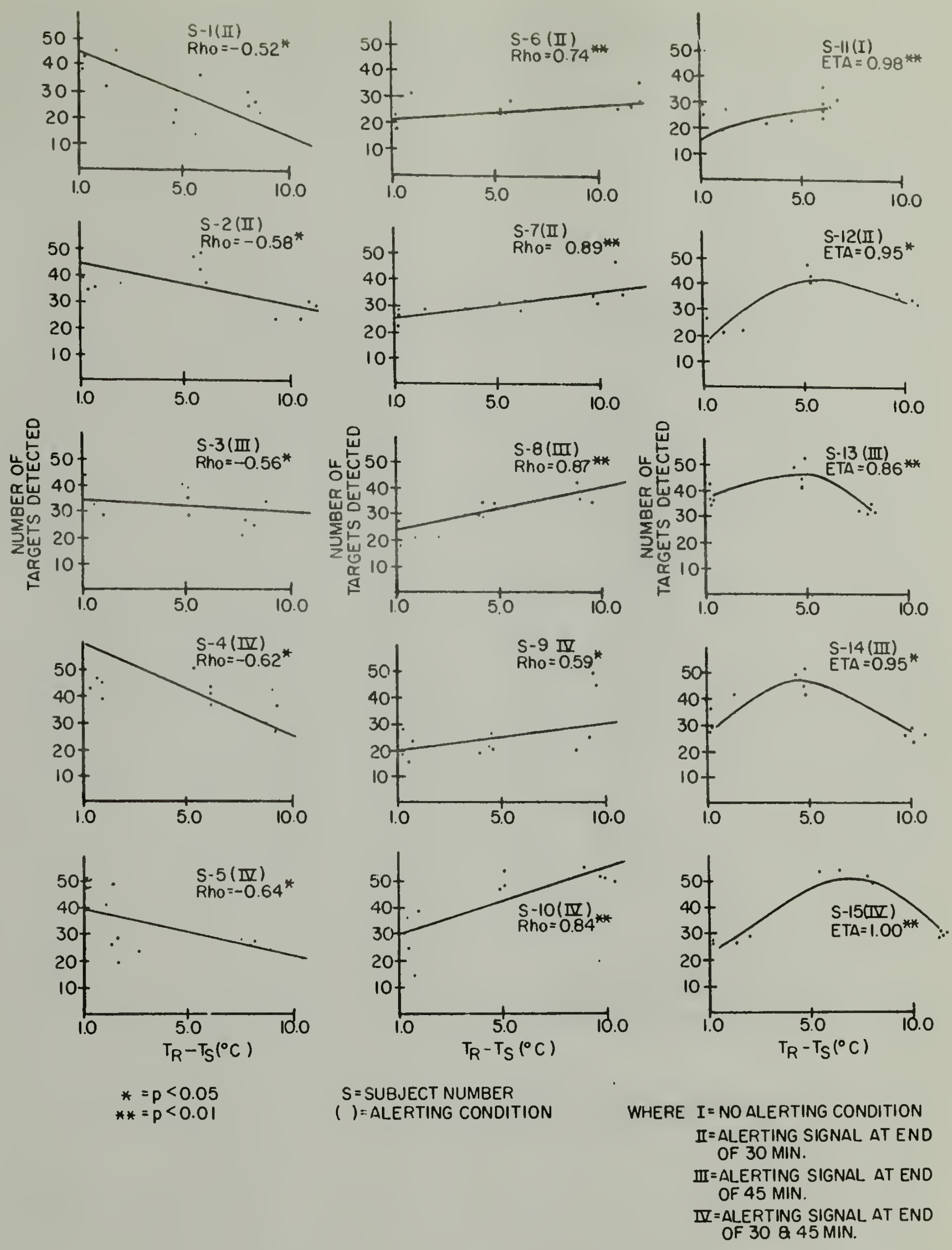

FIGURE 2. Significant Correlations Between Target Detection and Physiological Thermal Gradient (T_R-T_S) for Individual Ss

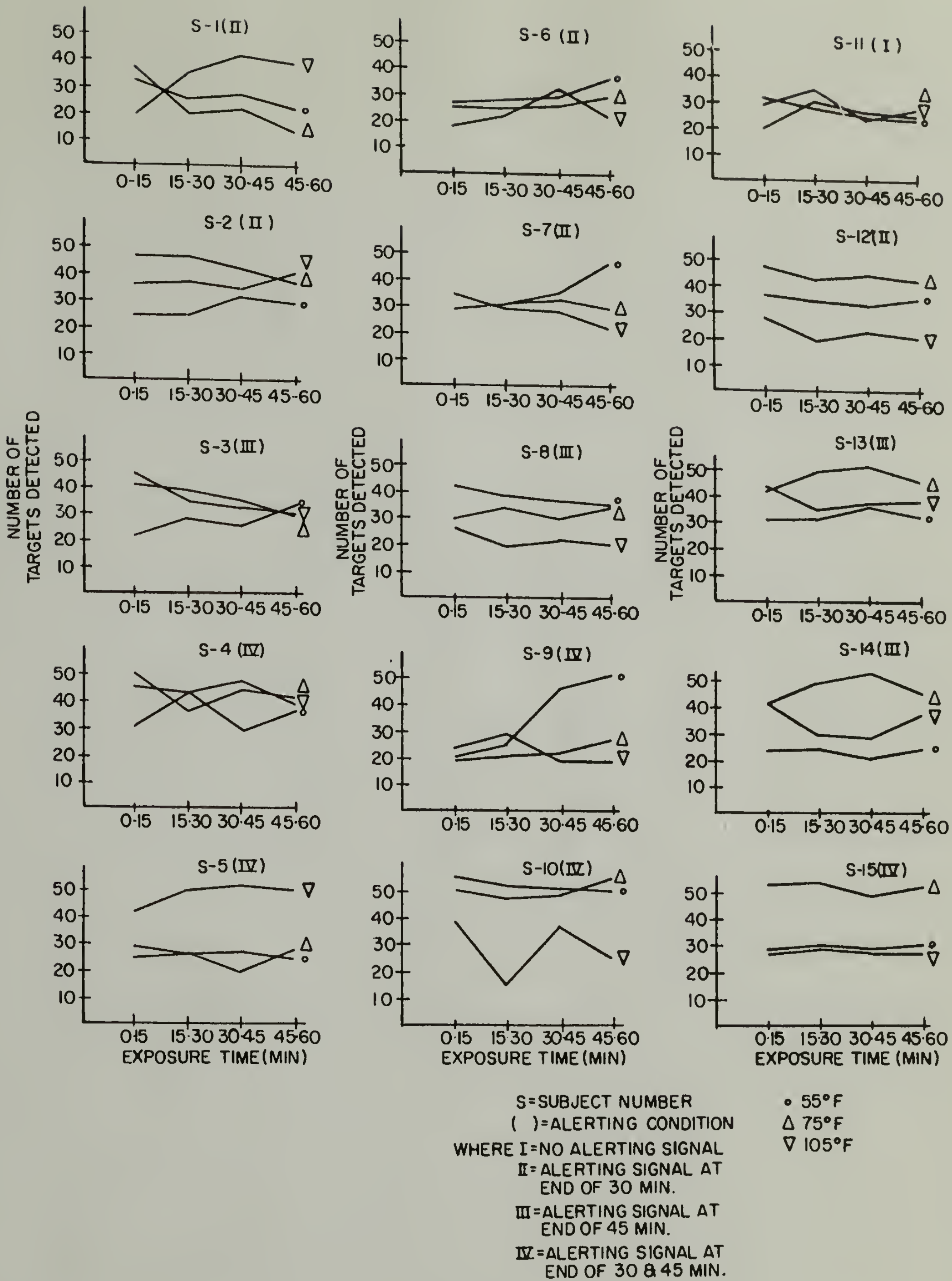

FIGURE 3 Significant Correlations Between Target Detection and Physiological Thermal Gradient (T_R-T_S) for Individual Ss Over Time With Temperature as a Parameter.

Table 5

Analysis of variance of target detection in 75° F. for Ss demonstrating a significant negative relation between target detection and the physiological thermal gradient ($T_R - T_S$).

Source of Variance	Sums of Squares	Degrees of freedom	Mean Square	F ratio
Total SS	2,083.41	19		
Exposure Time (T)	297.78	3	99.26	4.00*
Ss	1,487.50	4	371.87	14.97**
T x Ss[a]	298.13	12	24.84	

a Error term for T, Ss
* $p < 0.05$
** $p < 0.01$

Figure 4 shows the relationship between $T_R - T_S$ and the mean number of targets detected, averaged over the 5 Ss of each correlation group. It is evident for the curvilinear group that as the value of the thermal gradient increases, the mean number of targets detected increases and then decreases. The symmetry of this function is evident. Further, as the thermal gradient increases, the increase in mean target detection of the positively correlated group is approximately equal to the decrease in mean target detection of the negatively correlated group. That is, the slopes of the two straight lines are approximately equal, though different in sign. It may also be noted that the curvilinear function reaches a maximum at the center of the $T_R - T_S$ range and that the two monotonic functions cross slightly above the same point.

Since the various presentation patterns of the alerting stimulus are confounded within each of these 3 groups of Ss, the effect of the alerting stimulus must be analyzed on an individual rather than a group basis. Unfortunately, as Figure 3 shows, the number of Ss within each alerting condition for each of the three kinds of correlation-group was markedly and unevenly reduced. That figure also shows that among those few available Ss, no systematic alerting effect is apparent.

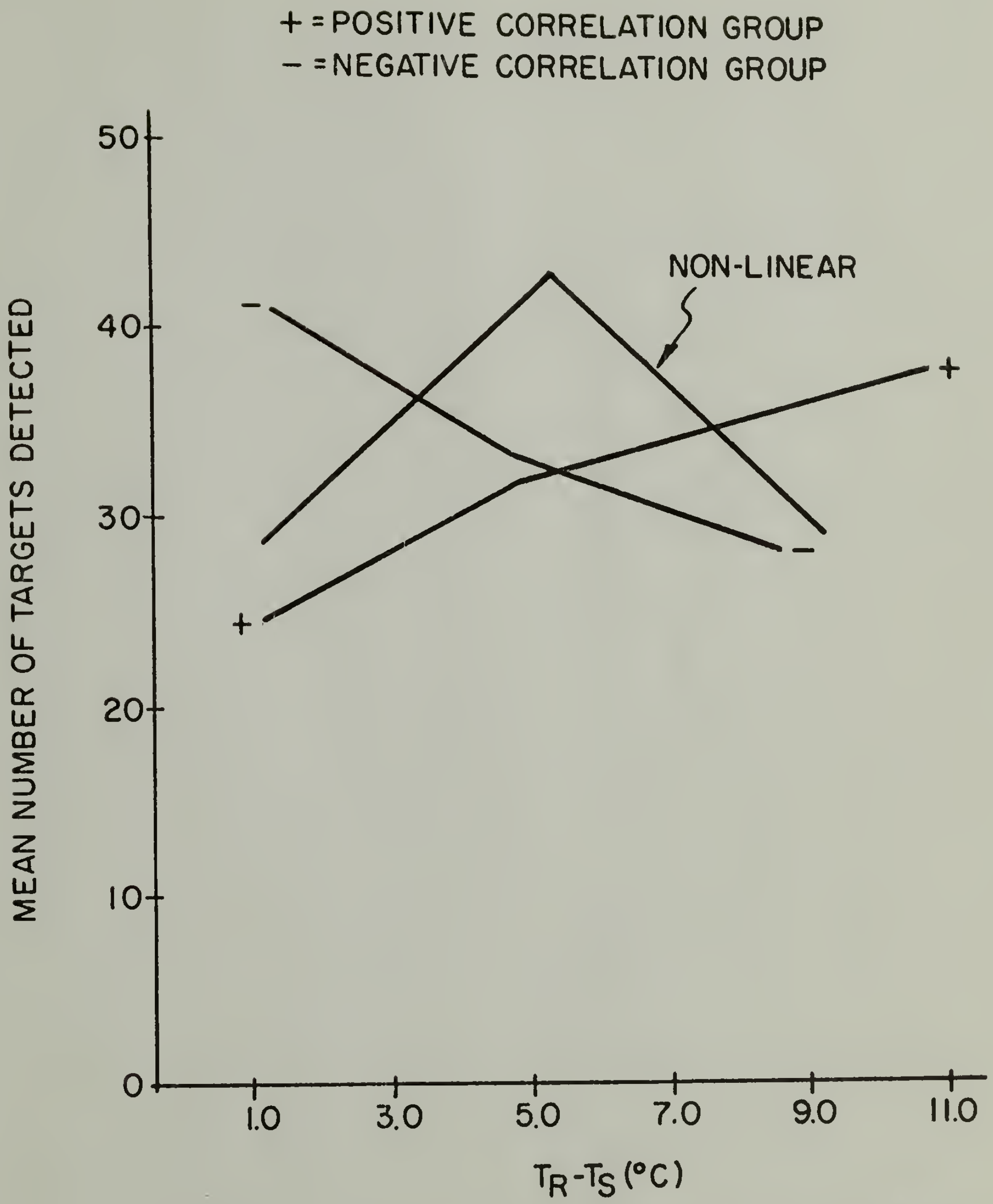

FIGURE 4. RELATIONSHIP BETWEEN MEAN NUMBER OF TARGETS DETECTED AND THE PHYSIOLOGICAL THERMAL GRADIENT ($T_R - T_S$) AVERAGED OVER 5 Ss FOR EACH CORRELATION GROUP.

An analysis of variance was also performed on the physiological thermal gradient obtained during each 15-min. exposure period to 75° F. to determine if the 3 groups of Ss demonstrated significantly different gradients when in thermal balance. Table 6, which summarizes this analysis shows that no significant difference in the thermal gradient was demonstrated.

Table 6

Analysis of variance of physiological thermal gradient in 75° F. for Ss demonstrating a significant relation between target detection and the physiological thermal gradient ($T_R - T_S$).

Source of Variance	Sums of Squares	Degrees of freedom	Mean Square	F ratio
Total SS	53.95	59		
Between Ss Total	44.69	14		
Correlation				
Groups (A)	4.61	2	2.31	0.69
Ss/A[a]	40.08	12	3.34	
Within Ss Total	9.26	45		
Exposure Time (T)	0.51	3	0.17	0.76
A x T	0.78	6	0.13	0.59
Ss x T/A[b]	7.96	36	0.22	

a Error term for A.
b Error term for T, A x T.

Discussion

On the basis of the experimental conditions studied, changes in the number of targets detected during the vigilance session, were expected to depend only upon variations in the thermal gradient during that session. Since, neither target detection nor $T_R - T_S$ varied with exposure time, this prediction could not be tested. The stability of the thermal gradient during the sessions indicates that constant thermal states were achieved and permitted comparison of temperature effects without having to consider a temperature x time interaction.

Noise as an alerting stimulus, was expected temporarily to increase the thermal gradient and thereby to produce a corresponding temporary increase in R-strength. The various noise exposures studied, resulted in no demonstrable long or short-term effect on either R-strength or the physiological thermal gradient.

Sadler (1961) has shown that adaptation to high intensity sound may be complete within 15-sec. Since the exposures of this study were 1-min. in duration, adaptation may have been complete well before the end of the exposure and thus any possible alerting effect reduced. Since, in addition, it was deemed necessary to use 2-min. measuring periods to obtain reasonable reliability in the

measures of target detection, the alerting effect might have been averaged out completely. Some evidence supporting this possibility may be found in a recent study by Teichner, Arees and Reilly (1963) which found that noise exposure data averaged over time tends to cancel the different effects present at different intervals of the exposure period.

When the data were averaged over all Ss, no correlation was demonstrated between target detection and the physiological thermal gradient. However, individual data analysis resulted in a significant relation between these measures. It is evident from the results that the Ss represented 3 populations, that is, a group which performed best in the lowest temperature, a group which performed best in the moderate temperature and a group which performed best in the high temperature.

If more extreme temperatures had been included in the experiment, the range of the thermal gradient would have been extended. Under these conditions, it seems reasonable to expect that the positively correlated group would have reached a maximum performance level at some high value of the gradient and that performance would have decreased at still higher values. Similarly, with decreasing and negative gradient values, the negatively correlated group might have become non-monotonic.

Such results would be consistent with the inverted U-shaped hypothesis even though the results suggest that the actual function and its maximum depend on other individual difference factors. According to Teichner (1963), the basis of these differences lies in individual differences in basal heat production and in the tendency toward continued peripheral vasoconstriction under stress.

Although there were 9 Ss who failed to yield significant correlations, the data from these Ss did suggest trends. Future studies should test a larger population in order to provide a more reliable definition of the dependence of performance on the thermal gradient. Such studies should also take measures of heat production into account.

The results of this study are promising, especially in applied situations, such as the monitoring of a radar screen, sky, sea, etc. They suggest that either the air temperature in which people work can be altered to permit an operator to perform at his optimum level, or if this is not feasible, that individuals can be chosen on the basis of the air temperatures in which they can best perform.

Summary and Conclusions

The purpose of this investigation was to evaluate the effects of air temperature and alerting signals on target detection in a prolonged search task and to evaluate the results in terms of their relations to the physiological thermal gradient.

Twenty-four Ss were exposed to air temperatures of 55°, 75° and 105° F. at 40% relative humidity under various presentation patterns of a 1-min. alerting signal. Consideration of the results suggests the following conclusions for the conditions involved:

1. Target detection correlates with the physiological thermal gradient for individual Ss. The correlation may be positive, negative or inverted U-shaped. As a result, best individual performance occurs at different air temperatures for different individuals. Thus, some people may be expected to perform best in low temperatures, others at moderate temperatures and still others at relatively high temperatures. There is no universally optimum air temperature.

2. As a consequence of the differing individual relations between target detection and the thermal gradient, target detection appears to be independent of the physiological thermal gradient and of air temperature when averaged over all Ss.

3. Alerting stimuli of the sort used have no effect on either target detection or the thermal gradient.

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Appendix A

Instructions read to each S

The task that you will perform in this experiment is very similar to tasks of radar detection in the military. You will please sit in this chair and face the panel in front of you. On the panel, you will notice a series of lights arranged in three rows and five columns. These lights will come on one at a time, in random order for a brief period of time. Your job will be to scan the entire display and when you detect a light that is on, push this button that you will be holding in your hand. (At this time, the experimenter showed S how to scan the display).

While you are performing this task, you will also be wearing this set of earphones. Sometime during the session, I will present you with a loud noise for a brief period of time. While the noise is on, you will just sit and listen to it. You will not have to scan the display as no signals will be presented during this time. When the noise is turned off, that will be your signal to resume your task of scanning the display. If you are told to "rest", just sit and relax until I tell you to resume your search. I will then say "end of rest". (The control group will be told "rest" and "end of rest" at the appropriate times of their rest periods.)

During the entire session, I will record your skin and rectal temperature. (At this point, the thermocouples were attached.) You will now please sit and relax so that your body may get accustomed to the air temperature. I will give you the signal over the intercom when to begin.

Do you have any questions before we start?

Appendix B

Number of targets detected per S in each 15-min. period

Temperature (° F.)

	55				75				105			
	Exposure time (min.)											
S	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
No alerting stimulus												
1	22	31	36	23	37	31	55	47	24	35	27	26
2	25	24	30	24	52	54	28	29	31	28	33	34
3	31	38	58	54	27	22	24	25	27	35	55	54
4	54	55	38	26	25	22	35	32	52	54	34	26
5	28	35	23	23	31	27	24	27	18	29	26	24
6	35	26	30	32	30	31	36	31	32	31	33	33
Alerting stimulus at the end of 30-min.												
1	31	25	27	22	36	19	23	13	32	45	42	38
2	26	27	29	36	24	24	25	28	17	22	31	21
3	39	37	43	40	28	31	33	25	26	32	34	31
4	34	31	35	47	28	31	32	29	28	29	27	21
5	36	33	32	35	47	41	44	42	27	19	21	20
6	24	24	30	28	47	46	42	36	35	37	34	39

Appendix B (continued)

	Temperature (° F.)											
	55				75				105			
	Exposure time (min.)											
S	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
	Alerting stimulus at the end of 45-min.											
1	21	27	25	34	40	38	35	28	44	34	32	29
2	32	27	27	31	35	25	31	36	22	29	30	30
3	31	31	35	32	41	48	52	45	43	34	36	37
4	23	24	20	25	41	48	52	45	41	29	28	37
5	42	38	36	35	29	34	29	34	27	19	21	20
6	37	30	44	44	29	23	22	30	35	37	34	39
	Alerting stimulus at the end of 30 and 45-min.											
1	20	25	45	52	19	20	21	26	23	28	17	18
2	30	43	27	37	50	36	43	41	45	43	47	39
3	29	30	29	30	53	54	49	52	27	29	26	26
4	55	52	51	50	50	47	48	54	38	14	36	25
5	28	26	27	24	24	26	19	27	41	48	51	48
6	38	35	42	48	42	42	48	48	41	41	41	49

Appendix C

Value of the physiological thermal gradient per S at the end of each 15-min. period

	Temperature (° F.)											
	55				75				105			
	Exposure time (min.)											
S	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
	No alerting stimulus											
1	7.64	7.38	7.22	7.30	2.38	2.32	1.80	2.18	1.36	1.06	1.28	1.44
2	7.72	8.12	8.80	8.72	5.48	5.52	5.50	5.02	2.18	1.34	1.56	1.76
3	7.42	7.60	7.50	5.98	4.96	4.86	5.02	5.06	0.98	1.08	1.18	1.32
4	8.24	9.28	9.18	8.98	5.46	5.98	5.74	5.90	1.50	1.02	1.36	1.16
5	5.72	5.92	4.76	3.64	6.52	5.94	5.84	5.88	1.80	1.06	2.20	1.08
6	9.08	9.64	9.76	9.34	5.58	5.56	5.62	5.66	1.08	0.70	0.80	1.96
	Alerting stimulus at the end of 30-min.											
1	8.50	8.62	8.98	9.02	5.74	4.68	4.86	5.50	2.20	2.62	1.38	1.22
2	10.80	11.32	11.60	11.66	5.30	5.46	5.36	5.66	1.24	0.98	1.80	1.20
3	6.04	6.90	6.22	6.20	6.24	5.60	2.78	4.94	1.04	0.98	0.98	0.96
4	8.90	9.90	10.82	10.64	5.96	5.16	6.28	3.86	2.38	1.28	1.00	0.86
5	9.72	10.40	10.56	9.88	5.22	5.34	5.32	5.50	1.26	1.38	2.70	1.98
6	9.52	10.50	10.90	11.02	5.64	5.34	5.78	5.86	1.66	2.50	1.48	1.26

Appendix C (continued)

	Temperature (° F.)											
	55				75				105			
	Exposure time (min.)											
S	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
	Alerting stimulus at the end of 45-min.											
1	7.10	7.36	7.60	8.30	4.94	5.16	5.10	5.24	1.24	1.40	1.52	1.82
2	8.26	9.58	10.12	10.00	6.44	6.72	6.42	5.70	4.72	2.22	2.06	0.56
3	7.40	7.86	7.68	7.14	4.84	4.50	4.90	4.88	0.70	0.58	0.68	1.16
4	10.22	11.62	13.24	12.38	4.84	4.51	4.88	4.86	2.10	1.06	1.06	0.96
5	9.02	9.24	9.24	9.76	4.32	4.44	4.44	4.90	1.26	1.38	2.70	1.98
6	8.40	9.42	10.18	10.68	6.16	6.10	6.00	5.96	1.66	2.50	1.48	1.26
	Alerting stimulus at the end of 30 and 45-min.											
1	8.94	9.42	9.76	9.52	4.28	4.76	4.64	4.64	1.26	0.94	0.94	0.76
2	8.02	8.34	8.34	8.42	5.32	5.94	5.92	5.90	1.76	1.34	1.62	1.84
3	10.94	11.76	11.84	11.56	5.34	6.22	7.42	7.34	1.72	2.64	1.28	1.22
4	9.28	9.84	10.08	10.38	5.12	4.98	5.16	5.14	1.72	1.64	1.44	1.40
5	7.06	7.82	8.50	9.12	3.24	2.24	2.40	2.48	1.88	1.06	0.98	2.20
6	9.26	9.66	9.74	9.84	6.42	6.14	6.26	6.02	1.98	1.78	1.98	2.04

A P P R O V E D

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Date: May 24, 1963