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Rigorous testing instruments and psychometric methods are required to assess the effects of environmental stressors upon cognitive performance. This paper presents findings and illustrates our methodology for evaluating the effects of several types of environmental stressors. Various cognitive performances were investigated experimentally with paper and pencil tasks in repeated-measures paradigms for several high altitudes, an altitude-treatment strategy, dehydration, cold, and atropine in a hot environment.

Cognitive performance was impaired on most tasks by each stressor. Impairments were usually due to decreases in the rate of performance rather than increased errors, e.g. problem solving rates decreased linearly from 4500-7600 m (15,000 - 25,000 ft) high altitude during a 40-day progressive exposure. Recovery of performance during 2 days at 4600 m depended upon the task; not all tasks improved fully. A treatment strategy (tyrosine) minimized altitude-induced performance impairments on some tasks.

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EFFECTS OF VARIOUS ENVIRONMENTAL STRESSORS ON COGNITIVE PERFORMANCE

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Rigorous testing instruments and psychometric methods are required to assess the effects of environmental stressors upon cognitive performance. Optimal instruments should be: 1) stable and sensitive, 2) given with minimal training and familiarization, 3) administered in a short time, 4) appropriate for test subjects with varied abilities, 5) useful in different environments, and 6) available in alternate forms for repeated assessment.

This paper summarizes six cognitive performance studies with environmental stressors which illustrate our approach and methodology for assessing environmental effects. The stressors included: hypobaric hypoxia, cold, dehydration, and atropine. The paper describes both our research findings and factors we surmise to be critical to the success of this approach.

METHOD

Subjects

A total of 87 men served as fully-informed medical research volunteers. Eighty were military personnel; seven were civilians.

Assessment Metrics

Cognitive performance was assessed with nine tasks. The Computer Interaction, Tower, and Map Compass tasks were developed in our laboratory (Banderet, Benson, MacDougall, Kennedy, & Smith, 1984; Jobe & Banderet, 1984); the other six tasks were adapted from the Navy's Performance Evaluation Tests for Environmental Research (PETER) Program (Bittner, Carter, Kennedy, Harbeson, & Krause, 1984; Carter & Sbisa, 1982). All tasks were generated by computer and printed, off-line, on a laser copier. Each task had 15 alternate forms. Task descriptions and sample items were as described elsewhere (Banderet, Lieberman et al., 1986; Banderet, MacDougall et al. 1986; Banderet, Shukitt, Kennedy, Houston, & Bittner (in review)).

Procedures

Experimental conditions, number of subjects, and elapsed times for cognitive assessment for each study were as shown in Table I. Except for the Dehydration Study, all were repeated-measures experiments. The Inspired Air, Operation Everest II, and Tyrosine Evaluation studies investigated high altitude exposure in a hypobaric chamber.

Repeated testing procedures and methods were similar to those for the PETER Program (Bittner et al., 1984; Jobe & Banderet, 1984). Initially, subjects were trained and given extensive practice with performance feedback. To insure performance was stable and near-maximal, each task was completed

STUDY	S	CONDITIONS	ELAPSED TIME OF REPORTED MEASURES	REFERENCES
Inspired Air	25	4600 m, 25 °C + 20% RH	1 or 6, 14 or 19, 24 or 29, 38 or 43 h	Banderet & Burse, 1984
Atropine	7	2 mg Atropine, 40 °C + 20% RH	2.0 to 2.5 h	Banderet & Jobe, 1984
Cold & Dehydration	36	-24 °C + 4 mph winds, Restricted Fluid Intake	50 & 54 h	Banderet, MacDougall, Roberts, Tappan, Jacey, & Gray, 1986
Dehydration	18[1]	2% Dehydration (body weight), 20 to 27 °C	9 h	Banderet, MacDougall, Roberts, Tappan, Jacey, & Gray, 1986
Operation Everest II	7	4600, 5500, 6400, 7600, 600, 600 m (25 °C + 75% RH)	8, 15, 24, 31, 38, & 41 Days	Banderet, Shukitt, Kennedy, Houston, & Bittner (in press)
Tyrosine Evaluation	24	4700 m + 15 °C (50% RH), Placebo	1.0 to 4.5 h	Banderet, Lieberman, Francesconi, Shukitt, Goldman, Schnakenberg, Rauch, Rock, & Meadors, 1986

NOTE: The predominate stressor in each study is listed first in the CONDITIONS column.

[1] These subjects were also in the Cold and Dehydration Study.

Table I.--Conditions for our studies of environmental stressors and their effects upon cognitive performance.

12-18 times before subjects were evaluated experimentally. All performance tasks were timed. The Tower, Computer Interaction, and Map Compass tasks were given typically for 5-6 min; all other tasks, for 3-4 min. Each task's actual duration, number of practice administrations, and other specifics were as described in the publications cited.

OUTPUT (number of problems attempted per minute) and ERRORS (number of problems wrong per minute) were calculated for each task. On tasks with limited response alternatives, ERRORS were adjusted to penalize for careless responding. A third performance measure (CORRECT) was calculated to reflect the combination of both problem solving and error rates. CORRECT (number of problems correct per minute) also included the adjustment for careless responding.

Statistical analyses were performed with Analysis of Variance and Student's t (one-tailed comparisons) statistics. Significance levels were $p \leq 0.05$.

RESULTS

The effects of practice on several cognitive tasks during baseline conditions are shown in Figure 1. Each task was practiced seventeen times in 9 days. Practice improved performance 30% (Coding) to 160% (Grammatical Reasoning) above initial values. Although increased practice resulted in diminishing gains in performance, performance was still improving even after 17 administrations.

Some environmental effects have dramatic timecourses. Figure 2 shows data from the same study after subjects were exposed to 4600 m altitude. Each cognitive task was significantly impaired (13-27%) from baseline values 1 or 6 hours after ascent. Impairments on Number Comparison (20%) and Addition (27%) were the greatest. With more time at altitude, performance returned to baseline values on most of the tasks, i.e. Coding, Grammatical Reasoning, Pattern Recognition, Pattern Comparison, and Computer Interaction.

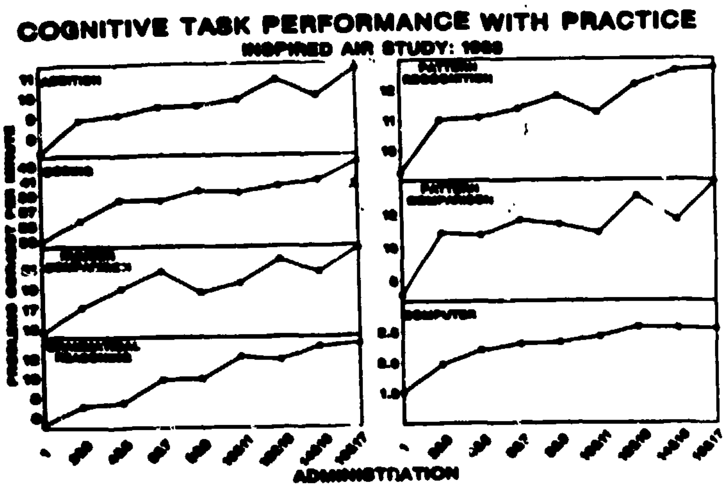

Figure 1.--Performances on seven cognitive tasks with practice.

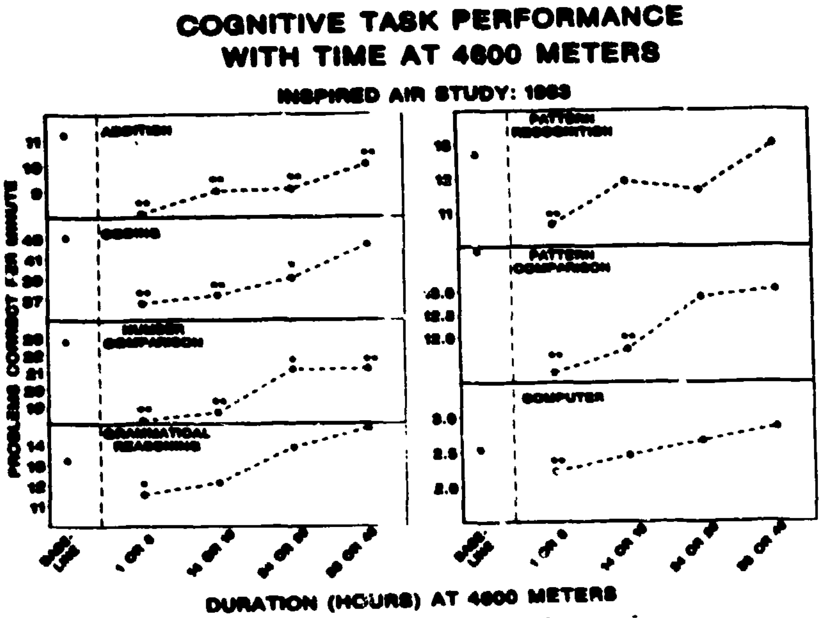

Figure 2.--Performances on cognitive tasks at 4600 meters after varied durations at altitude. Performance impairments, significantly different from baseline, are indicated with an asterisk above each data point.

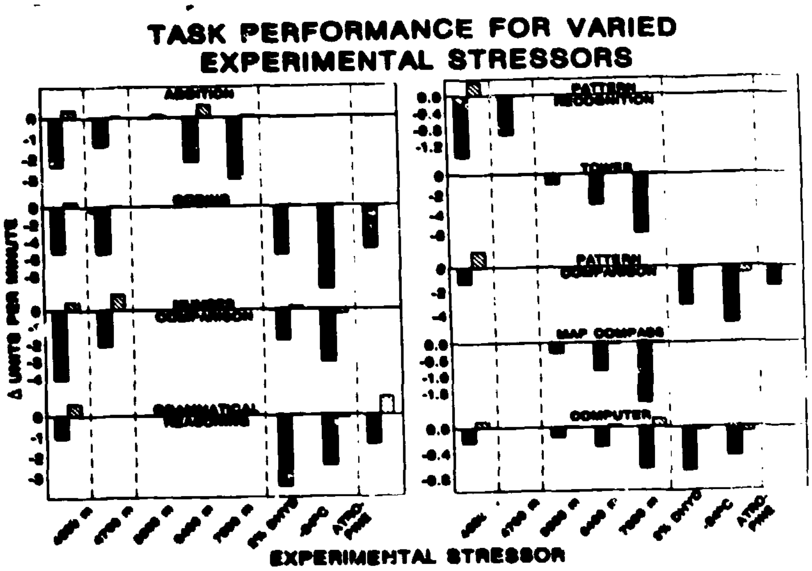

Figure 3.--Changes in task output or errors on nine cognitive tasks for varied stressors.

Cognitive performance was sensitive to a variety of stressful conditions. Impairments in cognitive performance are shown in Figure 3 for all stressors that we investigated. CORRECT, the measure influenced by both OUTPUT and ERROR rates, is not shown; however, it decreased significantly from baseline in all studies with the exceptions of Grammatical Reasoning (Dehydration and Cold Studies), Grammatical Reasoning (Atropine, $p \leq 0.10$), and Pattern Comparison (Atropine, $p \leq 0.10$). All nine tasks were not used in each study; bars are shown for those that were. Changes in OUTPUT are shown as solid bars; changes in ERRORS, as hatched bars. This figure shows slower problem-solving rates were responsible for the performance impairments observed for these varied stressors. ERRORS contributed little. Such OUTPUT impairments at 5500, 6400, and 7600 m increased linearly with increased altitudes during Operation Everest II.

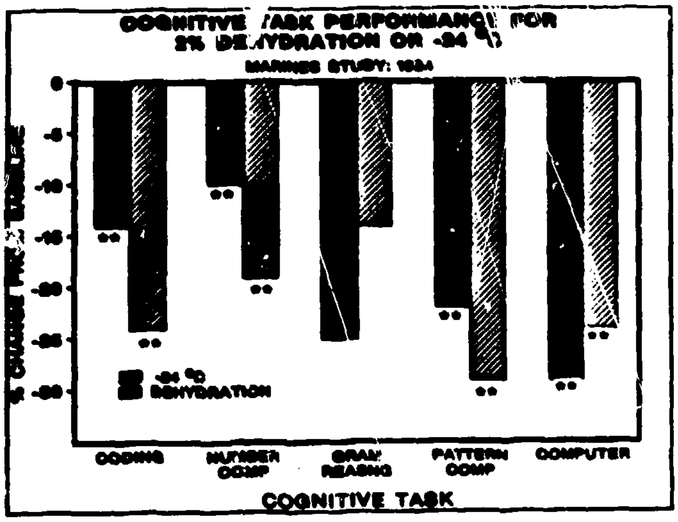

Figure 4.--Percent change from baseline on five cognitive tasks following 2% dehydration or exposure to -24°C and 6 km per hour winds.

The effects of 2% dehydration or windy cold upon five cognitive performance tasks are shown in Figure 4. Tasks involving verbal, spatial, or psychomotor processes were impaired 12-28% of baseline performance by these stressors. Grammatical Reasoning was not.

DISCUSSION

Impairments in cognitive performance were demonstrated for a variety of environmental stressors. Altitude impaired performance on all tasks at 4200 - 7600 m altitude. Furthermore, task performance at altitude was never significantly improved above baseline. With 2% dehydration or windy cold most tasks were impaired; however, Grammatical Reasoning was not. Atropine (2 mg) decreased Coding performance; however, impairments on Pattern Comparison and Grammatical Reasoning were marginally significant.

Impairments in performance resulted from a slowing of OUTPUT rather than increased ERRORS. This was a general finding across the stressors of hypoxia, dehydration, cold, and atropine. This is a very robust finding since our error adjustment exaggerated ERRORS, e.g. errors were doubled on tasks with only two response alternatives. Even with this exaggeration of actual errors, performance changes resulted from a slowing of problem solving.

The effects of altitude had a distinctive timecourse (Fig. 2). After 1 or 6 h at 4600 m all seven tasks were impaired; at 14 or 19 h four were impaired. At 38 or 43 h only two were still decremented. This information is critical for choosing appropriate times to evaluate environmental or treatment effects in altitude studies. It may also explain the negative findings in some earlier altitude studies.

These measures of cognitive performance can also be used to evaluate treatment effects. In data reported elsewhere (Banderet, Lieberman, et al., 1986) tyrosine, an amino acid, resulted in enhanced performance on the Addition, Coding, and Tower Tasks in a hypoxic and cold environment. Performances of the tyrosine-treated subjects did not differ from placebo-treated subjects on the Map Compass, Number Comparison, and Pattern Recognition tasks.

Our data demonstrate that cognitive performance deteriorates with environmental stressors. The fact that such impairments result with well-practiced and overlearned tasks suggests the sensitivity of our methodology. Adequate levels of stressors, enough subjects, practiced tasks with demonstrated stability and sensitivity, appropriate time sampling, and the establishment of near-maximum performance before experimentation are believed critical to our approach.

SUMMARY

Rigorous testing instruments and psychometric methods are required to assess the effects of environmental stressors upon cognitive performance. This paper presents findings and illustrates our methodology for evaluating the effects of several types of environmental stressors. Various cognitive performances were investigated experimentally with paper and pencil tasks in repeated-measures paradigms for several high altitudes, an altitude-treatment strategy, dehydration, cold, and atropine in a hot environment.

Cognitive performance was impaired on most tasks by each stressor. Impairments were usually due to decreases in the rate of performance rather than increased errors, e.g. problem solving rates decreased linearly from 4500-7600 m (15,000 - 25,000 ft) high altitude during a 40-day progressive exposure. Recovery of performance during 2 days at 4600 m depended upon the task; not all tasks improved fully. A treatment strategy (tyrosine) minimized altitude-induced performance impairments on some tasks.

Our results suggest even well-practiced and overlearned tasks deteriorate with environmental stressors. Adequate stressor levels, enough subjects, practiced tasks with demonstrated stability and sensitivity, appropriate time sampling, and the recruitment of maximum performance before experimentation are critical factors for our approach.

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ADDENDUM

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.