PERFORMANCE UPON SUDDEN AWAKENING

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USAF AEROSPACE MEDICAL CENTER (ATC)
BROOKS AIR FORCE BASE, TEXAS

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DAVID E. LANGDON, Captain, USAF (MC)*
BRYCE HARTMAN, Ph.D.†

*Flight Medicine Branch
†Neuropsychiatry Branch

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In advanced weapons systems, commanders must choose between requiring "alert duty" personnel to remain awake at night and permitting them to sleep. Decrement in performance results from the loss of sleep, in the first instance; potential decrement after sudden awakening is a risk in the second instance. This report describes an experiment on performance after sudden awakening. The results demonstrated significant decrements upon sudden awakening and a progressive recovery over 10 minutes of intensive performance. Proficiency on the tenth minute approached but did not reach presleep levels.

One of the characteristics of modern weapons systems and their employment is "alert" duty. Crews on alert duty are maintained in a holding area, ready to man the weapons system on command, for periods ranging from a day to as long as a week. Some squadrons allow personnel to sleep during the nighttime periods of the duty cycle, in an attempt to avoid the deleterious effects of sleep loss. This creates the alternate problem relative to the efficiency of personnel who are suddenly awakened.

For example, at one base of the Air Defense Command, pilots were allowed to sleep while on alert duty. They were expected to be airborne within 2 minutes after a "scramble" alarm was sounded. A crash occurred at 4 a.m. during takeoff on such a scramble. (One of the investigators (DEL) was a member of the board that investigated the accident.) Awakened from a deep sleep, the pilot was to scramble his fighter aircraft for the purpose of intercepting and identifying unknown aircraft. During the takeoff roll, he decided that the aircraft would not achieve sufficient speed to become airborne. He elected to abort the takeoff. The emergency barrier at the end of the runway failed. The landing gear sheared and the aircraft slid 2,000 feet on its belly, incurring considerable damage. Fortunately, the pilot and the observer were uninjured. It appeared that the pilot misjudged his position on the runway and misread the airspeed. Further, after electing to abort, he failed to utilize various auxiliary methods of slowing the aircraft.

In effect, there were numerous pilot errors ranging from misreading the airspeed to misjudging the "point of no return" during the aborted takeoff. As a result of this accident, although sudden awakening was not *proved* to be a factor, all alert pilots in ADC were subsequently required to stay awake.

The question of alertness after interrupted sleep and during altered day-night cycles will continue to arise. One might speculate that it will be necessary for future space crews to sleep, with an alarm awakening them when critical, decisive action is required. Is it reasonable to assume that individuals are effective during the few minutes immediately after such awakening? This paper reports the first of a series of studies designed to evaluate the problem.

The literature offers little guidance in this study. Sleep is a research area more than

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100 years old, and a voluminous number of papers have been published by workers all over the world. The curve of sleep depth, behavior during sleep, stimulus levels necessary for arousal, and physiologic concomitants of sleep are but a few of the topics of investigation (3). The most recent review of the sleep literature (5) focuses on the effects of drowsiness and sleep on performance but contains no reference pertinent to the effects of sudden awakening.

Diurnal variation in performance is another area relevant to our problem. The number of papers in this area is as great as for sleep, and well-documented cycles have been described. These cycles contribute to the problem of sudden awakening and must be included in the evaluation of changes in performance. This area is relevant, then, in the sense of being a confounding factor, rather than providing guidance. It permits us to predict a certain loss in proficiency as a function of the time of night, but only in a general sense, and without a prediction of short-term changes after any specific awakening.

One set of Russian studies is somewhat related to this project. Vasilev and colleagues (6), working in the USSR, found that mean values for peak muscle strength and sustained muscle strength were lower at night; however, differences in performance on the 40 m. and 1,000 m. running events were only slightly poorer at night. Their subjects were awakened, underwent various studies, and then performed the runs. The Soviets found that, in the 45 minutes between awakening and performing a 5 km. skiing race, muscular strength, body temperature, and pulse rates had risen to day-time levels. Thus, imminence of a stressful activity can abolish the diurnal variation. To the best of our knowledge, however, studies of performance immediately after being awakened have not been performed.

PROCEDURE

Five airmen volunteers between the ages of 18 and 23 years served as subjects for the experiment, which required three weeks to complete. During the first week they were briefed, given three one-hour practice sessions on the operator task which they were to perform, and administered a battery of paper-and-pencil and apparatus skills tests and intelligence tests to provide baseline data. All of these activities were accomplished during regular duty hours. During the second (experimental) week, they worked a regular duty period and reported for five successive evenings to a special isolated dormitory to sleep and take part in the study. The dormitory was air-conditioned, and the subjects slept in individual rooms on comfortable hospital beds. The third week was used for posttesting on the operator task.

Subjects performed a systems-type psychomotor task, utilizing the Complex Behavior Simulator (CBS). This device, described in a separate report (2), consists of an assembly of 29 subtasks in a desk-type console. Most subtasks involve discrete signals, such as a light flashing on, and simple, discrete responses, such as operating a toggle switch which turns the light off. While the simulator contains 3 complex subtasks requiring multiple responses and information-processing, they were not used in this study. Signals are programed by a punched paper-tape system, with the sequence of codes completely randomized. Once the signal appears at the subject's console, it remains "on" till he operates the correct control.

Signal rate was set at 2,000 signals per hour, which is the speed beyond which decrement due to speed stress appears. We have found this signal rate to be the maximum effective load for most subjects. It is the rate which is particularly sensitive to the effects of extra-task or environmental stress. Response time, which is measured from the onset of the signal to the completion of the response, was the measure of performance. Response times for a representative sample of 15 tasks were recorded on an Esterline-Angus event recorder. The 10-minute strip of record was divided into 1-minute segments to yield minute-by-minute scores for each run.

Reporting time for the experimental week was 2100 hours. Subjects prepared for bed and then, in turn, had a standard 10-minute presleep run on the task, after which they retired. All subjects were in bed by 2230 hours, a normal schedule for a week night.

Subjects were awakened individually twice during the night and at the regular time in the morning. The awakening periods were 2400 to 0100, 0300 to 0400, and 0545 to 0630 hours. Awakening was accomplished by turning on the bedroom light and shaking the subject, with a minimum of noise and disturbance to the other subjects. The subject was hurried to the task, located in a separate isolated room in the dormitory, where he immediately began operating the apparatus. The average time from the beginning of awakening to the beginning of performance at the task was 2 minutes. The average walking distance was 60 feet. After performing the task for 10 minutes, the subject returned to bed. The brief interval between tests for the different subjects was used for recording and setting up the apparatus for the next run. Subjects were awakened in a randomized order, so that no subject was always awakened first.

Oral temperatures were obtained on each subject throughout the experimental week. Four times each day the subjects recorded their own temperature to the nearest 0.1° F. During each run on CBS, oral temperature was taken by the experimenter. This measurement occurred during the first minute. Estimates of sleep depth were also obtained for each awakening. Using a four-point scale from very light *(1)* to deep sleep *(4)*, the experimenter and the subject gave independent estimates. Temperature and sleep depth data were obtained in anticipation of wide variability in performance, but were basically exploratory in this initial study.

RESULTS

Performance was evaluated in terms of average response time for two classes of subtasks on a minute-by-minute basis. One class of subtasks consisted of those in which the display is normally "off." The signal to subject consists of the display (i.e., a light) coming "on." All response times in a single minute for all tasks fitting this description were pooled and averaged to yield a "DD−" score. The other class consisted of subtasks in which the display is normally "on" and goes off when a response is required. All response times for all tasks were pooled and averaged to obtain a "DD+" score for each minute. These two kinds of scores were analyzed in separate triple classification analyses of variance, using minutes, awakenings, and days as the three major dimensions.

This analysis of variance of "DD−" scores is presented in table I. The F ratios for minutes, awakenings, and days were all significant at the 1 percent level. None of the interactions were significant. The effects which were obtained are shown graphically in figure 1. The top curve shows that proficiency improved in a linear fashion minute by minute during each 10-minute run. Days and awakenings were pooled to obtain these values. The subjects did not, however, reach their normal performance levels, indicated by the dotted line, which is the performance curve minute by minute for all presleep runs. The middle curve shows the

TABLE I

Analysis of variance of average response times (DD−)

Source of variation	Σx^2	d.f.	F
Within groups	1702.95	800	
Between people	678.77	4	
Residual	1024.18	796	
Between groups	588.94	199	2.300*
Awakenings (A)	89.97	3	23.310*
Minutes (M)	74.67	9	6.449*
Days (D)	231.19	4	44.922*
A x M	23.06	27	N.S.
A x D	34.37	36	N.S.
M x D	25.69	12	N.S.
A x M x D	109.99	108	N.S.
Total	2291.89	999	

*Significant at the 1 percent level.
N.S. Not significant.

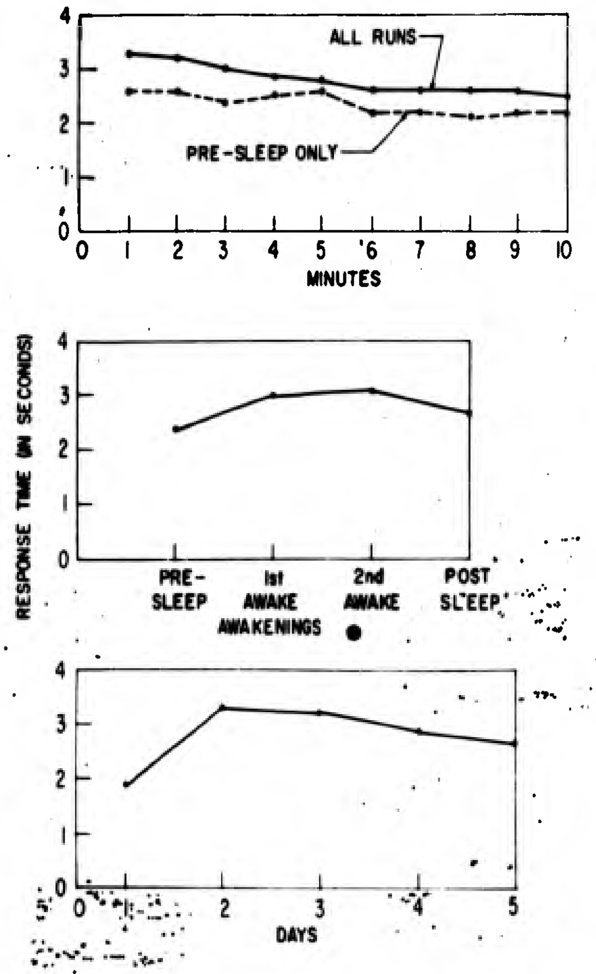

FIGURE 1

Mean response time (DD−) as a function of minutes, awakenings, and days. The dotted line in the top portion of the figure is based on the average presleep values only. Each of these three analytic dimensions gave a significant F ratio.

differences between the four runs each day, with days and minutes pooled. Performance during both awakenings is markedly poorer than on the presleep run. The morning, or postsleep run, yields response times almost as short as for presleep. The bottom curve shows differences between days, with minutes and runs pooled. The first day is clearly the best in terms of response time. A marked decrement occurs on day 2, and a gradual recovery follows.

The analysis of "DD+" scores is presented in table II. For main effects, only differences over days were significant. The interaction of

TABLE II

Analysis of variance of average response times (DD+)

Source of variation	Ex^2	d.f.	F
Within groups	8825.33	800	
Between people	2792.57	4	
Residual	6032.76	796	
Between groups	2408.33	199	1.597*
Awakenings (A)	288.85	3	N.S.
Minutes (M)	94.55	9	N.S.
Days (D)	706.41	4	5.808*
A x M	108.96	27	N.S.
A x D	271.56	36	N.S.
M x D	364.86	12	N.S.
A x M x D	573.14	108	4.012*
Total	11233.66	999	

*Significant at the 1 percent level.

N.S. Not significant.

days x awakenings was also significant. The effects which were obtained are shown in figure 2. The top curve, showing response time minute by minute, suggests a trend similar to that for "DD−" scores. The middle curve shows differences very similar to those in figure 1, although the F ratio was not significant. The bottom curve for days is also much like that obtained in the "DD−" analysis. Examination of the DD+ scores indicated a great deal of variability, which tends to attenuate the differences.

In figure 3, curves for each awakening on each day are presented. The curve for the first awakening is clearly different from the others, peaking on day 3 rather than day 2. It is likely that this accounts for some of the significant interaction. The range for day 1 is also much smaller than for the remaining days. This may also contribute to the interaction.

Since a return to normal levels after awakening is of importance, the curves for each run are presented in figure 4. This figure shows DD− response time minute by minute for each

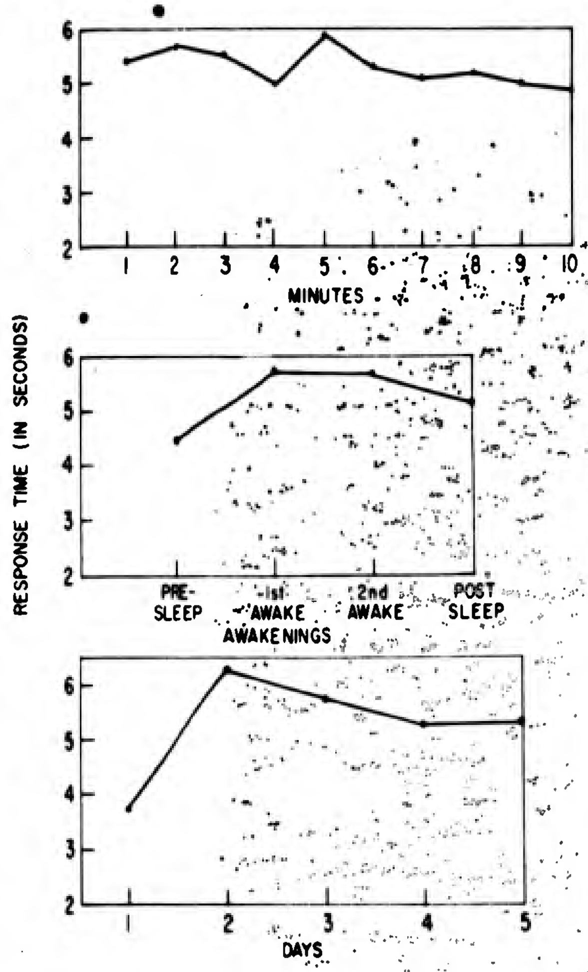

FIGURE 2

Mean response time (DD+) as a function of minutes, awakenings, and days. Although only days produced a significant F, trends are similar to the effects obtained for DD− scores.

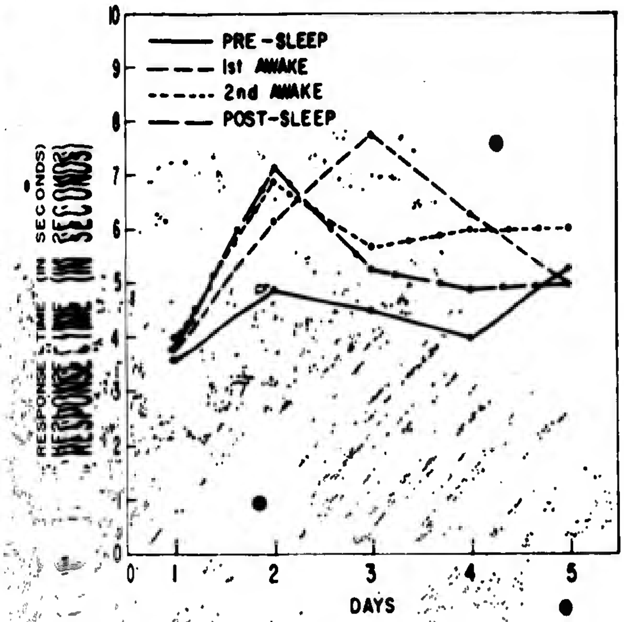

FIGURE 3

Mean response time (DD+) for each run on each day to demonstrate the significant interaction of runs and days obtained in the analysis of DD+ scores.

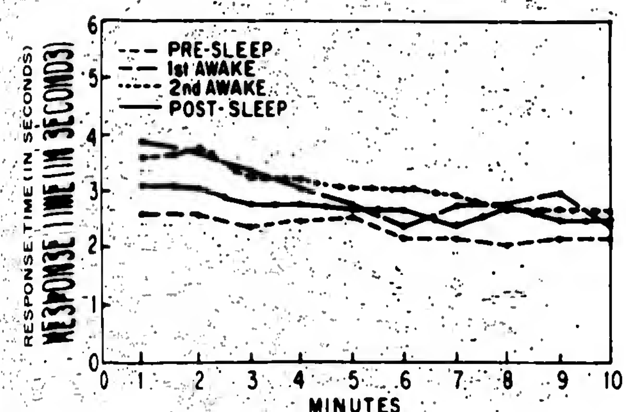

FIGURE 4

Mean response time (DD−) for each minute on each run, pooled across days.

run, with days and subjects pooled. While the significance has not been tested, the curve for the first awakening suggests an initially greater decrement and more rapid recovery than for the second awakening.

Temperature measurements were obtained for only four of the subjects and for only the second, third, and fourth days. Sleep depth estimates were obtained for all subjects throughout the week. The results are presented graphically in figure 5. The top curve represents the average temperature. It follows the characteristic temperature changes described in the literature. Average sleep depth estimates are presented in the middle portion of the figure. Both the experimenter's estimate and the subject's estimate are shown. Agreement is reasonably good. In general, the estimate ranged between light and moderate sleep. The individual estimates fell, for the most part, in this same range. Deep sleep was rarely reported. In the lower part of the figure are the mean response times (DD−)

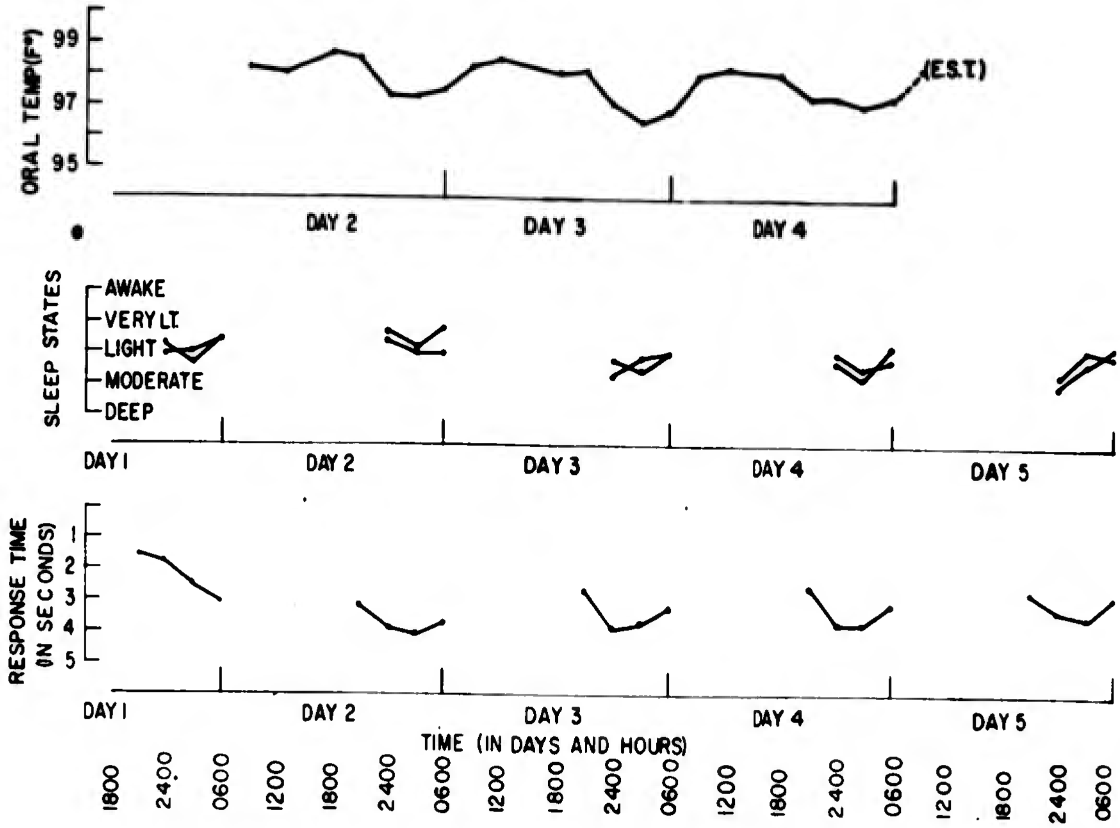

FIGURE 5

Average body temperature, estimated sleep depth, and performance levels (DD−) across days. Both the experimenter's and subject's estimates of sleep depth are presented. Data from only four of the five subjects were used to calculate the means plotted in this figure.

for each of the runs each day. These values are based on only the four subjects for whom we had complete temperature measurements. The general shape of the curve for awakenings given in figure 1 is present in these curves for all but day 1. In general, day 3 looks different for temperature, day 2 looks different for sleep depth, and day 1 looks different for response time. In view of the problem of incomplete data and the grossness of sleep depth estimates, no further analysis was attempted.

None of the data from the pre-experimental week on intelligence and skills tests will be presented. The score from these subjects will be pooled with those of subjects in subsequent studies and will be reported later. Of some interest, however, are the pre- and postexperimental levels on the task. The means for DD− were 1.47 and 1.64 which does not indicate a practice effect. The means for DD+ were 2.14 and 1.78, which do suggest a practice effect.

DISCUSSION

The major findings of this study are clear-cut. Performance is significantly poorer upon sudden awakening than it is when the operator is already awake. The difference between pre-sleep and nighttime scores is, at the minimum, 25 percent (estimating from the values in the middle curve in figures 1 and 2). The estimate which we have given is conservative because it includes values for all five days. Day 1, which provides an estimate of the most efficient normal level, gives a value of 1.6 seconds, suggesting that awakening response times may be more than twice as long. This kind of relative decrement is not acceptable in modern weapons systems, which are becoming increasingly intolerant of operator dysfunction.

Whether the difference between the first and second awakening is significant is debatable. Figure 4 suggests that the first awakening was different not only in terms of the overall level but also for the course of the recovery. It is too soon to say whether this is of practical importance. It would probably be appropriate to consider performance after the two awakenings as equal. At any rate, it is clear that the recovery from decrement on sudden awakening is gradual and that 10 minutes of intensive performance is not sufficient to reach the normal levels.

The failure of postsleep performance to return to presleep levels confirms statements by Kleitman(4). He reports that both performance levels and body temperature are lower upon arising and that they peak later in the day. Although our subjects had completed a normal day's work before the presleep run, their performance was better than for the postsleep run. This postsleep decrement might be considered to reflect a "whole organism" warm-up effect like that found in industrial fatigue studies. It is a factor which operational commanders should keep in mind.

There is another aspect of the effect of the diurnal cycle upon performance which needs to be considered. Is the day-night cycle itself sufficient to account for the differences between awakenings? A curve presented by Kleitman (4) to show characteristic performance changes suggests that decrement on the order of 8 percent might be considered typical. Our decrement is 25 percent, as a conservative estimate, or three times as great as that expected from the day-night cycle. A recent study by Adams and Chiles (1), however, provides data indicating that the low point in performance is around breakfast time, considerably later than our nighttime awakenings. While the latter findings suggest that we need not consider diurnal decrement in evaluating our results, the problem remains essentially unresolved. It seems reasonable, however, to conclude that the decrement obtained upon awakening cannot be explained *solely* by the diurnal cycle.

The operational significance of differences over days is difficult to evaluate. While clearly significant, they may reflect only the disturbed sleep pattern and anticipation of the nighttime runs by the subjects. Alert crews, of course, anticipate being awakened and will have similar disturbances in sleep if awakening occurs, but not with the regularity in this study. Adaptation to our schedule is demonstrated by the gradual improvement after day 2, but no definite statements can be made about the reasons for improvement. We cannot tell whether subjects were adapting to "being awakened" or adapting to the task imposed on them after being awakened. A practice effect is another possibility. The improvement in DD+ scores over the three weeks probably contributes to the significant F for days, but we obtained no such improvement in DD− scores. Considering the results as a whole, it is unlikely that practice on the task per se made a major contribution.

A note should be added concerning the differences between DD− and DD+ scores. Large variability and relatively poorer sensitivity to experimental manipulations have been characteristic of DD+ scores in other studies using CBS. Technics which give DD+ subtasks greater priority eliminate this difference, but at the expense of increased response time in DD− tasks. We did not use technics for manipulating subtask priority in this study. Although response times for DD+ tasks did not yield all of the significant differences, the trends were the same as those obtained for DD− scores.

The data on sleep depth and body temperature (fig. 5) provide nothing very remarkable. We obtained the characteristic body temperature curve, but individual curves showed the considerable variability typical of such data. The fact that sleep depth was rarely estimated to be deep was somewhat unexpected. Anticipation and the newness of the sleeping environment probably affected this estimate. More than likely the two factors play a similar role in the "alert" situation, too. We have no clear indication that either sleep depth or body temperature contributes substantially to the effects which were obtained. Body temperature was lowest for the postsleep run, but sleep was estimated to be at least as light as either of the awakenings, and performance was markedly better. The technics for assessing the state of the organism were gross, and individual variability was great. This aspect of the problem requires a more definitive approach.

In summary, two conclusions of operational significance can be reached: (a) Proficiency is significantly poorer upon sudden awakening. (b) Recovery is progressive during 10 successive minutes of intensive performance, but it does not reach normal levels.

The operational significance of differences over days requires further study. The same statement can be made about the pre- and postsleep difference, which is most intriguing. And finally, while this study demonstrates that allowing "alert duty" personnel to sleep creates a proficiency problem, it says nothing about the alternate problem of keeping them awake, or the relative advantages of either approach. This final question may be most significant for the coming exploratory period of space flight.

SUMMARY

Five subjects participated for five successive nights in a study of performance upon sudden awakening. Four 10-minute runs of a systems-type psychomotor task were obtained each night. Performance for the two awakening runs was markedly poorer than for either the presleep or postsleep runs. Recovery from decrement during the awakening runs was progressive but never reached presleep levels of performance. Differences across days were also significant. While no systematic relationship between performance and body temperature or sleep depth was obtained, no firm conclusions could be reached on this aspect. It appears that significant proficiency problems exist for weapons systems personnel who are permitted to sleep while on alert duty.

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