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Effect of Environmental Temperature on Display Monitoring Performance: An Overview with Practical Implications*

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The present paper provides an overview of studies which have examined the ability of personnel to monitor displays while exposed to reduced or elevated environmental temperatures. Certain ambiguities, in the results of these investigations, may be attenuated by analysis of operator body temperature change under the prescribed thermal conditions. Skill level (specific to the performer) and precise task composition are identified as potent influences on monitoring efficiency under this environmental stressor. In practical terms, the synthesis suggests that to maintain optimal performance, workers engaged in monitoring type tasks should be protected, where possible, from levels of thermal stress sufficient to induce dynamic, non-compensable body temperature change.

Introduction

As the trend toward automation in the workplace continues, the role of the industrial worker is evolving progressively from one of system operator to system monitor. Such monitoring performance is periodically required in non-optimal environmental conditions. On such occasions, impinging environmental stressors can alter performance capability.[1] Environmental stressors may be regarded functionally as deviations from normative or comfortable values of any of several metrics of the physical surroundings. They may act singly or, as is more commonly the case in applied settings, in combination. At the current time, relatively little is known about the effect of such complex additive, synergistic and antagonistic interactions upon performance capability.[2-4]

One major reason for this lack of understanding is that the effect which individual stressors exert on the execution of specific tasks is still unclear. Consequently, the present paper provides a review of studies which have investigated the effect of a single stressor (*i.e.*, environmental temperature) upon a specific class of activity namely, monitoring tasks. This category of tasks, in which the operator is required to respond to irregular signals for action, usually against a background of non-signal stimuli, has been variously described as watchkeeping ability and vigilance in early work,[5] to the sustenance of attention, in more recent approaches.[6,7] In the industrial setting, this type of performance composes elements of tasks such as simple visual inspection or quality control. For the purpose of the current review, the tasks identified are referred to under the generic title, "monitoring."

Even in the earliest empirical investigations concerning the ability of operators to monitor displays for irregular signals, the effect of the thermal environment received initial attention.[5,8] This problem has also formed the focus of recent practical research efforts ranging from the study of driving behavior in hot climates,[9] to work capability in the Arctic.[10] Variations in environmental temperature have been demonstrated to produce facilitation,[11] decrement[12] and no change in monitoring performance efficiency.[13] These diverse and somewhat equivocal results are not due simply to error in experimental procedures. Rather, they reflect complex interactions between different elements of the task, the environment and the worker himself. Several factors, whose influence traverses a variety of environmental stressors, have been previously identified.[14] In the section which follows, certain of these factors including precise composition of the task and skill level of the performer are examined in an attempt to produce a coherent picture of monitoring performance under the thermal stressor.

Overview

In recent and influential analyses,[7,15] it has been asserted that the optimal temperature for vigilance performance occurs at 26.7°C, Effective Temperature (E.T.),[16] a condition which exceeds the upper limit of the thermal comfort zone.[17] This position is based primarily upon the results of two seminal studies. The first of these[5] found optimal performance in terms of response time, signal omission and a combined performance measure, occurred at 26.0°C, E.T. compared with one lower, 21.0°C, E.T. and two higher, 31.0°C, E.T. and 36.0°C, E.T. conditions. This finding was essentially replicated using only signal omission as a performance measure.[8] In the latter report, the least signals were missed at the middle of the three, 19.4°C, E.T., 27.8°C, E.T. and 33.3°C, E.T. conditions. These data are reproduced in Figure 1.

However, in both of the above experiments, the subjects who wore only gym shorts and training shoes were either naturally or artificially acclimatized to a relatively high temperature. Consequently, when performing the sedentary

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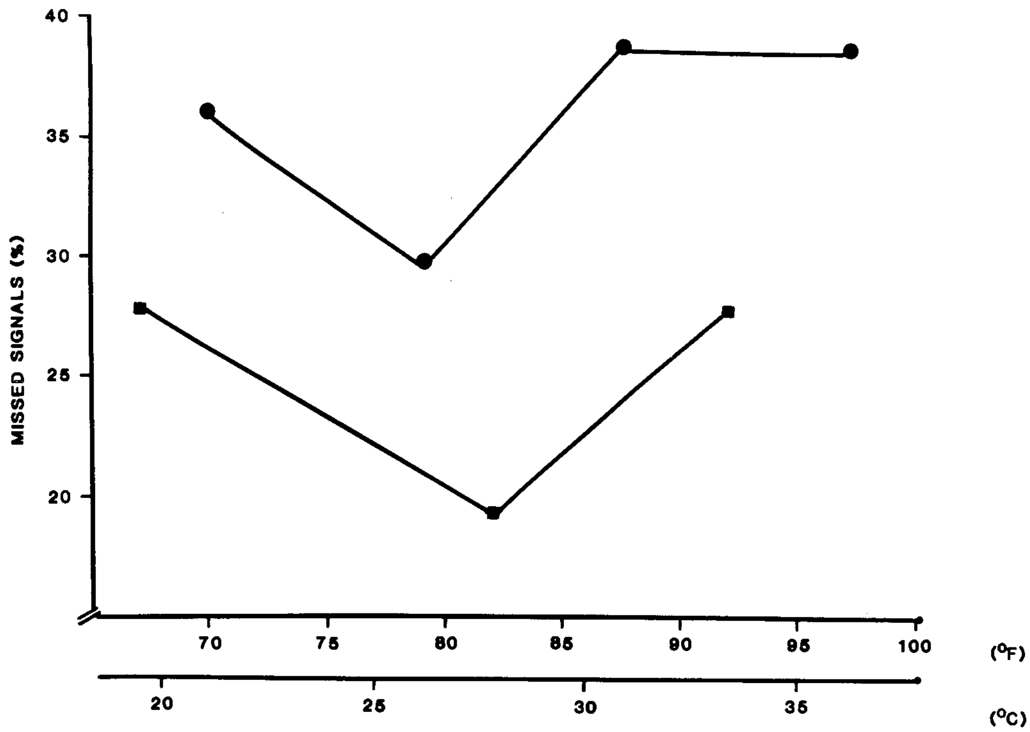

Figure 1 — Incidence of signal omission versus environmental effective temperature (E.T.), data from[5] represented by circular symbols (●), data from[8] represented by square symbols (■).

monitoring task, subjects experienced a drop in body temperature in the two lowest ambient temperature conditions.[5,8] At the two highest temperatures in the initial study and at 33.3° C, E.T. in the latter study, subjects experienced a rise in body temperature. Therefore, from these reports it is not possible to distinguish whether optimal performance was elicited by an ambient temperature exceeding thermal comfort or if monitoring efficiency was depressed in circumstances which induce a dynamic and noncompensable change in body temperature of the observers.

There are three studies which provide direct support for the suggestion that it is perturbation of body temperature which degrades monitoring.[18-20] In the first of these, the time of exposure covaried with the severity of the heat stressor. However, despite this potential confounding effect it was noted that the number of missed signals increased as observer body temperature was elevated. This pattern, which is displayed in Figure 2, was present in the monitoring of both visual and auditory signals and was independent of the manner in which such body temperature elevation was achieved, *i.e.*, exposure to a high ambient temperature for a short period or a longer time in a relatively lower environmental temperature.[18]

This general trend was also reported in two subsequent investigations.[19,20] In one study,[19] an almost linear relationship was found between ascending dry-bulb temperature and percentage of missed signals. Analysis of actual body temperature change under the prescribed ambient conditions confirmed that decrease in monitoring efficiency was dependent directly upon mean body temperature increase.

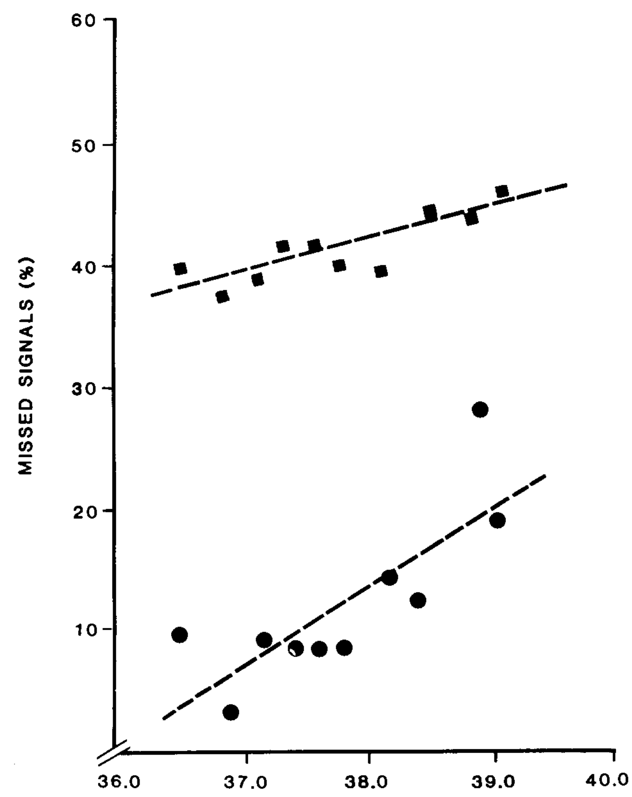

Figure 2 — Incidence of signal omission versus observer oral temperature, square symbols (■) represent auditory monitoring, circular symbols (●) represent visual monitoring. Data from[18], reproduced with permission.

However, in an important applied manipulation, it was demonstrated that augmented body cooling increased tolerance time to the heat and also prevented body temperature increase. Under such circumstances monitoring performance was essentially unaffected by the increase in ambient temperature. The same effect on performance efficiency as noted in heat, has also been identified in cold conditions. In a practical evaluation upon the efficiency of naval lookouts on vessels operating in high latitudes, it was noted that signal monitoring was progessively poorer in conditions which induced a dynamic *decrease* in operator body temperature.[20]

Certain investigations, which have reported environmental condition but have not recorded concomitant body temperature change, give evidence that monitoring performance breaks down beyond a threshold ambient temperature. This threshold is identified as in close proximity with the heat stress level at which the sedentary worker can no longer thermally equilibrate[21] *i.e.* conditions which by themselves, induce dynamic and non-compensable body temperature increase. Among these studies are works on monitoring of complex displays,[22] the performance of a military fire command task,[23] and tests of simple monitoring in heat and noise, both singly and in combination.[24]

The current weight of evidence suggests therefore, that monitoring is not facilitated in ambient conditions that exceed thermal comfort but rather performance is depressed in environments which induce body temperature to vary from stable conditions. However, the tendency for monitoring decrement to be related to body temperature perturbations has not always been observed in experimental investigations. An examination of these exceptions is important as it gives indications toward practical ways by which performance depression may be alleviated.

It has been observed that entry into a heated environment does not induce an instantaneous decrement in monitoring efficiency. Rather, there is a time course of events when exposed to such conditions. In one experiment,[11] the first minutes of such an exposure have been shown to elicit facilitation on a complex monitoring task. However, it is the case that such facilitation is quickly extinguished with prolongation of the exposure. These variations have been accounted for by invoking the notion of behavioral arousal[25] but regardless of any suggested underlying construct, there is a certain time period or inertial interval available during which deep body temperature resists change due to thermal condition. The length of this inertial interval will covary with the severity of the stressor and calculation of this tolerance period may be utilized to set safe exposure limits for this type of performance in extreme heat.[26]

This physiological characteristic of the human worker in part also underlies the suggestion of varying work/rest ratios in order to prolong efficient monitoring in heat.[27] An additional rationale for this latter investigation was that in practical work conditions, while the level of thermal stress may be relatively fixed by the precise industrial operation, some control can be exercised over the time that the worker is exposed to such an environment. Of the three work intervals, 20, 40 and 60 min and three heat stress levels, 74°, 82° and 90° F, E.T. investigated, only the combination of the longest work period in the highest temperature was sufficient to elicit a measurable and dynamic increase in body temperature. Results from this study, which are illustrated in Figure 3, confirm that it was only under these latter circumstances that significant monitoring decrement was observed.[27]

There are two studies which have reported no decrease in monitoring performance with ascending ambient temperature[13] or fluctuation in worker body temperature.[28] In the initial study,[13] subjects were exposed for a longer period, 120 min and at a higher temperature, 92° F, E.T. than in several previous studies in which decrement had been reported.[12,22,27] Although several factors which may have contributed to these null results were discussed, no particular element was identified as primarily responsible. These findings would be supportive of the current position if, for example, subjects had been fit, well acclimatized and consequently able to equilibrate to the highest heat stress level. However, analysis of data presented belies this simple explanation and some additional explanation of this null effect is needed.

This is even more imperative in a later study[28] where body temperature was specifically elevated by prescribed increments and no essential change in detection skill was found. These results may be due to two elements which pertain to the monitoring task itself and to the capabilities of the performers. First, the task, which was coincident for each study,

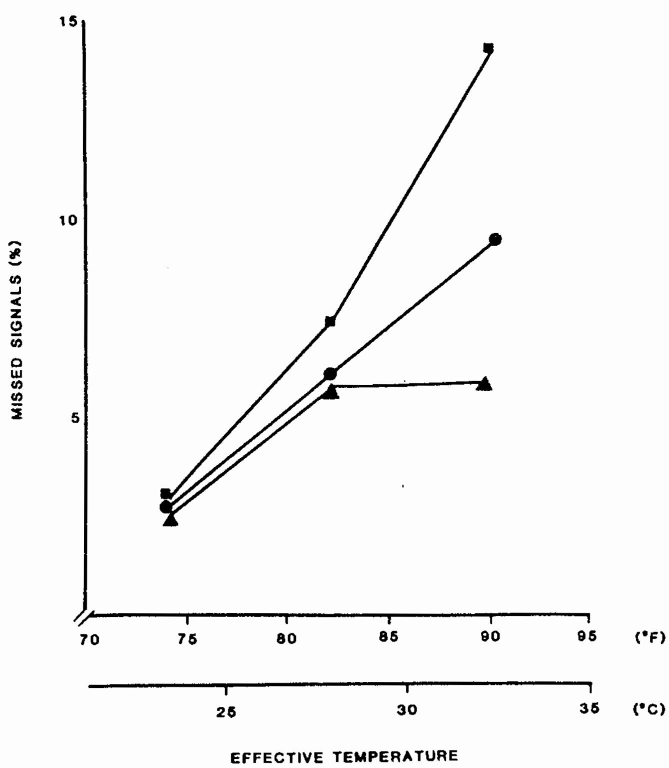

Figure 3 — Incidence of missed signals versus environmental effective temperature (E.T.). Data from [27], triangular symbols (▲) represent 20 min on watch, circular symbols (●) represent 40 min on watch, square symbols (■) represent 60 min on watch.

appears amenable to the development of a process of automated attending.[29] This process has been suggested as relatively uninfluenced by various forms of environmental stress including the action of the thermal environment.[30] Such attending is dependent upon prolonged practice. It is only in the above studies[13,28] that subjects have been noted as highly practiced upon the specific task. It is suggested, therefore, that one major reason why performance decrement was not observed in these studies is the development of automated monitoring in the practiced observers.

Conclusions

There are both theoretical and practical implications to be drawn from this brief overview of experimental results. First, little support appears for current assertion that optimal monitoring performance is elicited in ambient temperatures above thermal comfort.[2,7] Second, most studies give either direct evidence[5,8,18-20] or indirect support[22-24] for the position that monitoring is degraded in conditions which perturb worker body temperature in a dynamic and noncompensable manner. Third, this relationship between temperature change and capability means that inertial intervals, in which body temperature resists ambient thermal stress, may be used to calculate brief but safe tolerance periods for monitoring performance in extremes of heat.[26] This concept may be extended to allow repetitive exposures using work/rest ratio intervals. This is the first of three practical ways in which the harmful effect of heat may be palliated.[27]

Where such work/rest performance strategies are inappropriate, the use of augmented heating or cooling as relevant to the operational environment, can prolong both tolerance and safe and efficient performance.[19] A third avenue to limit the effect of the thermal stressor is through the structuring of monitoring tasks such that well practiced individuals may develop automated detection. Under these conditions the effect of the stressor appears to diminish.[13,28,30] This may be an important practical proposal as this effect appears to transcend the action of several stressors, although more experimental work is currently needed on this phenomenon.

In summary, as the worker is made more remote from both repetitive operations and potentially harmful stressful conditions, the necessity to monitor rather than operate machinery grows in importance. This monitoring may occur in the presence of diverse and interactive environmental stressors. While some stressors appear to exert a greater effect on monitoring than others,[1] environmental temperature appears the single most interuptive stressor. The current overview indicates that performance is detrimentally affected as body temperature deviates in a dynamic and noncompensable manner. In consequence, this observation may be employed in setting safety and tolerance limits based upon the physiological response of the individual worker, in addition to certain time/temperature safety limits currently in operation.

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