664.

Space and Cognition: The Measurement of Behavioral Functions During a 6-Day Space Mission

TH. BENKE M.D., O. KOSERENKO, Ph.D.,
N. V. WATSON, Ph.D., and F. GERSTENBRAND, M.D.

BENKE TH, KOSERENKO O, WATSON NV, GERSTENBRAND F. *Space and cognition: the measurement of behavioral functions during a 6-day space mission.* Aviat. Space Environ. Med. 1993; 64: 376–9.

We measured nonspecific (attention, mental flexibility, psychomotor speed) and visuospatial cognitive processing in a single case study during a 6-d visit on the Russian orbital complex MIR, using computer-based psychometric tasks. Reaction times and accuracy scores showed only minor, nonsignificant changes between preflight, flight, and postflight assessments. These results suggest that several behavioral functions, among them complex visuospatial processing skills, remain essentially intact on short space visits, provided that the performing subject experiences no symptoms of space motion sickness or other physical impairments. Computerized psychometric tasks are a sensitive and flexible tool to measure behavioral functions in space life sciences.

IT IS GENERALLY accepted that intact cognitive function is vital in the control and research activities of every space crewmember. However, in the past two decades research programs and publications in the field of life sciences space research have almost exclusively concerned bioengineering and medical sciences, thus largely neglecting the behavioral and cognitive aspects of space missions (7). This methodological bias probably stems from two beliefs; namely, that psychological theories are hard to verify, and that psychological results are considered "soft" compared to physiological data. Nevertheless, a sojourn in space presents some interesting challenges for cognitive processing, and may induce behavioral changes (3). Theoretically, various factors can exert influence on cognition in microgravity, among them altered sensory perception and integration, the cerebral and vascular-circulatory effects of space motion sickness, but also changes in sleep-waking behavior, permanent stress, or isolation. However, the present understanding of mechanisms leading to altered behavior in space is very limited. Two lines of future research will be required for a closer understanding of cognitive processing in microgravity: appropriate research paradigms and the development of adequate psychological measurement techniques. The present study represents an initial attempt to develop a suitable paradigm for a behavioral assessment in space missions. This joint Austro-Canadian-Russian project, Cogimir, assesses higher cognitive processes, such as attention, memory, and visuospatial processing during short and long-duration spaceflights. By employing "hard," computer-based measurement techniques, Cogimir avoids the confounds introduced by using self-reports, psychological questionnaires and paper-and-pencil tests. It will be demonstrated that exact monitoring of elaborate cognitive functions during spaceflights is possible, even with relatively simple technical equipment, in a short time and at moderate cost.

Scientific and Organizational Background

Cogimir was part of the Austro-Russian Austromir project, a 6-d mission to the orbital complex MIR which took place in October 1991. Cogimir is a single case study based on models of normal cognitive functioning as hypothesized by cognitive psychology, and of altered or impaired behavior as studied in neuropsychology (4). The value of single case studies has been widely discussed; today, most cognitive neuropsychologists agree that studies assessing the behavioral performance of single subjects allow valid inferences about cognitive processes in general (2). Cogimir had to accept several constraints originating from the general mission framework, among them a short experiment duration (30 min)

From the Neurological Department, University Clinic, Innsbruck, Austria (Th. Benke and F. Gerstenbrand); IMBP (Institute for Medical-Biological Problems), Moscow, Russia (O. Koserenko); Department of Psychology, University of British Columbia, Vancouver, Canada (N. V. Watson).

This manuscript was received for review in May 1992. It was revised and accepted for publication in September 1992.

Address reprint requests to Dr. Thomas Benke, Assistant Professor, University Clinic of Neurology, Anichstr. 35, A-6020 Innsbruck, Austria.

and repeated measurements in a pre-fixed schedule. To avoid measuring random fluctuations instead of flight-related alterations, a setup was chosen where both flight candidates were trained extensively before the flight until they reached their apparent maximum of test performance; declines from this peak level during or after the flight would then be taken as flight-induced changes.

METHODS

Technology

MEL (Micro Experimental Laboratory, 6), a commercially available integrated software system which has proved useful in experimental psychology, was employed for psychometric measurements. MEL generates visual stimuli, stores experiment specifications and is equipped with an advanced system for data analysis. MEL's software is sufficiently flexible for quick adaptation during the period of test generation. The system was installed and run on the hard disk of the central processing unit (total programme size 3 MB). Tests were presented on a 158 × 228 mm monochrome screen, and reactions to stimuli were recorded via keyboard; on most tests only one or two keys had to be used for answering stimuli.

Tests

Test designs and stimulus features followed classical tasks of experimental and clinical psychology. Psychomotor speed and sustained attention were measured by two reaction time tests: simple reaction time (SREACT) required immediate reaction (pressing of a key) to one, choice reaction time (CREACT) to one of two symbols appearing after variable interstimulus intervals. Mental flexibility was tapped by a Stroop-paradigm (ARROWS); subjects reacted to arrows pointing briefly either left or right by pressing one of two corresponding keys. Stimuli appeared in random sequence in one half of the screen; thus, four conditions, two congruent (e.g., arrow pointing left, located in left visual field) and two incongruent (e.g., arrow pointing left, located in right visual field) were created and required constant mental set shifting.

A central question of the experiment was whether microgravity-induced altered sensory integration had any impact on specific cognitive functions. Thus, we studied visuospatial processing, which is a sensitive indicator of alterations in visuomotor, proprioceptive and vestibular input. Visuospatial perception was tested by two modified versions of the line orientation test (1). Stimuli were single target lines (length 25 mm) appearing tachistoscopically (stimulus duration 250 ms) and without previous fixation point in 16 different angular directions (every 10°) of a semicircle; the vertical and both horizontal directions were excluded from the study. After a delay period (500 ms), the target line had to be identified on a response array, a semicircular rosette of 19 lines, each supplied with a letter of identification on its peripheral end. Subjects had to match target and response line and then press the appropriate letter. Stimulus sequence was randomized; each stimulus was presented twice. On LINE 1, stimuli were presented in the center of the screen; on LINE 2 they were shown eccentrically.

Working memory for spatial location was tapped by SPATLO. On this test, a set of four, five, or six letters in a two-dimensional spatial arrangement was presented during a learning period of 10 s. Then, the previously shown letters appeared one by one in a centered frame; subjects were required to locate each letter from memory on a grid of 3 × 4 positions. Each position was marked with a digit (1–12); letter position was indicated by pressing the appropriate digit. SPATLO made demands on the ability to keep a two-dimensional spatial arrangement in mind while being simultaneously busy with distracting procedures like recalling, locating, and matching symbols.

Tests were presented over a 30-min period in a fixed sequence and with a short optional break before every new task. During the test session the cosmonaut was fixed to a chair while the monitor and keyboard were attached on a desk in about 50 cm distance. To avoid learning effects, stimuli appeared in random order; for SPATLO, a variation of letter sets was used. Reaction times (RT, in milliseconds), and accuracy scores (AC, percentage correct) were recorded and evaluated for every single trial. Except in SREACT where no accuracy scores were obtained, all resulting data are functions of RTs and AC scores; thus, for a proper evaluation and interpretation of test results, both latency and accuracy have to be considered.

Procedure

The research protocol was approved by the project's Human Use Committee; both trainees gave their informed consent to participate after being informed about the nature and purpose of the experiment, its potential hazards, and their right to withdraw from the study. During the design period of the investigation, all tasks were repeatedly administered to two populations of healthy subjects at the Department of Neurology, University of Innsbruck, and at the IMBP, Moscow, who were age- and education-matched to both flight candidates (C1 and C2). Based on this pilot study, several adaptations, changes, and improvements were made to assure the functionality of the final test versions and to avoid ceiling or floor effects. Both trainees were instructed to rank accuracy over speed in all tests. To reach the maximum performance level (high accuracy scores and short reaction times) both candidates were made familiar with the tasks in approximately 30 test sessions over a period of 8 months. This training increased AC's about 20% to 30% and reduced RT's by 60% to 70% in both subjects. For the actual experiment a single-case sequential testing procedure (performed by C1) was used with 4 preflight, 3 inflight and 3 postflight test sessions. Preflight reference measures were recorded on days 54, 30, 28, and 6 before the start; however, training was continued during this period. Despite the length of this recording period, preflight results were homogenous, documenting that a stable condition at a high performance level had been reached by both candidates. Flight sessions were held on days 1, 3 and 6 of C1's visit on the orbital complex; the first inflight session was performed after an approximate duration of

TABLE I. RESULTS FROM TESTS OF PSYCHOMOTOR SPEED, SUSTAINED ATTENTION AND MENTAL FLEXIBILITY.

	RT (ms)				AC (% correct)			
	pre	F	post	p	pre	F	post	p
SREACT	242.7	249	244.7	ns	—	—	—	—
CREACT	382	369	380.3	ns	95	94.7	94	ns
ARROWS	316.5	330.7	311.3	ns	89	94.7	89.7	ns

Pre = preflight; F = flight; post = postflight; p = p value (Kruskal-Wallis analysis).

56 h in microgravity, a period filled with the routine start, approaching and coupling procedures. Postflight test dates were on days 1 (several hours after landing), 2, and 5, except for LINE 1 and LINE 2 which were only run on postflight days 1 and 5. For statistical evaluation, all preflight, flight and postflight data were averaged; the three resulting groups were compared in a nonparametric one-way analysis of variance (Kruskal-Wallis test).

RESULTS

Personal information from the cosmonaut (C1) as well as objective measurements (EOG, cardiovascular recordings, ECG) and observations (TV monitoring) indicated that C1 experienced no symptoms of space motion sickness or other impairments of his physical condition at any time of the flight. All inflight measurements were performed according to schedule and without any hardware or software problems. Nonspecific tests showed only minor, statistically nonsignificant fluctuations but generally maintained preflight performance levels (Table I).

On both line orientation tasks RT's and AC's fluctuated only slightly during the observed periods (Fig. 1a and 1b); a Kruskal-Wallis analysis revealed no significant group differences. Even in the first hours of adaptation to microgravity, no marked changes in performance, such as decreased processing speed or higher error rates, were observed. As a consequence of more complicated task demands, noncentered stimuli (LINE 2) were processed less accurately than centered lines (LINE 1), whereas latency scores differed only marginally between both test versions.

Similarly, only insignificant changes in speed or accuracy were found in SPATLO. Latency curves (Fig. 2) were highly consistent for the three observation periods with similar shapes and moderately increased overall RT's for larger letter sets. Variation between preflight, flight, and postflight accuracy scores was also negligible.

DISCUSSION

Despite the interference of many physical and psychological factors, repeated measurements revealed only minor behavioral changes in cognitive processing during a 6-d spaceflight; similarly, postflight measurements differed only insignificantly from the pre- and inflight performance levels. These fluctuations never reached levels of statistical significance in comparison with preflight reference values. Flight performance, as assessed by speed and accuracy measures, was stable in nonspecific functions such as sustained attention, psychomotor speed, and mental flexibility, but also in specific tasks of spatial working memory and spatial perception. What is particularly surprising is the constancy of visuospatial processing in all test sessions, as experiments (5) have shown that human spatial processing is quite sensitive to alterations of vestibular, oculomotor, and postural input, all of which are dramatically affected in microgravity conditions. Performance changes in the observed range may rather be interpreted as nonspecific signs caused by adaptation to a different envi-

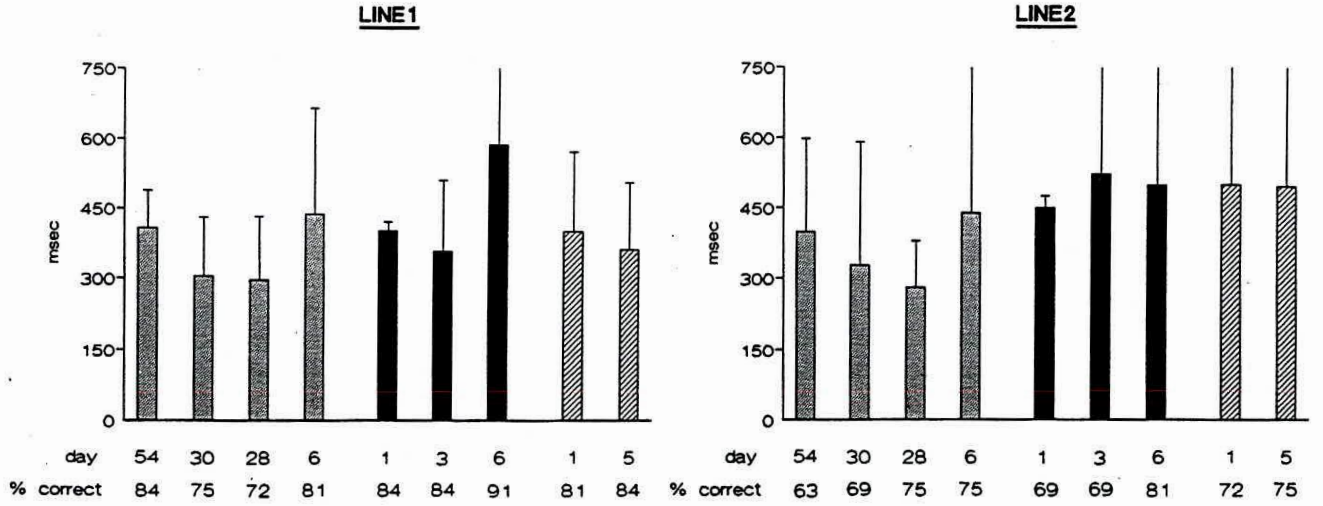

Fig. 1a and b. Reaction times (graphs) and accuracy scores (below x-axis) of experiments LINE 1 (a, left) and LINE 2 (b, right). Bars represent average scores of four preflight (dotted bars), three flight (black bars) and two postflight (hatched bars) test sessions. Day of testing period is indicated on x-axis.

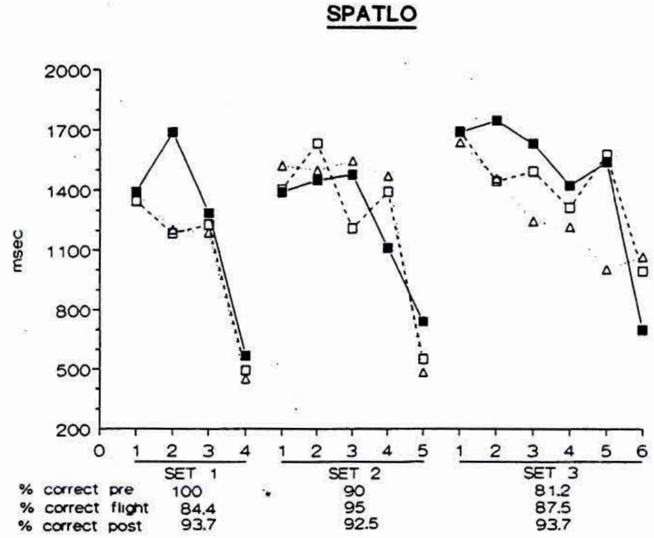

Fig. 2. Recall for spatial location of letters. Lines indicate average of four preflight (broken line, empty rectangles), three flight (solid line, filled rectangles) and three postflight (dotted line, empty triangles) latency measures; letter sets (1–4, 1–5 and 1–6) and accuracy measures are given below x-axis. Only correctly identified letter locations are included in this sample.

ronment, stress, or unstable concentration than as specific microgravity-related effects.

Several factors are presumably relevant for the cosmonaut's steady cognitive performance in microgravity. Most importantly, it appears that C1's physical condition was unimpaired during all flight phases and that he was able to keep up with and adapt to microgravity-related body changes, and also with altered sleep cycles and the large load of scientific, control, and communication work onboard. In addition, compensatory mechanisms may play a crucial role for the maintenance of spatial cognition. Thus, it is likely that C1 used his immediate visual environment, such as the contours of the monitor or the outlines of the cabin, as stable reference frames for his visuospatial performance. These extrapersonal aids may provide sufficient support in two-dimensional tasks to overcome the "noisy," altered, or missing information from systems mediating body posture and position.

It is worth emphasizing that the absence of major behavioral microgravity-related changes in our study can certainly not be generalized for future space missions. The dataset of Cogimir is relatively small and was collected from a single, highly motivated and healthy subject during a short exposure to microgravity. Our findings are, therefore, not suitable to preclude alterations of behavior in other cognitive tasks, or during longer term flights; neither can they predict the performance of subjects with motion sickness. However, they suggest that a high level of cognitive performance can be maintained in microgravity. In addition, they indicate that exact control of "hard" cognitive data is possible within the constraints of space missions, during both the training and inflight phases. Further studies, especially from long-duration flights, will be necessary to confirm and extend these findings.

ACKNOWLEDGMENTS

The authors would like to thank Franz Viehböck, the cosmonaut of the Austromir project, for his helpful suggestions during the training period, and for his committed performance on all experiments. This study was supported by the Austrian Ministry for Science and Research.

REFERENCES

1. Benton AL, Varney R, Hamsher K deS. Visuospatial judgement: a clinical test. Arch. Neurol. 1978; 35:364–7.
2. Caramazza A, McCloskey M. The case for single patient studies. Cog. Neuropsychol. 1988; 5:517–28.
3. Christensen JM, Talbot JM. A review of psychological aspects of space flight. Aviat. Space Environ. Med. 1986; 57:203–12.
4. Ellis AW, Young AW, eds. Human cognitive neuropsychology. London: Lawrence Erlbaum, 1988.
5. Kerr B, Condon SM, McDonald LA. Cognitive spatial processing and the regulation of posture. J. Exp. Psychol. 1985; 11:617–22.
6. Schneider W. Micro Experimental Laboratory: an integrated system for IBM PC compatibles. Behav. Res. Method. Instr. Comp. 1988; 20:206–17.
7. Taylor AJW. Behavioural science and outer space research. Aviat. Space Environ. Med. 1989; 60:815–6.