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Heat Stress Limits for the Sedentary Worker

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Performance on four sedentary tasks was monitored during temperatures of 85°F, 95°F, and 105°F WBGT for work periods up to 2 hours. Results were compared with limits recommended for occupational safety and health regulations. It is suggested that this limit is not a single line, but rather a range of temperature–time combinations. Further, man's compensating nature during short exposures supports a higher temperature limit for brief work bouts.

Introduction

THERE HAS BEEN and there continues to be an interest in predicting impairment in perceptual motor performance as a function of hot environments. By definition, the sedentary worker or operator is seated and is performing psychomotor or mental work tasks which involve minimal metabolic requirements. The recent criteria document developed by the National Institute for Occupational Safety and Health (NIOSH) contains a recommended standard for man performing sedentary tasks in hot environments, and specifically states:[1] "For sedentary jobs where continuous unimpaired mental performance is required, no employee shall be exposed to condtions which exceed the limits set forth in Figure 1." Figure 1 is an adaptation of results obtained by Wing[2] and is a summary of fifteen different studies concerning sedentary (mental performance) tasks in the heat. According to the NIOSH document: "It is quite apparent from these studies that thermal stress is an important factor where the worker has to make critical decisions, make fine discriminations, or have to perform fast or skillful actions, because safety will depend on constant alertness."

Current literature has been reviewed and summarized according to those studies in the temperature that relate to specific sedentary tasks. Results of these investigations have been plotted in Figure 2 to depict the combination of working time, temperature, and results of tasks performance.[3-23] This is the same type of analysis as Wing's,[2] but it includes a larger group of studies. Wet-bulb globe temperatures (WBGT) were stimated, if not given, for each of the cited studies. Each vertical line in Figure 2 represents an individual study performed for some given

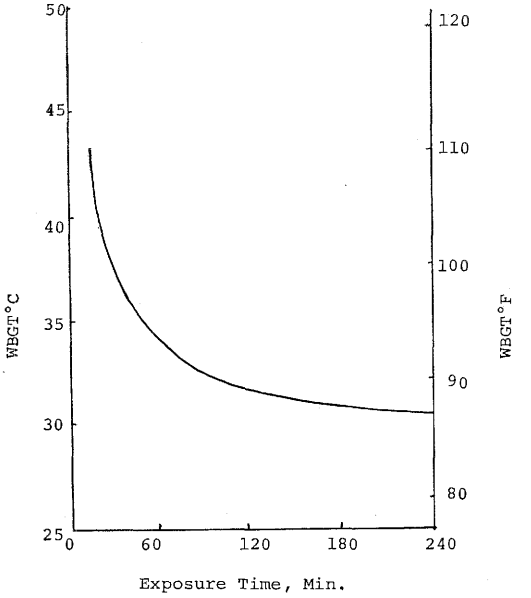

Figure 1. Upper limits of exposure for unimpaired mental performance (from "Criteria for a Recommended Standard . . . Occupational Exposure to Hot Environments," NIOSH, 1972).[1]

duration of time in the heat. The circle at each intersection of temperature and time indicates whether significant ($\alpha < 0.05$), partial, or no performance decrement was observed at this condition. Superimposed across the top of this figure are lines representing the NIOSH proposed limits.

In reviewing Figure 2, we see that there are numerous studies that do not support the proposed limit. Some studies do not

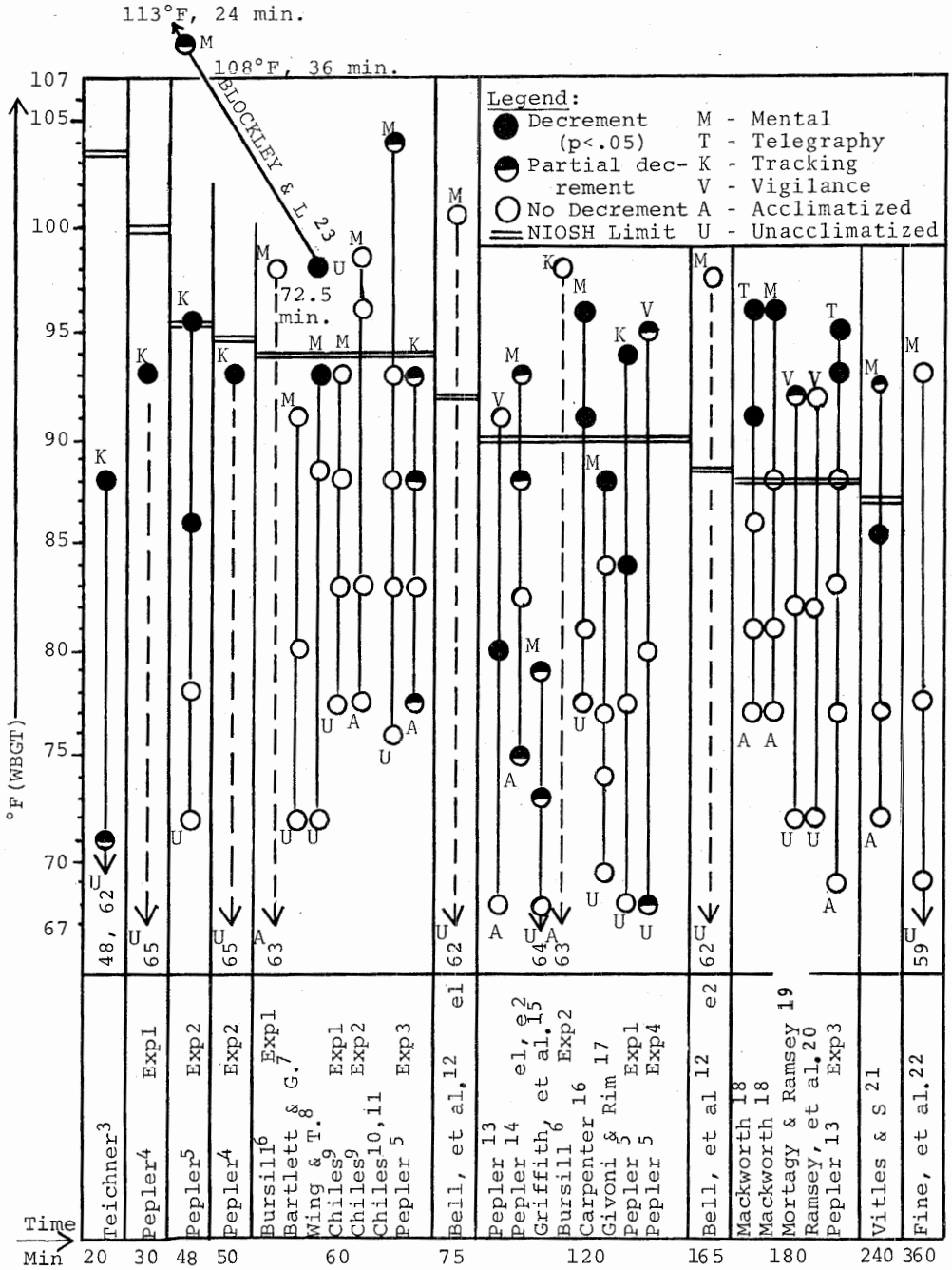

Figure 2. Sedentary work performance for specific mental tasks.[3-23]

show performance decrement at the time–temperature conditions above the limit, while others do show performance decrement occurring below the limit. On the other hand, there are numerous studies that do support the hypothesis of performance decrement above the limit. Thus, the evidence is somewhat contradictory as to impaired performance at a specified level of temperature and time duration.

Figure 2 also identifies the studies according to the type of tasks. Studies using mental, tracking, and vigilance tasks indicate results where impairment was observed on each side of the proposed limits. The telegraphy tasks, however, support the NIOSH proposed limits in that both Mackworth[18] and Pepler[13] depict decrement above the limit and no decrement below the limit. In general, this evaluation does not clarify task differences which would contribute to the wide range of performance results observed above and below the temperature–time combination of the NIOSH limit.

In an attempt to explain performance differences based on acclimatization of the subjects, Figure 2 has been further modified to show whether acclimatized or unacclimatized subjects were used in the reported studies. The studies using acclimatized subjects support the NIOSH limit in all cases except in those by Pepler.[5,14] The unacclimatized subjects, however, show no such pattern. This indicates that perhaps the unacclimatized subjects performed with higher degree of variability than is found with the acclimatized subjects. The proposed NIOSH limit for sedentary workers does not specify a degree of acclimatization in conjunction with its proposed limit for sedentary work.

Rationale

The composite of research concerning man's performance on sedentary work in the heat is contradictory. It is felt that this is in part due to the wide variety of experimental conditions. The WBGT has seldom been used as an index to control temperature levels, since its wide popularity as an index has come only recently (as a result, no doubt, of NIOSH recommendation of WBGT). The study reported herein controls and standardizes the temperature, time, tasks, and experimental conditions so that the procedure should be more sensitive to genuine performance differences resulting from thermal stresses. This study presents initial results from an effort which will be continued with a larger and more diverse population of subjects.

Independent Variables

Temperature

Three levels of temperature were selected for this study: 85°F, 95°F, and 105°F WBGT. These WBGT values were based on a 45% ± 2% relative humidity and a wind velocity of approximately 80 feet per minute. This represents dry bulb/wet bulb values of 99°/79°F, 110°/89°F and 120°/99°F. These temperatures provide data points on both sides of the limit values prescribed in Figure 1.

Duration

Another major independent variable was duration of time on task. The performance measures were obtained for each discrete work period in the heat by a work procedure in which the subjects rotated through four work tasks on a schedule of 2½ minutes of work and 1 minute of rest. When each subject completed the four tasks, he was given a 2-minute break and then began the cycle again at his original starting task. Since each work cycle consumed 15 minutes, the subjects performed each task eight times during a 2-hour work session. This provided an independent work score for each task during each 15 minutes of work. Since the work duration in the heat is an important parameter in evaluating impaired performance, this experimental procedure allowed assessment of sedentary performance on a variety of tasks, with a variety of temperature condi-

tions, and over an extended duration of time.

The total duration of the experimental sessions differed for the various temperatures. An exposure of 120 minutes was used for 85°F, 90 minutes for 95°F, and 45 minutes for 105°F WBGT.

Tasks

Four different tasks were selected to represent an array of commonly encountered occupational skills. The first task was a mental task in which the subjects were required to multiply sets of three by four digits. The subjects were scored on both speed and accuracy by means of counting all correct digits in each line of multiplication and in each column of addition. An eye–hand coordination task was also used in which subjects were required to pick up a small straight pin with a standard pair of tweezers. The pin was then placed in the center of a small circular target. This task was scored in terms of speed (number attempted) and errors (number missed). The third task was one of simple reaction time to a light stimuli. The subjects were given an electric contact button with which to signal the onset of a light. The fourth task was a pursuit rotor tracking task in which the subjects were required to hold a stylus against a moving metal target located at the edge of a 10-inch-diameter rotating wheel. Performance was measured as total time on target.

Subjects

Ten male college-age students were selected as subjects for this task. The experimental design required that each subject spend time in the chamber for each of the three temperature levels. An initial training session without thermal load was utilized to minimize task learning effects. The subjects were unacclimatized, and their sequence of exposure in the environmental chamber was counterbalanced to minimize these effects.

Dependent Variables

Measures of performance, normally in terms of speed and accuracy, were obtained for each of the four tasks. Additionally, each subject's oral temperature was sampled every 15 minutes during his work bout in the environmental chamber. Oral temperature, a correlate to deep body temperature, was taken as a safety precaution and as a means of estimating heat loading on the subjects during the different thermal environments.

Results

The physiological response of subjects under various thermal environmental conditions was measured in terms of oral temperature. This temperature was sampled during each 15 minutes in the chamber. Figure 3 depicts a significantly higher oral temperature ($\alpha < 0.05$) associated with 105°F, but also shows no significant difference between the 95°F and 85°F thermal levels. The 105°F temperature generates a physiological reaction to the heat stress in that it represents a condition well above the prescriptive zone as described by Lind.[24]

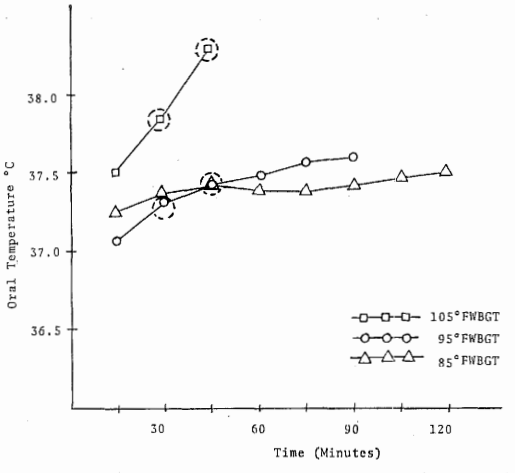

Figure 3. Oral temperature versus time and WBGT.

Since the combination of short duration and 85°F is considerably below the NIOSH limit for performance decrement, these conditions served as bases for testing relative decrement at higher temperatures and longer

durations. Randomized block factorial analysis of variance and *t*-tests were used as the primary statistical methods for analysis.

Figure 4 depicts performance on the reaction time task. Reaction time in the 105°F temperature is significantly longer ($\alpha < 0.05$) at the 45-minute than at the 15-minute period. No other statistically significant differences exist, but Figure 4 shows a slight trend for the 105°F reaction time to be higher than that at 95°F and 85°F.

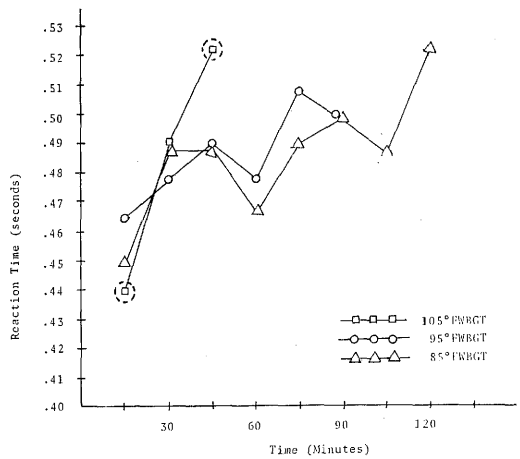

Figure 4. Reaction time versus time and WBGT.

The number of pins successfully inserted during the pin insertion task did not differ significantly under variable temperature–time conditions. This task indicated a continuing improvement in motor skill during each work session. Although subjects were given pre-experimental training sessions to minimize this effect, it apparently was not adequate to gain a stable level of motor skill performance. A second and related task measure was the number of pins missed or omitted. This measure did not display the same learning effect, and it indicated at 60 minutes a slightly significant ($\alpha < 0.10$) difference between the 85°F and 95°F thermal conditions (see Figure 5).

Figure 6 depicts the number of problems attempted on the multiplication task. Two combinations of temperature and time appear to be slightly significant ($\alpha < 0.10$).

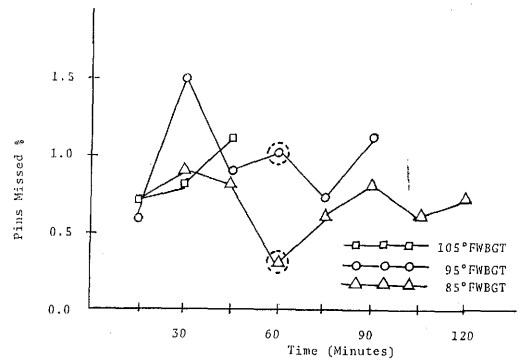

Figure 5. Pins missed versus time and WBGT.

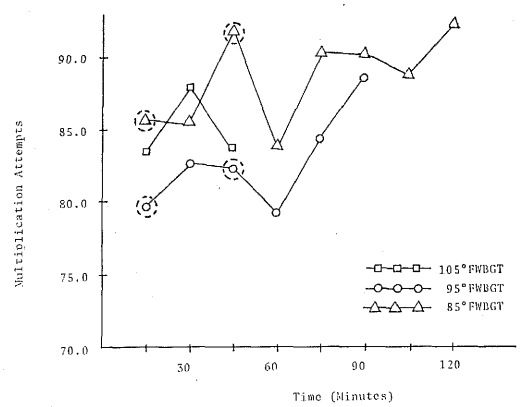

Figure 6. Multiplication attempts versus time and WBGT.

These are the differences between 85°F and 95°F at both the 15-minute and the 45-minute interval. No other temperature conditions are statistically different for this multiplication task or for the pursuit rotor task scores.

Conclusions

Figure 7 summarizes the conditions of temperature and time investigated in this study. The charting scheme of Figure 1 is again used to present this array of information. The performance scores on each task at 85°F and a brief thermal exposure were used as criteria of normal performance. These were selected, since neither the NIOSH criterion nor the evidence from previous studies indicates that performance of mental tasks would be affected to any degree by this level of temperature and time.

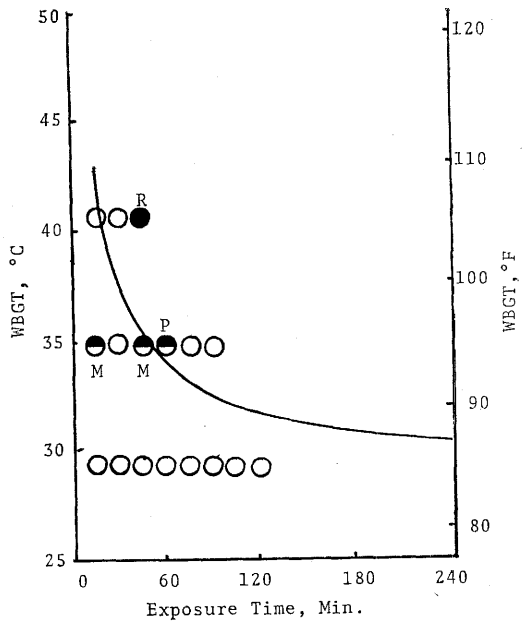

Figure 7. Summary of results: performance decrement versus time and temperature.

A single circle on Figure 7 actually represents four individual tasks performed at this temperature and time combination (mutiplication, pin insertion, reaction time, and pursuit rotor). Further, the multiplication and pin tasks had performance scores for both speed and accuracy. Thus there were six opportuinties for performance decrement to occur at each temperature–time combination. At 105°F only the reaction time task showed a significant decrement during the first 45 minutes. At the 95°F level, there were three task–time combinations that indicated a partial or slight decrement significant at the 0.10 level. The multiplication attempted—that is, speed of multiplication —at 15 and 45 minutes showed slightly lower scores than were obtained for 85°F. The number of pins missed (accuracy) in the pin insertion task showed a slight decrement at the 1-hour duration task at 95°F compared to that at the 85°F base line. The performance of task at the 85°F level did not show a decrease in performance level over the 2-hour period during which performance was measured.

These results do not close the issue of whether a cause/effect relationship can be established between time and performance on sedentary tasks as a function of the thermal environment. They do not, however, lend strong support to the NIOSH criteria for thermal limits that will avoid degraded performance. The finding that none of the tasks were significantly affected during the first 30 minutes at the 105°F temperature is no doubt a substantiation of the fact that man has great reserve capability to perform under adverse conditions for brief bouts. After performing in the chamber at 105°F, the subjects were physically exhausted and noticeably affected. Since this strain was not reflected strongly in their task performance, it appears that, with effort on the individual's part and perhaps driven by the heat, a person can keep his mental faculties and simple motor skill faculties at a high level of performance during short work bouts. This unimpaired performance was observed with subjects who received no special motivation. The student subjects were volunteers with no reward or feedback related to performance scores.

Intuitively, one would expect a relationship, similar to that depicted by NIOSH[1] and Wing,[2] to exist between time in the heat and level of heat. It is likely, however, that this is not a single line, but rather a range of temperatures associated with each time, or, inversely, a range of times associated with each temperature, within which the likelihood of performance impairment is increased. Additionally, the compensating and adaptive nature of man would support a higher temperature limit for brief work bouts.

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