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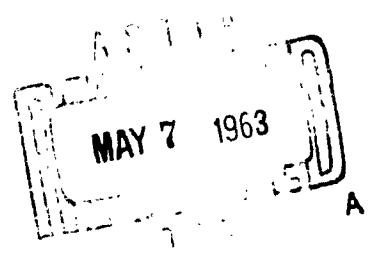
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MEASURING PERFORMANCE CHANGES IN HIGHLY TRANSIENT EXTREME HEAT STRESS: RATIONALE, PROBLEM, AND EXPERIMENTAL PROCEDURES

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Biomedical Laboratory
6570th Aerospace Medical Research Laboratories
Aerospace Medical Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio



Contract Monitor: William C. Kaufman, Maj., USAF
Project No. 7222 — Task No. 722204

[Prepared under Contract No. AF 33(616)-6763
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FOREWORD

This report was prepared under the terms of Contract No. AF 33(616)-6763, Project No. 7222, "Biophysics of Flight", and Task No. 722204, "Human Thermal Stress". The study was initiated by the Biomedical Laboratory of the 6570th Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, with William C. Kaufman, Major, USAF of the Biothermal Section, Biophysics Branch, Biomedical Laboratory, as contract monitor. The study was made in the Biotechnology Laboratory of Engineering, University of California, Los Angeles, by Dr. Hilde Groth and Dr. John Lyman. L. M. K. Boelter is Chairman of the Department of Engineering and P. F. O'Brien acts as his representative for research activities. Dr. Lyman is the Project Leader for research under the above contract.

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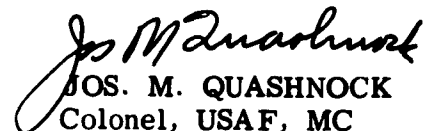
ABSTRACT

A review of the existing state of the art for handling human performance under transient heat stress has been made. It was concluded that it would be necessary to develop a new methodology based on "micro-performance" measurements to assess severe localized transient heat stresses as relevant to contemporary flight problems.

The test procedure proposed is based on the rationale that a primary task with difficulty that can be varied according to subject error in order to maintain a relatively constant subject performance level can be used as a measure of the moment-to-moment perceptual load. In addition to the primary task, secondary tasks have been suggested to help simulate problems in decision-making and verbal communication.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.


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INTRODUCTION: OBJECTIVES AND RATIONALE

Transient high temperature overloads may impinge on man in space vehicles, high performance aircraft, and aircraft flying in the vicinity of thermo-nuclear explosions. Under such conditions, both physiological and psychological stresses detrimental to man's performance will be created. (17)

Heat stress can be expected to affect the various body parts with different degrees of severity, depending upon the type of the heat source and the type and amount of clothing worn by the operator. Therefore, it is necessary to assess the effects of localized heat exposure on human performance as well as those performance effects attributable to total body exposure.

This report is concerned only with the problem of measurement of thermal stress effects which cannot be tolerated for durations longer than a few minutes and which are too transient to contribute significantly to overall body heat storage. The performance changes of interest are those that may be related primarily to local pain, anxiety, distraction and startle responses rather than to physiological problems of heat exchange between the organism and its environment. It is assumed that the exposure time for any given intensity of the thermal stimulus will remain below a level which could inflict serious tissue damage.

Tolerance times to aerodynamic heating transients have been determined experimentally by Webb. (42) He found that pain was reported when the intra-dermal thermocouple registered about 115° F; a finding which was consistent with results of other investigators.

In order for a testing procedure to have maximum utility it must have satisfactory sensitivity, validity and reliability. Also it should be versatile enough to serve as an instrument for making multivariate performance analyses as well as represent a practical training device. The importance of the latter function for familiarization programs has been discussed by Eckstrand and Rockway. (14)

For highly transient conditions the device must be capable of measuring "micro-units" of performance in order to adequately assess both immediate and more lasting changes of human output. Another requirement includes a capability to permit a nearly continuous change in task demands and load on the data processing ability of the operator corresponding to "rest" situations and enabling assessment if there are relevant changes in performance.

The task necessarily must reflect those aspects of operator performance which are considered most important to be maintained at a high level of proficiency during thermal stress conditions and which often have extremely small permissible tolerance limits. Such performance includes vehicle guidance and control, decision-making based on integration of current and stored information and the necessary motor output to accomplish a chosen action.

In-flight activities of the astronaut have recently been discussed by Voas. (40, 41) They can be summarized as follows:

1. Continuous monitoring of all sub-systems
2. Monitoring of 'critical events' during launch and re-entry
3. Attitude control of vehicle
4. Ground and astronavigation
5. Ground communication
6. Research observations

Since unexpected heat stress could demand an immediate mission abort action, the astronaut would be faced with the very difficult attitude control task consisting of a three-dimensional tracking problem. This would mean that environmental stress, task stress and task load will all coincide and be accompanied by a high level of motivation, namely to achieve a personally safe return. This situation has been described by Fitts⁽¹⁷⁾ as follows: "One of the most critical aspects of this flight is the maintenance of proper vehicle attitude during retrorocket firing. . . . The present design of the rocket system produces a very high information rate for a period of about thirty seconds, a rate which may come close to exceeding the human tracking ability. . . ." (p. 314).

Similar conditions will obtain also for the conventional aircraft pilot in the vicinity of an atomic blast. His task requirements may be somewhat simpler, but he also will experience task and environmental overloading at an instant when he must make vital decisions. The complexity of pilot decision-making in a modern airborne weapon system has been analyzed and presented in diagrammatic form by Williams and Hopkins.⁽⁴⁵⁾

The preceding considerations will both guide and delineate the scope of this study. Emphasis is placed upon the evaluation of available measurement techniques for physiological and performance variables and their appropriateness for the specified conditions.

AN EVALUATION OF THE CURRENT STATUS OF PERFORMANCE RESEARCH UNDER HEAT STRESS

None of the studies prior to the past five years have employed heat stress conditions similar to those described in the objectives for this study. Experimentally applied thermal stresses were less severe but exposure was generally for prolonged periods of time. The tasks ranged from simple motor tasks to highly complex mental functions and emphasis was placed most often upon discovering a relationship between changes in physiological variables and simultaneous changes in performance.

In order to obtain a valid indication of the detrimental effects of heat stress on performance, these effects should be treated as a time-intensity relationship. Historically, this point has often been overlooked, as for example in the classical study of Viteles and Smith.⁽³⁸⁾

Measurements of physiological changes such as body core temperature or various physiological indices based on several parameters (for example the Craig Index) have generally shown very low correlations with the time-history of performance change. A thorough analysis of these early studies has been made by Lyman⁽²⁸⁾ and will not be discussed here in greater detail.

The indirect relationship which is repeatedly found between physiological variables and performance raises the question as to what actually constitutes a 'thermal stress' if performance change is the criterion. Early work showed performance deteriorations for light and relatively simple psychomotor tasks at an effective temperature of around 86° F for exposures of several hours.⁽³⁹⁾

Later Pepler found in his studies at Singapore^(34, 35) that performance of simple and complex tasks of tropically acclimatized men deteriorated in experimental climates which differed as little as $\pm 5^{\circ}$ F from the usual ambient temperature of 81° F.

When introducing incentives, for example verbal encouragement and performance information, Pepler found that such incentives could offset the climatic effects. For instance, he found the level of performance in the least favorable climate under high incentives was as good as that in the most favorable climate under standard conditions. Extrapolation of this trend to extreme heat stress and probably the highest level of motivation, i. e. self-preservation, is of course not warranted.

Studies by Lyman⁽²⁸⁾ under much more severe conditions (exposures to 160°, 200° and 235° F) failed to show any pronounced effect on mental and psychomotor performance until a few minutes before the subjects reached their individual limit of tolerance. Each subject retained his relative level

of competence under heat stress, but individual differences were found in the time course of performance deterioration.

Only a relatively small number of more recent pertinent studies are available, but several facts emerge from these which seem to have a direct bearing on the present study.

Buettner⁽⁵⁾ reports that exposure of the face to slightly moving air with temperatures between 392° to 482° F could be endured without injury for short periods of time because of the secretion of a sufficient amount of perspiration. Subjects reported unbearable pain when unprotected skin was exposed to calm dry air of more than 284° to 320° F. However, if the skin had been soaked with sweat prior to radiant heat exposure, tolerance time for exposure to 392° F could be extended to 2 to 3 minutes. The pain threshold seemed to correspond to a skin temperature between 107.6° F and 113° F; it seemed to be independent of body location. Similar results were also reported by Webb⁽⁴²⁾ and the duration-intensity dependency was demonstrated: "Exposure to slow heat pulses with slopes ranging from 15° F per minute to 100° F per minute with nude subjects resulted in intolerable pain at temperatures between 325° F and 400° F. The faster the rate of temperature rise, the higher the temperature which could be tolerated. A lower maximum temperature was tolerated at the slow rates" (p. 60). Nasal breathing discomfort was reported at 260° F. At 300° F air temperature, mouth breathing also became uncomfortable.

Recent investigations of performance deterioration generally deal⁽⁹⁾ with very simple tasks or with less severe heat stress. Crocker and Waitz reported discriminative visual reaction times during exposure to 400° F thermal transients (peak wall temperature). Reaction time (RT) was measured about every 20 seconds for 12 minutes prior to exposure and during the heat exposure. RT showed an immediate sharp increase which reached a maximum after 3 minutes in the heat.

The effects of heat stress on serial reaction time and arm steadiness have been investigated by Peacock⁽³³⁾ in a field test. Subjects were exposed to desert temperatures between 97.2° F and 111.2° F. No changes in vertical or horizontal tremor were found, but a problem in methodology precluded an unequivocal interpretation of the reaction time data.

A similar lack of performance change for anagram solutions and auditory discriminations was observed by Fine and collaborators⁽¹⁵⁾ when subjects were exposed to the following ambient dry bulb/wet bulb temperatures with minimal wind: 70°/53° F, 70°/68° F, 95°/70.5° F, 95°/92° F. Chiles⁽⁸⁾ administered a paced visual discrimination task at five dry bulb/wet bulb temperature combinations: 85°/75° F, 90°/80° F, 110°/90° F, 120°/90° F, 120°/105° F. All subjects were acclimatized for 30 minutes prior to testing and the total time in the climatic chamber was approximately one hour. No

significant performance decrement was found. A change in the errors committed was found only under the extreme condition (120°/105° F). Profuse sweating may have interfered with vision at this temperature.

Carlson⁽⁷⁾ utilized a vigilance task as an index of strain during exposures of 1, 2 or 3 hours to 68°, 77° and 122° F and relative humidity of less than 20 percent. Simultaneously, he recorded the physiological strain as reflected in rectal temperature, weight loss, pulse rate and changes in skin resistance (GSR). The vigilance task consisted of a simulated radar-watching situation in which the subject indicated signal detection by pressing the spatially corresponding response button. Two levels of input rates were administered: 2 bits/sec. and 8 bits/sec. Also, the subjects rated their "feeling state" on a five category scale.

Performance scores seemed to corroborate a "limited channel capacity" hypothesis. For low signal input rates, little change or slight facilitation of performance was found at higher temperatures. For the high input, errors were found to increase at high temperatures. No detailed analysis of the data over exposure time was presented, but a diagram of individual records⁽⁷⁾(p. 11) shows considerable fluctuations in the "time to recognize signals" over the experimental session and wide individual differences for performance errors.

Skin resistance decreased at higher temperatures and the number of non-specific responses increased as would be expected with an increase in sympathetic neural activity. Little relationship between performance and subjective judgments of alertness was found.

In summary, this short review of the state of the art highlights the following areas that require further research:

1. Performance changes have been assessed in "macro-units" which preclude an evaluation of the effects of transient thermal changes. Results averaged over longer time intervals and/or over subjects may smooth out significant short duration changes.
2. Complex performance has only been measured during long duration exposures and no information on the disruptive effect of transient stress is currently available. There does not seem to be any justification for extrapolating results obtained from thermoregulatory heat stress studies to those in which the stress will primarily evoke pain, fear, and anxiety.

3. None of the studies were extensive enough to permit evaluation of a critical level of "mental" complexity at which performance under stress deteriorates.
4. Tasks employed were often arbitrary and do not seem related to the basic abilities necessary to maintain the pilot's or astronaut's task within specified tolerance limits.

EXPECTED PHYSIOLOGICAL STRESS EFFECTS

Any systemic stressor of adequate intensity and duration will activate the stress syndrome as postulated originally by Selye.⁽³⁷⁾ This syndrome consists of specific regulatory effects such as reflex vasodilation for heat stimuli and general neuroendocrine response changes. It has been shown repeatedly that the same neuroendocrine effect can also be evoked by psychogenic stimulations like fear and anxiety⁽¹⁾ without any apparent external stimulation. Stress is assumed to change the autonomic balance toward a predominance of sympathetic activity and will be reflected by high palmar conductance.⁽⁴³⁾ Palmar conductance also reflects the level of wakefulness of an individual and shows a certain degree of relationship to vigilance performance.⁽¹¹⁾ Since it is a continuous measurement, it seems to be a possible index of stress for a future study. An increase in muscle tension is another manifestation of a high level of activation, and it also can be monitored continuously.⁽³⁰⁾ However, the tension increase may be general or be localized in a specific muscle which may vary from subject to subject. Malmo reports on a vigilance study: "One muscle area, a different one for each S, showed significant rise in tension over the vigil. It was the neck muscles in one S, the forehead in another, and the biceps muscle of the right arm in the third."^(30, p. 383) Such variability necessitates EMG monitoring from several areas of the body.

Direct measurement of skin temperature is, of course, indispensable in order to assess the relation to pain and avoidance responses which may interfere directly with performance. It is also a safety measure in a laboratory experiment. In a recent study by Kaufman, Swan, and Davis⁽²⁴⁾ bare forehead skin temperatures up to 126° F and skin temperature of the cloth-protected knee of 104° F were reported. Maximum forehead skin temperature was attained in about 3 seconds after stimulus onset, maximum knee skin temperature in about 4.5 seconds.

Breathing rate and cardiac responses alter as a direct reflex response to heat stress and indirectly to anxiety and fear. In either case, they may be related to impeded performance and can serve as a useful index of individual stress levels.

The complexity of the cardiac response to electro-shock-induced anxiety has been investigated by Deane⁽¹²⁾ who found that expectation of a noxious stimulus of unknown severity will induce tachycardia a relatively long time before the stimulus is expected. If, however, the subject expects the stimulus at a particular instant in time, fear will be associated with bradycardia immediately prior to stimulus onset and during stimulation.

Apparently, long-term anxiety and acute fear can sometimes be successfully distinguished by the differential cardiac response.

Experiments assessing only the cardiac regulatory response to heat stress without accompanying fear and/or anxiety show a gradual increase in heart rate with increased body heat. Exposure to approximately 122° F ambient temperature causes only very slight acceleration during the first 10 minutes of exposure.⁽¹⁹⁾ For our purposes, where body heat storage will not be a variable, the cardiac response should provide an index of anxiety and fear.

EXPECTED PSYCHOLOGICAL STRESS EFFECTS

Sensations of heat and pain and the emotional responses of anxiety and fear can be expected to be psychological stress effects that are potentially detrimental to performance. Impending death, bodily harm and extreme pain are generally accepted conditions leading to fear⁽²⁶⁾ and these same "threats" are also expected to accompany transient heat stress in the operational situation.

Schaffer⁽³⁶⁾ discussed in detail the characteristics of behavior under stress and arrived at the following conclusions:

1. There will be a change in rate and range of activity depending on whether the stress elicits excitatory or inhibitory behavior.

- a. Change in rate of activity:

The excitatory type is considered to be more common and "... behavior is greatly speeded up and disorganized, and the fine adjustment of reaction to stimuli found under normal circumstances is lost."^(36, p. 324) In the inhibitory type, slowing down of motor responses, decreased sensitivity, and, in the extreme case, cataleptic-like complete immobility may ensue.

- b. Change in range of activity:

As in a neurosis, under stress, behavior shows a great reduction in directed or adaptive variability and responses become narrowed down and stereotyped. "Failure to benefit from previous experience and the tendency to persist within a narrow range of responses are thus further characteristics of behavior under stress."^(36, p. 325)

2. Changes in the learning process under stress may show the following characteristics:

- a. An increased rate of acquisition of certain responses
 - b. Persistence of stereotyped responses without reinforcement.
 - c. Acquisition and retention of unadaptive responses.

Sensory overloading represents a second area leading to psychological stress and concomitant performance changes. If the human operator is considered a communication system with limited channel capacity, the operator under stress has been found to develop some protective defense mechanisms. Miller⁽³²⁾ summarizes the basic defense mechanisms which are employed by biological systems against the stresses of information overload as follows:

"OMISSION, which is simply not processing information whenever there is an extreme of overload;

ERROR, which is processing incorrectly and then not making the necessary adjustment;

QUEUING, which is delaying responses during peak load periods and then catching up during lulls;

FILTERING, which is systematic omission of certain categories of information, according to some sort of priority scheme;

APPROXIMATION, which is an output mechanism whereby a less precise or accurate response is given because there is no time to be precise;

MULTIPLE CHANNELS, parallel transmission subsystems that can do comparable tasks at the same time and consequently handle altogether more information than a single channel can transmit alone;

DECENTRALIZATION is a special case of this, and finally there is

ESCAPE, which is leaving a situation entirely or taking any other steps that effectively cut off the flow of information."^(32, p. 222)
In any given situation, some of these mechanisms will be less adaptive and more detrimental to overall system performance than others and the particular strategy employed may vary from one situation to another as well as be different for different people. Research on consistency and the amount of variability in using these defense mechanisms is still lacking. In the transient situation under discussion here the problem is even more ill-defined, and yet at least a partial understanding appears to be central to establishing realistic performance assessment.

CURRENT STATUS OF MEASUREMENT TECHNIQUES FOR QUANTIFICATION OF STRESS EFFECTS

A major problem in measuring stress effects is to establish a stable base line for the selected variable so that deviations from it can be a representative measure of the imposed stress effects. This means that a reference point for each individual subject must be established and careful attention given to extraneous learning and fatigue effects. The pitfalls in the measurement of stress effects and the sometimes seemingly conflicting experimental results have been discussed by Lazarus and colleagues.⁽²⁷⁾ In 1951, these investigators concluded: "Research in the area of psychological stress must begin practically afresh. Any systematic program must take into account the difficulty of producing realistic stress situations and making effective measurements of the stress effects which are independent of the skill required by the task itself."⁽²⁷⁾ Although another 11 years have passed and the technological aspects of measurement techniques have been vastly improved, the status of stress research has not changed significantly. More empirical data have been accumulated but many of these measurements are still open to criticism; prediction on an individual basis at present remains virtually impossible. It appears to the authors that stress effects cannot be divorced from the skill decrements to which the stress is relevant. The "micro-behavior" approach as described in this report is proposed as a direction for developing the necessary information to resolve some of the difficulties.

I. Physiological Indices of Strain

Palmar skin conductance has proved to be the most widely used variable in studies dealing with concomitant autonomic changes to stress, and it seems to be a sensitive indicator of the level of individual tension or activation. Best performance has usually been obtained at a moderate level of activation, although exceptions have been reported.⁽³²⁾ The general relation of skin conductance to performance proficiency can be described by the U-hypothesis. Malmö⁽³⁰⁾ suggested the following working hypothesis for prediction of stress effects on performance:

		<u>Activation Levels</u>		
		Low	Moderate	High
<u>Expected Performance Levels</u>		Low	Optimal	Low

A major disadvantage of this measure is the wide variability of basic conductance patterns among individuals and that each record must be treated independently.⁽¹¹⁾

Care must be taken to differentiate between in-task variability of conductance changes as described by Kling and Schlosberg⁽²⁵⁾ and those due to the specific stressors employed. Also the occurrence of non-specific responses without an identifiable external stimulus may easily contaminate the records. Therefore, an analysis must include not only the change in conductance level but also any changes in the frequency of occurrence of non-specific responses.

The shortcomings as well as the utility of this measurement for monitoring psychophysiological responses in laboratory situations has been adequately described by Johnson et al.⁽²³⁾ Under well-controlled conditions, changes in level of skin conductance and changes in response patterns have proved to serve as a valid index of stress. Further advantages are that these fluctuations can be recorded continuously, and the apparatus can be designed for any level of desired sensitivity. Reliability must be empirically established; reports on repeatability of GSR records vary, and it is generally not possible to identify the probable causes for the obtained variability.

Changes in muscle tension, as measured by the changes in strength of the muscle potential, also represent a favorite index of psychophysiological stress. However, direct sympathetic innervation of skeletal muscle apparently still lacks positive histological proof. Bartley and Chute⁽³⁾ report several studies which showed that stimulation of the sympathetic system prevented diminution of muscle tension, and if this stimulation follows intermittent somatic stimulation, the tension already developed will be augmented. As discussed in a previous section, this increase in tension may be general or localized and its locus may vary between individuals. To obtain a representative index, multichannel recording seems imperative. Use of inexpensive low mass electrodes⁽³⁸⁾ should facilitate multichannel surface recording.

A major drawback of this method is the possibility of confounding tension increases due to stress with those due to the motor activity of the specific muscle. If the stress-induced tension is localized and this locus also corresponds to a muscle actively engaged in a motor task during the stress period, it will be impossible to partial out the differential components producing a particular EMG pattern.

Although an inverse relation between response latency and muscle tension has been reported,⁽¹⁶⁾ methodological problems as discussed above may render such inferences invalid in a dynamic situation.

Psychologists have studied the relationship between skeletal muscle tension, mental processes and emotional states for at least 100 years.

Exaggerated emotional states such as might be expected to occur under postulated operational conditions of this study have found to increase the frequency and amplitude of recorded muscle potentials. But again, these measurements have usually been taken on muscles not involved in simultaneous movements and quite often the recordings have been obtained from a motionless subject.

In short, although it seems possible to assess the importance and severity of environmental and task stress by electromyographic recordings during task performance, the difficulties of obtaining valid and reliable records seem rather great at present. Much more basic research seems necessary before this measure can be properly assessed as a stress index related to psychomotor performance.

The sensitivity of EMG can be easily adjusted to the specific aims of the investigation. Adjustment of the integration interval and the particular type of smoothing function employed for conversion of the highly irregular data into a more meaningful pattern are well known aids for facilitation of interpretation.

Continuous measurement of surface or intradermal skin temperature at key body locations is required throughout the testing period in order to provide the experimenter with immediate data concerning possible tissue damage. Additionally, these data will serve for establishing individual correlations to pain and associated emotional responses as well as their direct relation to detrimental motor reactions, as, for example, undesired withdrawal responses or a generalized agitation. Since temperature is the only direct measurement of the severity of the environmental stressor impinging upon the biological system, it becomes imperative to obtain an immediate reliable record of the distribution of instantaneous temperatures over the body surface. The utility of this measurement depends most heavily upon the quality and response characteristics of the sensing element and the recording equipment.

Continuous monitoring of pulse rate as an easily obtainable measure of the cardiac response will serve again as a safety precaution. It also is intended to shed additional light on its possible utility for distinguishing general anxiety and acute fear in an operator and relating it to possibly different performance responses associated with either condition.

Changes in the heart rate are initiated by changes in autonomic balance; the vagus nerve exerts the main regulatory effect, which is considerably stronger than the influence of the sympathetic nerves. (22)
Moderate vagal stimulation may induce bradycardia and completely mask stronger sympathetic impulses, providing a physiological basis for a possible differentiation of fear and anxiety by cardiac response analysis.

With regard to the time interval between the onset of the emotion-producing stimulus and the cardiac response, Whitehorn⁽⁴⁴⁾ reported acceleration as soon as 4 seconds after the stimulus was given. This fast response may have been due to vagal inhibition since it has been estimated that in mammalian hearts the latent period required for a cardio-accelerative response via the sympathetic pathways is approximately 10 seconds. But regardless of the exact underlying mechanism, the response change will occur very rapidly, and cardiac changes provide an immediate and sensitive index of the physiological stress response.

The most appropriate measurement technique will depend upon the general experimental situation. It should not impede task performance or other measurements.

II. Performance Measures Reflecting Emotional Stress

At present, this area of research is still more closely related to clinical and pathological inquiries than to human factors interests. Consequently, the relevancy of many data to the present purpose is highly questionable. A good review of the effects of emotion cue utilization by Easterbrook,⁽¹³⁾ however, places emphasis on the more pertinent aspects related to this study. He hypothesizes that "emotional arousal acts consistently to reduce the range of cues an organism uses" . . . (see ref. 13, p. 183) Such change may be performance facilitative, if irrelevant or redundant cues are being neglected or detrimental if relevant cues are not being processed. An increase in motivation seems to affect a reduction in processing of peripheral cues with an associated performance decrement and facilitation of the central task performance. This effect has been demonstrated by Bahrick and co-workers⁽²⁾ where subjects performed a central tracking task in conjunction with two peripheral tasks, reporting the occurrence of occasional lights and responding to infrequent deflections of a dial needle. Increased motivation led to better tracking scores and to increased error scores on the peripheral tasks. Bursill⁽⁶⁾ reports a study of a central dial tracking task and a peripheral task where the operator had to respond to an occasional illumination of one of six lights. The lights were arranged in a semicircle around the central display; the two extreme lights were 80° degrees on either side of the center. Two levels of heat stress were used, 60-70° F, and 95-105° F, and for the higher temperature a "funneling" effect was reported, with greatest impairment in the responses to the lights at the extreme periphery. Reduction in the perceptual load of the central task alleviated the detrimental effects on the peripheral task.

These studies demonstrate the utility of employing a central task in conjunction with some peripheral tasks for quantification of stress effects.

For the measurement of transient changes and also to keep close to the "real" situation the designation "central" versus "peripheral" tasks should not be based solely upon the geometric configuration of the equipment but upon the combined factors of spatial layout and permissible performance bandwidth during the stress period.

Some attempts have been made to identify performance changes specific to a certain type of emotional stress reaction, for example, anxiety.

The general problem of obtaining valid measures of anxiety has been reviewed recently by Martin.⁽³¹⁾ He found that there is no unequivocal pattern of behavioral responses associated with anxiety and distinct from other emotional states. Several studies are cited which suggest measures that seem to be especially sensitive to the effects of anxiety. He concludes ". . . . that the tasks most likely to be affected by stress are learning and memory tasks involving novel or relatively poorly learned responses where competing responses are both numerous and relatively strong; or perceptual tasks in which conditions are imposed that make appropriate discriminations difficult." (see ref. 31, p. 246). The immediate applicability of this description to the expected operational situation does not require further elaboration. However, none of the employed measures, as, for example, learning of nonsense syllables and digit span memory, seems appropriate for the objective of this study. Scoring of speech disturbances during anxiety as developed by Mahl⁽²⁹⁾ may have a greater practical utility since part of the overall operational tasks will consist of verbal communication.

Apparently, no continuous performance measures have been obtained for different states of anxiety. A short mention is made by Easterbrook⁽¹³⁾ that in reduced cue situations, it has been found that anxiety prior to parachute jumping causes impairment in discrimination.

Instrument reading errors under startle-stress have been found to be primarily errors of omission, not defective readings.⁽¹⁰⁾ That this finding could validly be interpreted as a performance change specific to startle cannot be determined from the study. But the results indicate the need for the development of a testing procedure which permits a detailed error analysis in order to identify possible stress-specific performance decrements.

III. Performance Measures Reflecting Task-Induced Stress

Speed and load stress and their effects on operator performance have been studied by many investigators, often in conjunction with monitoring and vigilance problems. The current status of this area of applied research has been adequately reviewed by Hartman.⁽²¹⁾ Speed stress is generally

produced by changes in signal rate, whereas load refers to the number of information channels to be processed. Discrete tasks were generally employed to assess these effects and served to isolate performance changes attributable to either of these variables.

Most of the tasks employed, however, seem to provide a measure that is not sensitive enough for evaluation of super-imposed highly transient stress effects.

The effects of fatigue or isolation prior to addition of a stressor and the evaluation of the combined effects on performance seem to be relatively unexplored and no appropriate measurement techniques relevant to transient stresses could be found in the literature.

PROPOSED TEST PROCEDURES

From the facts of the past as they appear in the literature, it is evident that any task proposed as a valid test of response under transient heat stress must be capable of providing an instant-to-instant performance state relevant to assigned mission requirements. To do this, it must take specific account of the following relevant variables:

1. Profile of local as well as general thermal time-history patterns.
2. Acceptable performance bandwidths that define the human functions of guidance and control, monitoring, decision making and communication.
3. Personal state of the operator in terms of clothing configuration, restraints imposed on movements and length of time of mission.
4. Performance measurement criteria such as sampling rate, definition of error, time dependencies and subject self-assessment.
5. Concomitant physiological state as measured by the configuration of variables sensitive to deviations from individual homeostatic base lines.

As a means of achieving these requirements the following procedural rationale is proposed:

1. A laboratory environment should be provided which permits arbitrary programming of intense heat sources whose defined localization can be varied.
2. A task should be devised which should be continuously variable in difficulty such that an arbitrary level of subject performance may be maintained within defined limits regardless of changes in environmental stress levels.
3. Concomitant physiological measures, including Palmar skin conductance, skin temperature, EMG and pulse rate, should be taken as indications of physiological cost for maintaining a specified performance level.

Arbitrary high intensity heat sources should be provided by means of heat lamps programmed to turn on and off at specified locations for specified intervals. They should be calibrated for rise times and area of stimulation covered. General facilities and procedures for implementing the desired tasks are specified as follows:

I. Central Task:

A two-dimensional pursuit tracking task in which the difficulty of the forcing functions can be arbitrarily set by the experimenter. This can be accomplished through changes in its spectral composition.

The output error of the subject should be coupled to the forcing function in such a manner that his average performance will stay within a specified bandwidth. The coupling required should alter the forcing function to become more or less difficult according to the subject's immediate response. The criterion of stress effect would be the change required in the forcing function to maintain relatively constant performance.

A particular advantage of this technique is that it should be possible to derive an index of the perceptual load compatible with the operator's capabilities. The data should be scored with respect to variability within the assigned bandwidth, response lacunae and applicable response leads and lags.

II. Secondary Task

1. A spatially-distributed visual task requiring verbal responses to prior learned symbolic inputs. Varying difficulties of decision making logics and time sequences would serve to specify the response requirements of the secondary task. A measure of stimulus coding efficiency could be derived based on the rate and adequacy with which the secondary information is processed.

2. Either concomitantly or alternatively with the visual task, graded auditory information requiring verbal response should be presented.

Speech time delays, speech disturbances, and specific errors should be recorded.

For physiological measures standard laboratory procedures in current use can be employed. It is recognized that in order to handle the large amount of data expected from a "micro-performance" experiment, it would be necessary to utilize the facilities of a high-speed computer. Accordingly, data recording for all measurements must be highly automated and compatible for computer analysis.

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<p>Aerospace Medical Division 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio Rpt. No. AMRL-TDR-63-1. MEASURING PERFORMANCE CHANGES IN HIGHLY TRANSIENT EXTREME HEAT STRESS: RATIONALE, PROBLEM, AND EXPERIMENTAL PROCEDURES. Final Report, Jan. 63, iv + 22 pp incl. 45 ref. Unclassified Report</p> <p>A review of the existing state of the art for handling human performance under transient heat stress has been made. It was concluded that it would be necessary to develop a new methodology based on "micro-performance" measurements to assess severe localized transient heat stresses (over)</p> <p>as relevant to contemporary flight problems.</p> <p>The test procedure proposed is based on the rationale that a primary task with difficulty that can be varied according to subject error in order to maintain a relatively constant subject performance level can be used as a measure of the moment-to-moment perceptual load. In addition to the primary task, secondary tasks have been suggested to help simulate problems in decision-making and verbal communication.</p>	<p>Aerospace Medical Division 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio Rpt. No. AMRL-TDR-63-1. MEASURING PERFORMANCE CHANGES IN HIGHLY TRANSIENT EXTREME HEAT STRESS: RATIONALE, PROBLEM, AND EXPERIMENTAL PROCEDURES. Final Report, Jan. 63, iv + 22 pp incl. 45 ref. Unclassified Report</p> <p>A review of the existing state of the art for handling human performance under transient heat stress has been made. It was concluded that it would be necessary to develop a new methodology based on "micro-performance" measurements to assess severe localized transient heat stresses (over)</p> <p>as relevant to contemporary flight problems.</p> <p>The test procedure proposed is based on the rationale that a primary task with difficulty that can be varied according to subject error in order to maintain a relatively constant subject performance level can be used as a measure of the moment-to-moment perceptual load. In addition to the primary task, secondary tasks have been suggested to help simulate problems in decision-making and verbal communication.</p>	<p>UNCLASSIFIED</p> <ol style="list-style-type: none"> 1. Environmental Physiology 2. Psychomotor Performance (Human) 3. Thermal Stress 4. Biothermal <ol style="list-style-type: none"> I. AFSC Project 7222, Task No. 722204 II. Biomedical Laboratory III. Contract AF 33(616)-6763 IV. University of California, Los Angeles V. Hilde Groth and John Lyman <p>UNCLASSIFIED</p> <p>VI. In ASTIA collection</p> <p>VII. Aval fr OTS: \$0.75</p> <p>UNCLASSIFIED</p>	<p>UNCLASSIFIED</p> <ol style="list-style-type: none"> 1. Environmental Physiology 2. Psychomotor Performance (Human) 3. Thermal Stress 4. Biothermal <ol style="list-style-type: none"> I. AFSC Project 7222, Task No. 722204 II. Biomedical Laboratory III. Contract AF 33(616)-6763 IV. University of California, Los Angeles V. Hilde Groth and John Lyman <p>UNCLASSIFIED</p> <p>VI. In ASTIA collection</p> <p>VII. Aval fr OTS: \$0.75</p> <p>UNCLASSIFIED</p>
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