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# The Effect of Skill on Performance Under an Environmental Stressor

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**This paper examines the effect of individual skill level upon task performance in transient extreme heat. A summary of published data suggests that individuals who are skillful at the task are better able to withstand the detrimental effect of the stress exposure than their unskilled counterparts. Three theoretical explanations of such performance superiority are reviewed: behavioral arousal; attentional capacity; and automatic and controlled processing. It is concluded that the automatic and controlled information processing approach holds the greatest potential to account for this effect at the present time. It is suggested that the ability of skilled subjects who are able to resist the effect of heat stress may be a more general attribute of personnel who operate under a variety of non-optimal environmental conditions.**

THERMAL STRESSORS are problems that accompany certain human operational environments. Heat stress, as reflected in increasing ambient temperature, may be a product of either operating machinery, an intrinsic element of the geographical location, or generated by high vehicular velocity (7,23). Under many of these circumstances it is often impractical and occasionally impossible to remove all or part of the excessive heat from the workplace and its active agent. Therefore, it is valuable to understand how human efficiency may vary with progressive thermal load and what environmental or body temperature may denote the onset of both performance degradation and physiological collapse. In addition, it is of both practical and theoretical importance to elucidate the characteristics of those operators who are able to resist such breakdown as tolerance limits are approached. The present paper reviews the impact of one factor, the effect of individual skill level upon the maintenance of task performance in extreme heat. The paper is divided into three sections. A review of literature concerning individual performance variation in heat is followed by a brief elaboration of three current theoretical positions. The final concluding section illustrates both the applied and theoretical importance of the work reviewed. One outgrowth of the present observations is that the automatic and controlled information processing framework (38,39) may account for the ability to resist performance decrement under a variety of state and environmental stressors and not just heat effects alone (17).

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## Pertinent Literature

The study of cognitive and psychomotor task performance under conditions of elevated ambient temperature has been of interest to concerned military and industrial agencies who require personnel to function in thermally stressful environments (6,8,20). Experimental attention has focused on the performance of individuals in tropical latitudes (35), in elevated temperatures associated with real and simulated cockpit conditions (20,33), or both in combination (24). Previous reviews of performance under heat stress have indicated that the onset of significant decrement in certain cognitive and psychomotor abilities occurs at the environmental temperature where complete thermophysiological compensation ceases to be tenable (13,14). This limit, identified as 85.0°F (29.4°C) on the Effective

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Temperature (E.T.)* scale, represents the point at which both a rise in deep body temperature of the performer and significant performance decrement are observed.

An elaboration of this perspective divided tasks into three broad categories and identified the onset of impairment in these mental, tracking, and dual-task performance categories with dynamic deep body temperature increases of 2.4°F (1.3°C), 1.6°F (0.9°C), and 0.4°F (0.2°C), respectively (15). A more recent analysis has indicated that sustained attention is particularly vulnerable to the effect of heat. With this type of task it appears that any uncontrolled perturbation, either increase or decrease of deep body temperature, away from a steady state level is sufficient to degrade signal detection efficiency (16,19). These physiologically non-compensable increases in body temperature lie below the level of absolute physiological heat tolerance, which has been identified as a rise of 3.0°F (1.6°C) in deep body temperature (12,26,40). To account for such trends, it has been suggested that as the required "complexity" of the response increases across the three task categories, a progressively smaller perturbation in deep body temperature is sufficient to disrupt performance (15).

In the formulation of the above limits, means of group capability were extracted from a number of studies which reported task characteristics, level of heat stress, temporal duration of the exposure and onset time of the significant performance breakdown (3,4,36). However, it should be noted that one study reported improved tracking performance close to the proposed threshold of 1.6°F (0.9°C) (15,34). From this evidence and the analysis of differences in individual performance, one factor emerges as influential in subsequent stress-induced performance decrement. This is the level of skill which the performer showed on the task, prior to the heat stress exposure.

The origin of much of the above work can be traced to the initial investigations of Mackworth (30). However, there is one experimental study concerning individual performance difference in heat stress which predates his work. In this earlier study (41) two groups were tested each at a normal room temperature and an elevated 91.0°F (32.7°C) E.T. condition. The first group which was unacclimatized to the heat, performed a skilled motor coordination task. This was the transfer of ball-bearings across a rotating disk with the use of forceps. The results of this study indicated that the greatest percentage decrement in performance during the heat stress was exhibited by the subject of least competence, where competence was measured by the score on a final group of trials in a 3-week prestress exposure practice period. In three of the four subjects, there was a positive relationship between pre-exposure skill level and performance decrement during exposure to heat stress (41).

A second experiment in the same study used six different acclimatized subjects who were required to perform the same task in equivalent thermal conditions. The pattern of results for this group were generally less systematic. Although some of the performance elements, i.e., time per individual movement, support the contention that skillful individuals were less vulnerable to the effect of stress, overall findings were more equivocal. One reason for this uncertainty could be the difference in absolute level of deep body temperature of each of the individuals examined. The experimental procedure required participants to exercise prior to the heat stress exposure and consequently each subject experienced a different increase in core body temperature (41). This variation in deep or core body temperature appears to be an influential factor in overall performance level (1,2,11).

The most systematic investigation of the effect of skill on subsequent performance in heat was conducted by Mackworth (30). He studied accuracy of morse code message reception as a function of increasing environmental E.T. Experimental results indicated that summed errors of omission and commission increased as room temperature was elevated. The curvilinear form of these group data could be described by a logarithmic equation which had been developed previously to represent tracking performance in heat. Prediction from this equation allowed Mackworth to infer that significant performance breakdown in the telegraphic reception task would occur as room temperature exceeded 90°F (32.2°C) E.T. However, this unitary function was unable to accommodate individual variations and, as a result, overall group data was divided on the basis of subject competence. Performance in each of three skill level groups was subsequently analyzed as a function of increasing E.T. These data are presented in Fig. 1.

It is readily apparent that the pre-exposure skill level determined the extent of performance deterioration at a given ambient temperature (28). When the data for the whole 3-h exposure were divided into three sequential 60-min periods, an interaction was obtained between heat, time on task, and pre-exposure skill level. The less-skilled operators were disturbed more, and earlier, in their performance by the heat stress than their skilled peers. This finding was obtained in all but one case in the experimental series reported by Mackworth (28).

In a subsequent study by Mackworth (29), he reported results of a physically taxing pull-test which apparently contradicted the relationship between skill level and decrement due to increasing heat load. He dichotomized subjects into "good" and "average" groups, and found that men with higher initial output deteriorated more than those of "average" output during heat stress exposure. He commented that this paradox may be resolved by considering the nature of the different tasks undertaken. It was suggested that the

* Effective Temperature (E.T.) is a scale built around the thermal perception of the occupant and is *not* the most appropriate scale for use in conjunction with behavioral measures. However, most experimenters in this area have failed to report sufficient detail on the thermal surround for the construction of more pertinent scales. As performance limits also are expressed in terms of change in body temperature, it should be feasible to express the proposed thresholds in terms of time of exposure for other heat stress indicies, e.g., WBGT. However, this is a matter of empirical validation, rather than the simple translation of performance curves from one scale to another as was done in the NIOSH criteria document (32).

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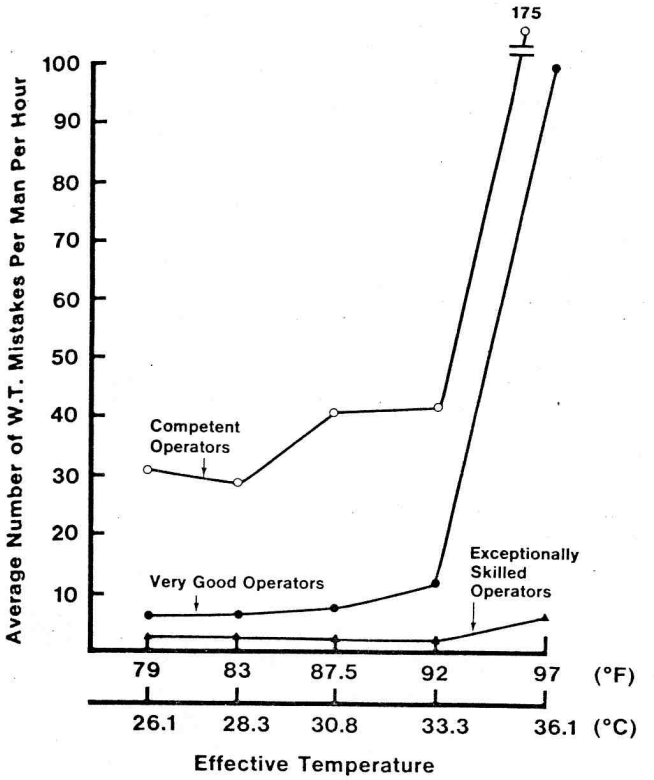


**Fig. 1. Incidence of errors in telegraphic reception by groups of differing task ability exposed to increasing Effective Temperature (after Mackworth, 1946: Reprinted by Permission of the British Medical Association).**

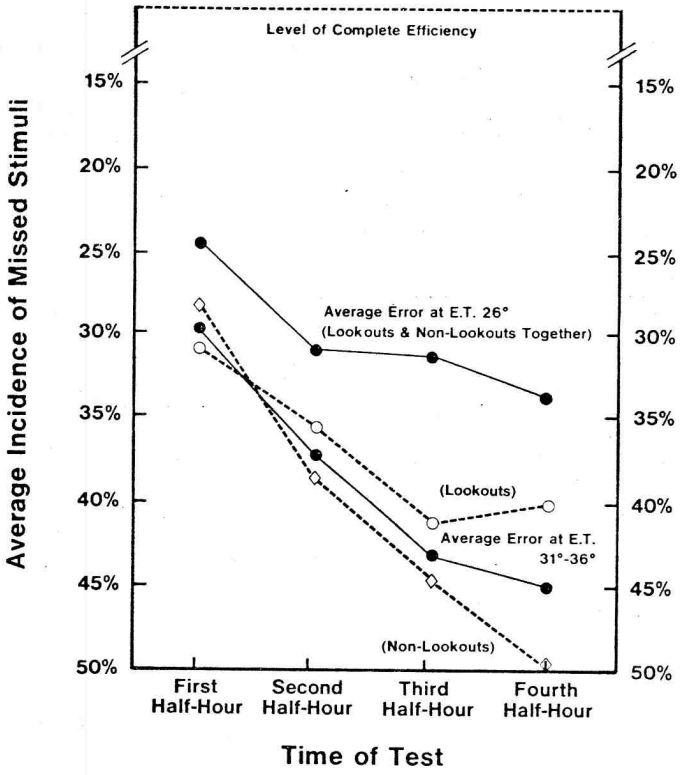


**Fig. 2. Incidence of signal omission against temporal exposure in a watchkeeping task. The effect of experience and its interaction with ambient temperature and time on watch is illustrated. Data from Mackworth (1950).**

highly skilled performers required less *effort* to satisfactorily accomplish the task in which they are skilled. Consequently, low error incidence in the telegraphic reception task in normal room temperature was equated with low average output on the pull test. Subjects whose effort was sufficient to reduce error production in normal room temperature consequently experienced greater difficulty in supporting the additional burden of increased room temperature (29).

The effect of skill was not confined to these two tasks only. Rather, the phenomenon was also observed where subjects were required to exercise vigilance in progressively higher temperatures. Fig. 2 represents the results of this study, which confirmed the interaction between time on task, severity of the thermal stressor and level of skill as noted earlier for telegraphic reception. In this illustration, the skill of the experienced subjects was gained through previous familiarity with Naval Look-Out duty, a task which is analagous to the monitoring required in the experiment itself.

Following this early work, a series of studies explored task performance at exceptionally high temperatures and correspondingly brief exposure times (3,4). One study reported on the performance of pilots navigating an experimental flight pattern in a neutral thermal environment and in conditions of 100.5°F (38.1°C), 109°F (42.8°C) and 114°F (45.6°C), E.T. The authors noted that their four subjects fell naturally into two pairs based on performance competency, which was defined as the general operational ability of the subject on the task apparatus. During the second half of the exposure at each of the heat stress conditions, the less competent pilots exhibited considerably larger error rates than the more competent pair. In addition, the less skilled pair displayed poorer performance, relative to their own prestress level, throughout a subsequently monitored recovery period. From a physiological perspective, these poorer performers also recovered from the stress less quickly than their skilled counterparts. While noting that the effects of the thermal stressor appear dependent on the type and complexity of the task, it is evident from this and previous work that level of competence is a critical factor (4).

Further analysis of the effect of skill was reported in a study specifically concerned with movable-wing aircraft operation in conditions of high ambient temperature. As with the previous study (4), four pilots served as the experimental subjects. They performed a precision-demanding flight pattern and measures of performance and physiological response were taken in various environmental conditions. These recordings were used subsequently to construct a multifactor equation to predict flight performance in heat. These pilots also could be divided into two pairs on the basis of initial competence. One major problem with this division is that only one pilot in each group was studied over multiple flight conditions. Although the relationship between prestress skill level and the subsequent resistance to heat-induced decrement was

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affirmed, the comparison was essentially between only two individuals. The results also indicated that hot conditions were related to greater decrement in complex components of performance, and that this tendency was most obvious in the less skilled performers (31).

This trend on the effects of heat on complex elements of performance was also reported in a more comprehensive examination of pilot capabilities (22). Performance in an aircraft simulator was assessed in dry bulb temperatures of 43.0°C (109.4°F) and 60.0°C (140.0°F). Although this work did not differentiate for individual performance variation, the authors noted that selected portions of the simulated flight were performed with no significant decrement. These were 'routine' and associated with straight and level flight. Performance on more complex segments, i.e. transition maneuvers and off-localizer operations, was affected adversely by the increased ambient temperature. The conclusion of the study was that the effects of heat are most apparent when the pilot is involved in the most complex and critical flight components. The authors further suggested that thermal stress and task criticality were separate and summative stressors upon the human operator, although their data support the present contention that these elements are more interactive in nature (22).

With the exception of the latter study, each of the above observations relating skill level and subsequent performance in heat stress have been derived from examination of a relatively limited number of experimental participants. However, more recent work has been conducted using a larger number of subjects. In one investigation, nine individuals were trained to plateau performance on a compensatory tracking task and subsequently exposed to a warm 89.2°F (31.8°C) and hot 94.0°F (34.4°C) E.T. condition for a period of 120 min (34). In the two most difficult levels of the tracking task, no effect for increasing heat stress was found. The highest temperature condition used by Nunneley and her colleagues in this study was in close proximity to the limit previously outlined for a breakdown in tracking performance in heat stress (15). One major variable which may have enabled these subjects to withstand the effect of the heat was their level of task proficiency as demonstrated by the plateau performance prior to the stress exposure. In an alternate study by Nunneley and her colleagues (33), it was observed that individuals showed learning during the heat stress exposure and that in aircraft performance, heat induced decrement may occur particularly in new or emergency situations.

In sum, the foregoing studies all point to the conclusion that those operators with high skill levels on a task are better able to withstand the subsequent effect of heat stress (41). An additional conclusion is that prior experience with the stressor itself is also beneficial in reducing subsequent stress-induced performance deterioration (43). The action of acclimatization with repeated exposure of particularly brief intervals to conditions exceeding 85.0°F (29.4°C) E.T. has yet to be fully clarified. However, mere familiarity with the stressor itself does result in some reduction in decrement after a critical initial experience (17).

## Competing Theoretical Accounts

### *Behavioral Arousal*

Despite the above observations, there have been few attempts recently to account for skilled performance under stress. Perhaps the most comprehensive theoretical proposal concerns the effects of behavioral arousal, which has been presented in most detail by Poulton (37). This proposal suggests that differing performance capability is subsumed by varying degrees of arousal, where arousal is mediated by factors intrinsic to the environment, the performer, and the task at hand. Skillful performers are less aroused by the task itself, or presumably if familiar with the stressor by the stressor itself (43). Therefore these individuals are less liable to experience the adverse effect of excessive arousal which would push them beyond the optimal performance point on the inverted-U shaped curve which relates arousal to efficiency.

There are a number of objections to the simple arousal notion which have recently been advanced (17,21). For example, it has been suggested that vigilance or sustained attention typically generates a low level of arousal. Therefore, increasing arousal should improve vigilance efficiency, while depression of arousal should further reduce performance capability. If skilled individuals are less aroused by the vigilance task then they should perform less efficiently than their unskilled companions. However, as illustrated in Fig. 2, this prediction is not reflected in the experimental data. In this case it is possible to salvage the arousal account by suggesting that the addition of the heat stress over-aroused the unskilled participants while keeping the skilled look-outs at close to optimum arousal level. This flexibility in explaining results is both the strength and the major weakness of the arousal proposal, in that it can account for a wide variety of data in a post hoc manner but is not amenable to accurate prediction in advance of exposure to real-life stressful conditions (17). There are some more recent developments which provide an alternative to the traditional arousal account which are founded in contemporary views of human attention (25).

### *Attentional Capacity*

Building upon early work (27), it has been proposed that human attention may be viewed through a capacity conceptualization (25). Attention is seen as a unitary resource of some finite capacity that may be used to perform any task. Dependent upon the "complexity" or number of concurrent tasks to be performed, greater or smaller amounts of this capacity, or attentional resources, are required for successful accomplishment. Total resource capacity is not static but may increase or decrease according to arousal state (25).

It has been suggested that stress may be one factor that competes for attentional resources and therefore reduces performance efficiency (5). Further, using data from studies of vigilance under thermal extremes it has been proposed that stress sufficient to overcome homeostatic efficiency acts to drain such attentional resources (19). An elaboration of this latter position

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results in the prediction that the more attention demanding a task, the more vulnerable it is to stress, and this is confirmed by experimental data on performance under heat stress (14,15).

There have been developments based upon the unitary capacity notion which are explored only briefly here. Among others, Wickens (42) has noted that some tasks may be time-shared, that is, they may be performed concurrently with no appreciable reduction in the efficiency of each. This led to his suggestion that attention may reside in several resource pools rather than the one global pool originally postulated (25). This elaboration is of practical importance, since efficient time-sharing is a vital element in procedures required of the modern day pilot. At this time, there are insufficient experimental data to indicate if skills are related to the multiple resource pools that Wickens has proposed. Therefore, it cannot be ascertained whether stress will have specific or more global effects on attentional resources, although the latter suggestion would appear the more likely of the two possibilities. As a result of this lack of empirical evidence, only the predictions based on the concept of a global pool are explored below.

From the original notion of a global pool, there are two possibilities which relate to the skillful performer under stressful conditions. The first possibility is that skilled individuals possess a greater absolute amount of resources and can, therefore, afford the excess attention which the stress demands. The second possibility is that performers who have acquired a high degree of skill on a particular task need less attentional resources to perform that task. This is the more favored alternative of the two, as there are some recent developments in theorizing about human attentional processes which would seem to support such a contention. This has emerged under the general heading of automatic and controlled processing (38,39).

*Automatic and Controlled Processing*

Operators may assimilate information in two differing ways; these have been characterized as automatic and control processes. Automatic processes, which are relatively attention-free, are the methods for dealing with highly consistent environmental stimuli that are common or routine. These take many repetitions of a consistent response to acquire. In contrast, control processes are used for unexpected or novel stimuli. These processes impose a high demand on the attentional capacity of the individual for successful performance. From the present work on stress, it is suggested that skilled individuals have acquired some degree of automatic processing with respect to tasks upon which they are skilled. Therefore, if stress drains attentional resources (19), the skilled performers who use relatively attention-free automatic processes are, in consequence, less vulnerable. This proposal is supported by several observations of individual capability under the impact of high ambient temperature (4,28–31,41). Such a position is also in accord with several observations that "routine" elements of performance, liable to exploit the utility of automatic processing, are little affected by heat stress (22,31).

If an operator is a novice, or is performing more complex task components, where control processes are liable to predominate, then they appear more vulnerable to the attention draining impact of stress (22,30). Stress would be particularly interruptive in novel or emergency situations where almost complete reliance is placed on control processing (33). Further, this argument would provide a rationale for consistent training on the performance task and on experience with the stressor, both of which appear beneficial procedures for reducing decrement associated with stressful conditions (34). In sum, the automatic and controlled information processing approach appears to be able to account for skillful behavior in the face of adverse conditions. While the above synopsis represents only a brief precis of detailed experimental findings (9,38,39), there is evidence that such a theoretical perspective is useful in considering performance variation under a wide variety of state and environmental stressors (10,18).

## Summary

Individuals are often required to perform multiple, attention-demanding tasks in the face of a variety of disturbing stressors. Nowhere is this more apparent than in aviation and space activities where the pilot must respond both rapidly and accurately in the presence of potential and actual disturbances. From the foregoing discussion, which has focused upon experimental data from thermal stress only, it is indicated that skillful performers are less vulnerable to adverse environmental conditions than novice counterparts. This resistance is due to the automated nature of performance on the task in which the operators are skilled. This account may be elaborated to include not only heat stress, but also a variety of alternate state and environmental stressors (10,18). The conclusion of this review indicates that familiarity with the stressor reduces the physiological impact of the stress (43), while consistent practice, or familiarity with the task, reduces the behavioral impact of the stress.

Stress is often an unwanted by-product of technological innovations which increase the size, rapidity and complexity of present day person-machine systems. This paper provides a rationale for the development of operator skill, through the use of automatic processes, to resist the potentially harmful effects of such stress. As such, it is of importance to all those who require personnel to operate under a variety of non-optimal conditions.

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