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HYPOXIA AND PERFORMANCE DECREMENT

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I. Introduction

In the study of hypoxia, the concept of "time of useful consciousness" (TUC) has been used to describe that period of time during which useful or purposeful acts can still be performed.[1] For a given altitude, the TUC is stated as a single figure or interim of a normal range. Accurate estimation of TUC values are still somewhat confounded by the fact that they are dependent upon how a given experimenter has defined useful behavior. Van Liere and Stickney [2] state:

> Most of the tests employed have been of an extremely simple nature, such as writing or simple card-sorting. It seems to the authors that the more challenging tests should be used, for example, problems in mental arithmetic (p. 311).

A simple task that is highly overlearned, such as writing one's name, will tend to give longer TUC values than more-complex, less-overlearned tasks. As a further consideration, the concept of TUC necessarily implies that a qualitative judgment be made as to the point in the task at which the subject's performance is no longer useful or purposeful. Though this arbitrary point can be predesignated before experimentation, its existence introduces further ambiguity. It is well recognized that performance in the hypoxic state does not suddenly change from normal funtioning to uselessness, but rather that there exists a progressive performance deterioration, perhaps reflecting the arterial-oxygen saturation.[3] In Hoffman's study, however, although they are presented quantitive curves reflecting the lowering of arterial-blood-oxygen saturation as a function of exposure to a given altitude, there is no comparable function representing decay in performance. A simple card-sorting task was used and performance was measured in terms of time to first sorting error. The time preceding this point is accepted as time of useful consciousness, although there may be considerable fall-off in operator capability before making this simple error. In attempting to set a TUC value, one is actually deciding at what point along this deterioration curve performance is no longer useful, the decision being reflected in the task and measure chosen.

The present study is aimed at replacing the concept of TUC with a less-ambiguous and a more-descriptive concept. It is proposed that the deterioration in rate of operator performance be utilized to describe the effects of hypoxia. Performance rate is defined as the ratio of task units completed in unit time under hypoxic conditions over task unit completed per unit time under non-hypoxic conditions. The resultant, an index value, is a metric, which would permit comparisons of different tasks' sensitivity to hypoxic conditions. This performance rate metric would also permit charting operator performance as a function of time exposed to hypoxic conditions. It would therefore follow that performance rate should show more rapid rates of decrement as the pressure altitude rises.

II. Procedure

The above conceptualization of the problem requires an experimental-performance procedure that will yield continuous measurement of performance comparable in complexity to that of the aircrew's task. The performance task was provided by a serial-reaction complex coordinator (Figure 1), which was originally designed as a modification of the Mashburn. The apparatus consists of four controls, one for each extremity. The subject's display is a panel containing a total of 45 lights, 20 stimulus lights and 20 response lights, plus 5 additional individually placed stimulus lights. Each quadrant of stimulus lights is controlled by one of the four controllers. Below these lights is an interval timer that can be preset any time up to 15 seconds. It resets when each problem is successfully completed. If the subject does not complete the problem in the preset time, there are two red lights on the controller forward of the hand controls that are lighted and remain on until the subject successfully completes the prob-

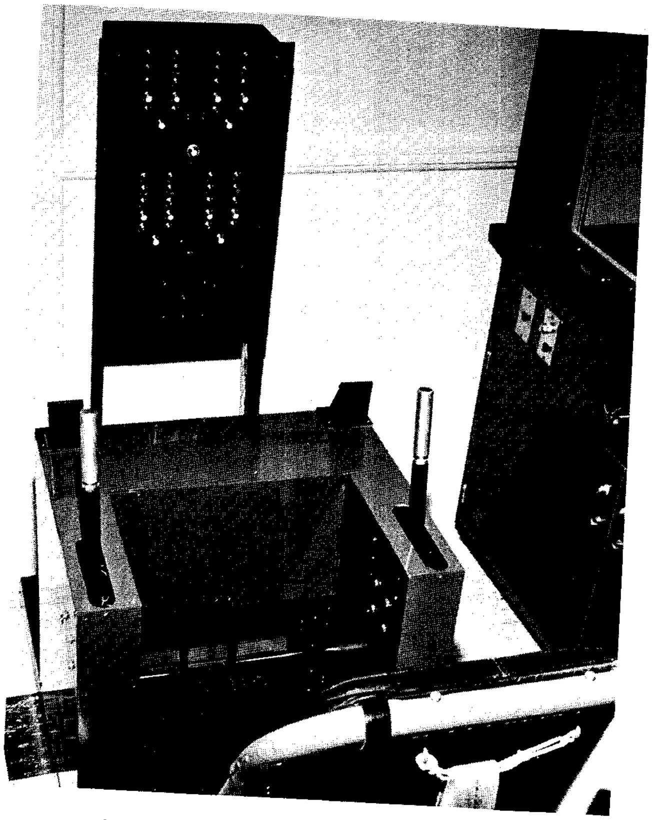

FIGURE 1. Scow complex coordinator.

lem. The sweeping red hand followed by the red lights serves to act as an additional motivating factor.

The test is preprogrammed on a revolving drum, and, as each problem is successfully completed, the drum moves one step and presents the next problem to the subject. Each step represents a trial and 25 trials represent a cycle. The measure of performance was time to complete a trial, which was recorded on an Esterline Angus event recorder.

In the series of runs at 35,000 feet, the subject was presented with a straight match problem; that is, one stimulus light was presented in each quadrant, which required the subject to respond with the matching response light. When all four lights were matched simultaneously, a new problem was automatically presented. In the second series of runs, done at 27,500 feet, a logic problem was introduced, which required the subject to determine the correct response lights. The logic aspect was programmed by using the remaining five stimulus lights. Thus, when the middle lower white light in each quadrant came on, it indicated the correct response was one light below the stimulus light for that quadrant. The fifth green central light was applicable to all four quadrants, and, when lit, it indicated that the correct response was one above the stimulus light. When both the quadrant white light and the green light were on, they cancelled each other and the correct response was a straight match. Before starting the hypoxia run, all subjects received a minimum of 15 cycles of training or 375 trials, which brought their performance down to a reasonably level plateau.

The experimental run consisted of 10 cycles of performance with interpolated rest periods. Concurrently, the subject prebreathed 100% oxygen, and an ear-sinus check to 10,000 feet was made. The experiment was conducted in a low-pressure chamber. The temperature inside the chamber remained at 72° F during the experiment. Each subject was fitted with an air-line crew-member oxygen mask. The oxygen regulator used was an A–14 diluter demand pressure-breathing type. All subjects prebreathed for 20 to 25 minutes prior to the onset of hypoxia. After return to ground level, an ascent to the experimental altitude was made at a rate of 3,000 ft/min.

The experimental protocol was in four phases as follows:

Phase 1. Subject prebreathes 100% oxygen for 20 minutes. Subject buckles in seat. Chamber at ground level. Subject performs 6 cycles or 150 trials on coordinator, in blocks of 50 with 1-minute rests between each cycle.

Phase 2. Ascent to altitude at 3,000 ft/min. At outset of ascent, subject starts 100 trials with no interpolated rest period until finished with the 100. Still on 100% oxygen. Ascent consumes 12 minutes.

Phase 3. At 35,000 feet. Most subjects will have completed ascent series of 100 trials prior to reaching 35,000 feet. If not, subject is to continue until he completes 100 ascent series, following which a 1-minute rest occurs. Subject resumes work now on cycle 11. After completing approximately 10 trials of block 11, the inside observer takes the subject off oxygen. The subject has no forewarning of this and is unable to observe the observer closing the oxygen valve. The subject continues to work as long as possible. The outside coordinator experimenter at this point monitors the event recorder, and when a 5-second period elapses in which the subject cannot either hold one of the four lights matched or effect a new match for 1 second on one of the stimuli, the signal is given to the inside observer to restore the subject's oxygen supply. The inside observer may, however, restore oxygen prior to this if he deems it necessary.

Following restoration of oxygen, the subject completes block 11 and goes immediately on to block 12. After block 12 is completed, the descent starts.

Phase 4. Descent. Subject remains on oxygen until inside observer claims it safe to go to ambient air. Descent at 3,000 ft/min.

All of the subjects were active air crewmen: pilots, navigators, or flight engineers who had had previous physiological training in the altitude chamber either by the military or FAA.

III. Results

Figure 2 presents the result of a subject exposed to hypoxia at 35,000 feet. Trials are plotted horizontally along the X-axis, while elapsed time starting from the onset of the seventh cycle of the experimental run is on the Y-axis. The lower sloping dashed line represents the subject's baseline performance rate. The solid line, representing the subject's performance, manifests his deterioration in rate of performance as it curves upward. The lower arrow indicates the point at which the subject went from 100% oxygen to ambient air, while the upper arrow shows return to 100% oxygen.

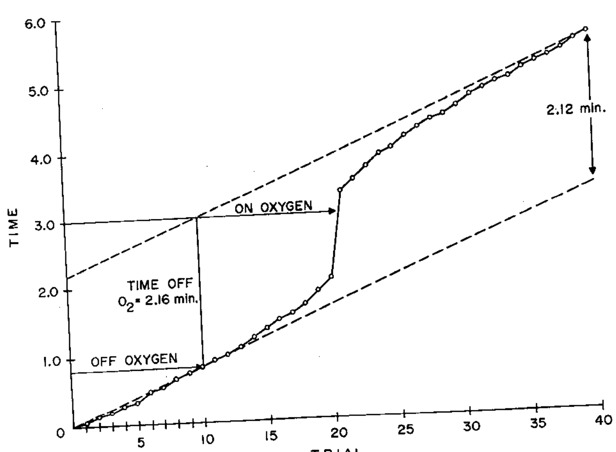

FIGURE 2. Cumulative trial-completion time versus trials, subject PU, 35,000 feet.

Figure 3 presents a plot of performance rate against time off oxygen in tenths of minutes. Performance over a given period of time is expressed as a percentage of baseline or normal work rate. Thus, for this subject the point plotted at 0.6 minute, indicates that for the 0.2 minute between 0.4 and 0.6 minute, his performance was approximately 68% of normal.

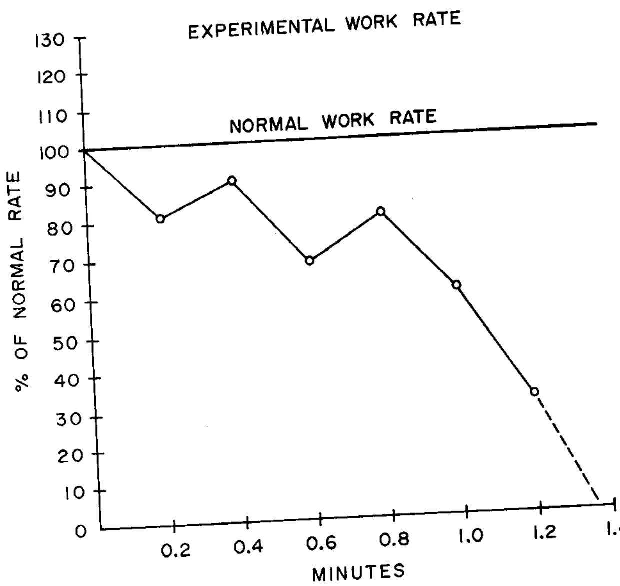

FIGURE 3. Performance for 0.2-minute intervals following switch to ambient air, subject PU, 35,000 feet.

Figure 4 presents the data for all subjects run at 35,000 feet. The solid line represents the subject's normal performance work rate as 100% efficiency, and the broken line shows the average experimental-performance work rate. The average line shows a dip immediately after the subjects begins on ambient air, which may be attributed to the distraction of having to shift one's mode of breathing. Note that at 0.8 minute the average is below all three plotted points. Actually, a fourth point exists, and if plotted, it would appear at 0% performance, as subject MA was put back on oxygen before 0.8 minute elapsed. In like manner, the averages appearing for the points 1.0 and 1.2 are based on scoring those returned to 100% oxygen before that time as having 0% rate of normal performance.

Performance versus time off of 100% oxygen for all seven subjects at 27,500 feet is shown in Figure 5. The broken line shows their average. Once the subject was placed back on oxygen, his experi-

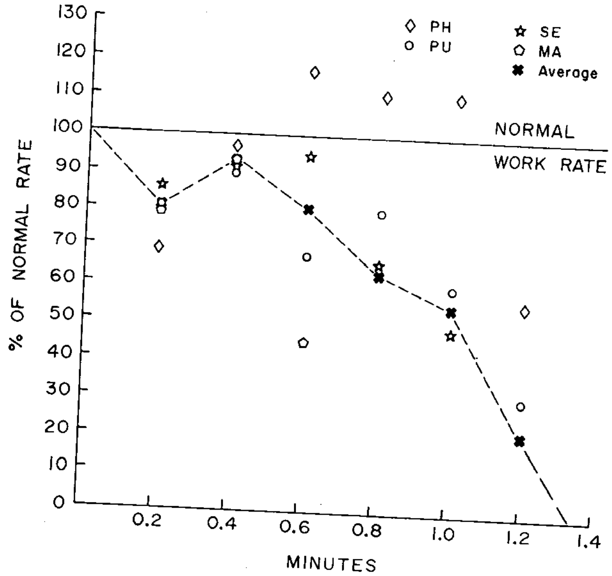

Figure 4. Individual and average performance rates for 0.2-minute intervals, 35,000 feet.

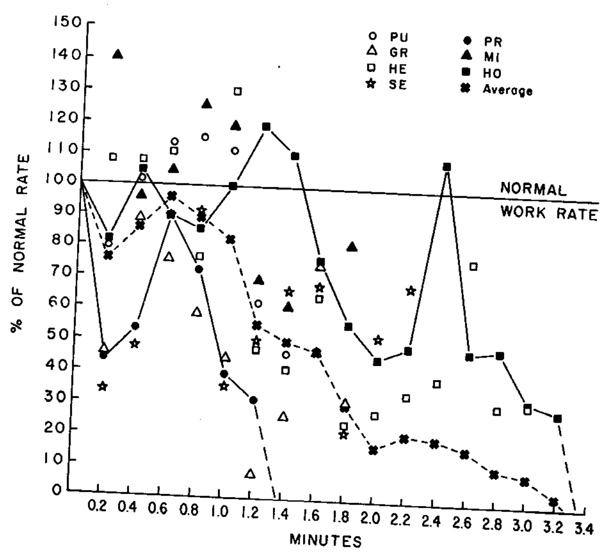

Figure 5. Individual and average performance rates for 0.2-minute intervals, 27,500 feet.

mental work rate was considered to be zero. It is assumed that had he not been returned to oxygen, he would not have completed another trial. The two solid lines represent the performance rates of the two extreme subjects.

A smoothing of the data by use of moving averages for the 35,000- and 27,500-foot groups appears in Figure 6. The use of moving averages tends to even out irregularities in the data and to make underlying trends more prominent. On the 35,000-foot data, averaging the values for three

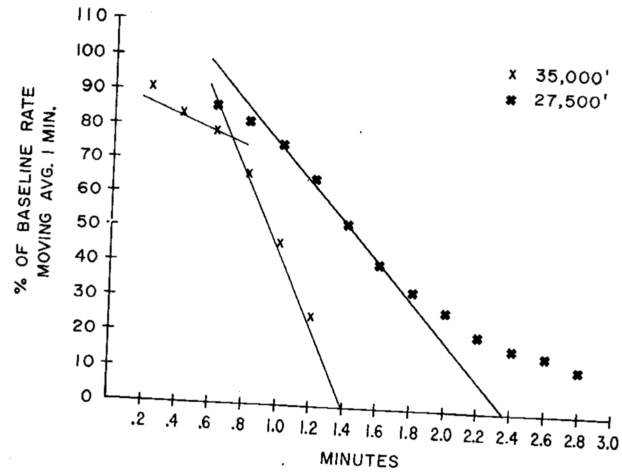

Figure 6. Moving performance-rate averages for 0.2-minute intervals, 27,500 and 35,000 feet.

successive time intervals yielded the average for the midpoint of the three intervals. The 27,500-foot curve covered far more intervals; therefore, the moving average was based on five intervals.

The straight line plotted for the 27,500-foot curve appears to disregard the tail of the curve at the right; however, the tail is caused by two subjects having prolonged performance time. After 2.2 minutes, the other five have been returned to oxygen.

The line for the 35,000-foot data shows a much steeper descent, indicating a more rapid decay in performance. These data are based on relatively few subjects but indicate that this approach yields data not only consistent with prior work but also gives a more accurate depiction of performance deterioration. Rather than having a single value for an altitude, performance capability is expressed at the rate at which deterioration occurs.

For 35,000 feet, there is a fall-off starting at approximately 0.4 minute (24 seconds) of approximately 10% in rate of performance for each 0.1 minute (6 seconds) of time. At 27,500 feet, this value is about 5% for each 0.7 minute of time.

IV. Discussion and Conclusion

This method of reporting deterioration or decay of work rate presents a more accurate means of associating task performance with degrees of hypoxia. This approach offers the possibility of supplanting the concept of time of useful consciousness, which is recognized as being an arbitrary all-or-none depiction of operator capability. Rather than being concerned with TUC, an operational definition is proposed wherein operator capability is assessed by means of changes from baseline performance rate.

The curves representing changes in rate of performance found for the two experimental altitudes manifest a correspondence to blood-oxygen saturation found for these altitudes. Additionally, this form is in accord with equations [1] that reflect the rate of oxygen transfer for a given pressure altitude.

The present study can at best be regarded as a preliminary one, exploring a means of quantifying performance deterioration as a function of hypoxia. The performance tasks were not identical for the two experimental altitudes, the logic task used at 27,500 feet being more difficult. The data suggest that quantified indexes of operator capability follow the blood-oxygen-saturation curves—a correlation that is severely attenuated when employing the dichotomous TUC concept.

It is felt that further investigation utilizing this approach should be undertaken to explore the quantifiable relationships between hypoxia at various pressure altitudes and degradation of operator performance. One immediate pedagogical value of such information would lie in demonstrating to airmen the progressive nature of hypoxia degradation.

REFERENCES

1. Webster, A. P., and Reynolds, O. E.: Time of consciousness during exposure to various pressure altitudes. U.S. Navy BuMed Research Project X 716, 7 August 1946.
2. Van Liere, E. J., and Stickney, J. C. Hypoxia.: Chicago: University of Chicago Press, 1963.
3. Hoffman, C. E., Clark, R. T., and Brown, E. B., Jr.: Blood oxygen saturations and durations of consciousness in anoxia at high altitudes. *Amer. J. Physiol.*, 145: 685–692, 1946.

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