Effects of Hypercapnia and Bedrest on Psychomotor Performance

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Two weeks of continuous exposure to simulated weightlessness (bedrest) and/or an elevated (30 torr) CO_2 environment had no detrimental effect on complex tracking performance, eye-hand coordination, or problem-solving ability. These results were consistent with previously reported behavioral findings which investigated these two factors only as independent stressors.

THIS PAPER REPORTS a study of the combined effects of chronic exposure to an elevated CO_2 environment and simulated weightlessness (bedrest) on the psychomotor performance of human subjects. The experiment was conducted at the USAF School of Aerospace Medicine in response to a NASA request evoked by two considerations. First, the accident which aborted the Apollo 13 mission generated renewed concern about elevated CO_2 environments. Second, the Skylab program focused attention on the problem of long-term weightlessness. The experiment was a multi-disciplinary study and this report is one of several resulting from the integrated effort.

There are no previous reports of the combined or interactive effects of bedrest and elevated environmental CO_2 on cognitive and psychomotor performance. As an independent stressor, chronic hypercapnia has received the greater amount of attention in the performance area. At CO_2 values ranging from 4-23 torr (0.5-3.0%), little, if any, consistent performance decrement has been reported for exposure periods up to 40 d (3,4). Some loss of central nervous system excitability, as indicated by sensory/perceptual tests (e.g., critical flicker fusion), has been reported (4), but the operational importance of this finding is doubtful. A broad range of behavioral tasks has been utilized in bedrest studies (9,10,11). In general, the investigations to date have found little or no psychomotor performance decrement during or following confinement to bed for periods ranging from 1 to 5 weeks.

The research reported in this paper was conducted by personnel of the Environmental Physiology Branch, Environmental Sciences Division, USAF School of Aerospace Medicine. Aerospace Medical Division, AFSC, United States Air Force, Brooks AFB, Tx. The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 80-33.

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MATERIALS AND METHODS

Subjects: Twenty-four volunteer airmen (ages 18-23 years) were selected as subjects. Selection was based on the individual's interest and motivation for participation in the experiment, and the ability to pass a Class III flying physical examination. For participating as subjects, each airman received 2 months hazardous duty pay and 30 d convalescent leave upon completion of the study.

Experimental Design: The experiment was of 6 weeks (42 d) duration and was sequentially subdivided into a 2-week Baseline phase, a 2-week Experimental phase, and a 2-week Recovery phase. The subjects were randomly assigned to one of four groups comprised of six subjects each. Groups 1 and 2 were housed in a large room for the 6 weeks of experimentation. Groups 3 and 4 were housed in an airtight environmental chamber. Aside from the different living quarters, all subjects received identical treatment during Baseline and Recovery. In both housing facilities, the air temperature, ventilation rate, and humidity were maintained at levels established as physiologically neutral. Barometric pressure approximated 744 torr at all times. A daily light/-dark schedule of light 0600-2300 and dark 2300-0600 was followed. An appetizing, well-balanced, and constant caloric diet was eaten by each subject throughout the 42 d experiment.

During the Experimental phase, Groups 3 and 4 were chronically exposed to a 30 torr (4%) CO_2 environment. P_{CO_2} and P_{O_2} were controlled by means of a servoregulatory mechanism, P_{CO_2} remained at 29.8 ± 0.3 torr and P_{O_2} remained at 149 ± 2.0 torr. Groups 1 and 2 continued in an ambient air environment identical to their Baseline phase. Also, during the Experimental phase, Groups 2 and 4 were placed on continuous bedrest, while Groups 1 and 3 remained active. During bedrest, Groups 2 and 4 were allowed to rest on one elbow while eating and bathing, and to leave their beds only for excretory collections.

Every effort was made to keep the subjects motivated and contented. Commercial television was available. Mail was delivered daily and each subject was allowed one free 15-min telephone call each week to any point in the continental United States. Books and simple hobby kits were allowed. Smoking was prohibited. Those subjects who smoked were light smokers and found this restriction only a minor inconvenience. With their permission, both subject groups were monitored 24 h a day by closed-circuit television.

Performance Measures: Prior to the initiation of the Baseline phase, a 2-week period was devoted to giving the subjects orientation and training on the SAM complex coordinator and the Repetitive Psychometric Measures. The complex coordinator is a subject-paced tracking task involving joystick and rudder controls. The device requires the lining up of adjoining red and green lights simultaneously in one vertical and two horizontal rows by carefully coordinated movements of the hand- and foot-operated, spring-loaded controls. When the red and green lights are successfully matched and held for a half second, a new problem is automatically presented by changing the pattern of lights to be matched. Scoring is based on the total number of successful matches accomplished per unit of time. In the study reported here, performance sessions were 30 min in duration. During training, Baseline, and Recovery, subjects received two sessions each day (morning and afternoon). Subjects were randomly assigned each session to one of two complex coordinator devices. The data analyzed were the daily mean session scores for the second week of the Baseline phase and the first week of the Recovery phase. During the Experimental (bedrest/CO_2) phase, none of the subjects was allowed to perform or practice on the complex coordinator.

The Repetitive Psychometric Measures (RPM) is a battery of six paper and pencil tests (7). Each of the tests measures ability on one of six well-established factors or attributes: aiming, flexibility of closure, perceptual speed, visualization, number facility, and speed of closure. For each of the tests, 20 forms equated for difficulty have been developed (6). Three important considerations contributed to the selection of this battery for use in the experiment. First, the battery was developed for use in longitudinal studies where it is desirable to test repeatedly at frequent intervals. The 20 forms prevent the memorization of any particular format. Second, by use of clipboards, the subjects could take the tests while lying in bed resting on one elbow. Thus, testing of some psychomotor skills could be accomplished daily, even during the Experimental phase. Third, the whole battery could be administered in approximately 20 min. Scoring is based on the number of correct solutions or responses for each test.

All subjects were tested once daily on the RPM and, on any day, all subjects received the same form of each of the six tests. The logistical design of the experiment obviously required independent administration of the battery to the subject groups assigned to the air vs CO_2 conditions. Groups 1 and 2 (air) received the test battery at 0900; Groups 3 and 4 (CO_2) at 0930. Throughout the three phases of the experiment, all 24 subjects took the RPM tests while lying down in their assigned bunks. Data obtained daily during the second week of the Baseline phase, both weeks of the Experimental phase, and the first week of the Recovery phase were submitted to repeated measurements analyses of variance.

The subjects completed subjective fatigue form questionnaires (8) at 3 h intervals from 0600 through 2100 on Monday, Wednesday, and Friday of each week during all phases of the experiment. The results of these self-ratings will be reported at a later date in a paper devoted exclusively to subjective fatigue.

RESULTS AND DISCUSSION

Repeated measurements analyses of variance revealed no significant ($p > 0.05$ considered nonsignificant) effect of the bedrest and CO_2 treatments, either singly or in combination, on complex coordinator performance or any of the six RPM scores. Complex coordinator performance did reveal significant improvement within both the week preceding ($F = 19.28$, 6/120 d.f., $p < 0.001$) and the week following ($F = 21.49$, 6/120 d.f., $p < 0.001$) the Experimental phase (Fig. 1). Thus, learning the tracking task was still occurring during the experiment. However, the presence of a learning or practice effect did not complicate the interpretation of no performance impairment related to bedrest and/or CO_2, as learning occurred at similar rates in all four subject groups. In fact, a few investigators have suggested that any detrimental effects of environmental stresses on psychomotor performance are more readily demonstrated during acquisition of skill than during asymptotic levels of skill (1,5).

An overall significant decrement ($t = 3.31$, 115 d.f., $p < 0.01$) in complex coordinator performance occurred from the last day of the Baseline phase to the first day (2 weeks later) of the Recovery phase (Fig. 1). This decrement occurred for all four subject groups and is, therefore, also attributable to general learning phenomena

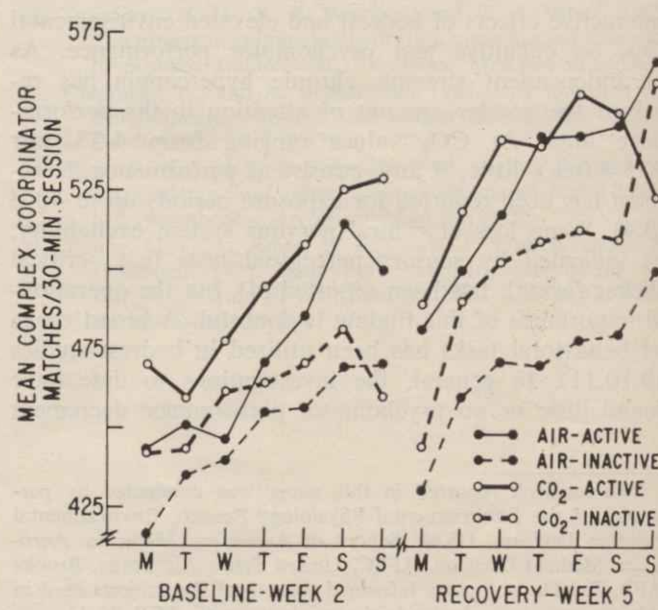

Fig. 1. Mean daily complex coordinator performance before and after the Experimental phase.

TABLE I. MEAN NUMBER OF CORRECT RESPONSES TO RPM TESTS.

RPM Test	Subject Group	Baseline Week 2	Experimental Week 3	Experimental Week 4	Recovery Week 5
Aiming	1	102.8	113.5	110.5	119.6
	2	94.0	108.1	109.6	117.5
	3	112.9	112.6	124.0	125.9
	4	115.8	124.5	129.6	139.0
	Mean	106.4	114.7	118.4	125.5
Flexibility of Closure	1	14.5	18.7	19.5	20.2
	2	12.4	13.2	13.9	16.5
	3	17.3	18.8	21.5	24.0
	4	16.9	18.7	20.7	23.1
	Mean	15.3	17.4	18.9	21.0
Perceptual Speed	1	35.9	37.2	38.3	39.6
	2	39.6	37.6	41.5	43.3
	3	46.5	46.3	52.7	52.7
	4	40.8	39.5	43.7	45.1
	Mean	40.7	40.2	44.0	45.2
Visualization	1	47.5	51.4	51.9	55.3
	2	47.7	49.6	49.2	55.0
	3	55.0	54.7	55.6	60.5
	4	52.8	53.0	54.1	60.1
	Mean	50.7	52.2	52.7	57.7
Number Facility	1	38.6	39.8	41.7	42.7
	2	34.9	35.5	38.2	38.6
	3	33.4	34.0	36.0	36.1
	4	32.9	33.1	36.0	37.2
	Mean	34.9	35.6	38.0	38.7
Speed of Closure	1	37.1	38.1	38.1	46.2
	2	33.7	33.3	32.8	39.2
	3	38.6	40.7	41.8	50.9
	4	36.9	37.6	38.4	45.5
	Mean	36.6	37.4	37.8	45.4

and not to the experimental treatments. Two weeks without practice simply resulted in some loss of skill. It is of interest to note that, for each subject group, mean performance by the third day of the Recovery phase was equal to or superior to any daily mean performance observed during the Baseline phase. Thus, the skill acquired during Baseline was rapidly (within 1 or 2 days) reestablished and was beneficial to a continued performance improvement during the balance of the Recovery phase.

Although there were no experimental treatment effects on the RPM scores, a significant week-to-week effect was found for the overall means of each of the six tests (F ratios were aiming, 37.29; flexibility of closure, 45.46; perceptual speed, 39.39; visualization, 31.07; number facility, 21.87; speed of closure, 79.15; 3/60 d.f. and $p<0.001$ in all cases). The mean number of correct responses for each test are presented in Table I and indicate a consistent overall improvement from Baseline-Week 2 through Recovery-Week 5. As with the complex coordinator, the RPM practice effect occurred in all four groups and, therefore, did not confound the interpretation of treatment effects. Since the collection of these data, other investigators (2) have reported a similar practice effect using the first seven forms of the six RPM tests.

SUMMARY

The evidence from this experiment consistently indicated that 2 weeks of exposure to bedrest and 30 torr (4%) CO_2 had no significant effect, either alone or in combination, on complex tracking performance, eye-hand coordination, or problem-solving ability. These results are consistent with previously reported behavioral findings which have investigated these two environmental factors only as independent stressors. The results also further substantiate the ability of the human to withstand the environmental rigors of space flight.

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