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COGIMIR - How to Measure Cognitive Functions in Space*

1. Introduction

Every survey of research programs and publications in the field of life science space research of the past two decades shows a heavy bias towards bioengineering and medical sciences. Thus, mental, emotional, and cognitive studies of space flights have been neglected or at least postponed to investigations of vestibular functions, bodily fluids, or altered sensorimotor control, just to mention some common topics [1]. However, visits in outer space are endowed with some interesting psychological aspects, and they may also induce a number of changes in behaviour and cognition [2]. It is also evident that the intactness of cognitive functions like attention, memory or visuospatial processing plays a vital and essential role in control and research activities of every space personnel. The exact reason why cognitive studies have been largely abandonned is unclear. One assumption is that psychological data are widely considered "soft" as compared to blood pressure values, electromyographic curves or laboratory data; a second that psychological models seem highly theoretical to researchers in biology and medicine. COGIMIR, a part of the cooperative AUSTROMIR project has been developed by Austrian and Russian neuroscientists with the aim of studying higher cognitive functions by means of "hard", computer based measurements. This paper describes the research guidelines, technical methodology, the experiment's procedure and some results of the COGIMIR study to demonstrate that exact monitoring of even elaborate cognitive functions is possible during space flights, even with a relatively simple technical equipment, in short time and at moderate cost.

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2. Scientific Approach

The scientific background of COGIMIR is based on models of normal cognitive functioning as hypothesized in cognitive psychology and of altered or impaired behaviour as studied in neuropsychology [3]. Within the AUSTROMIR frame of organization COGIMIR had to accept several constraints, among them a short experiment duration, repeated measurements in a fixed schedule and a single subject to perform the tasks. The value of single case studies has been discussed extensively [4]; today there is general agreement among researchers in the field of cognitive neuropsychology that single case studies allow valid inferences about cognitive processes. However, the evaluation of time series and repeated measurements of psychometric data may pose an uncommon statistical problem [5]. To avoid measuring random fluctuations instead of flight-related alterations a set-up was chosen where both flight candidates were trained until they reached their maximum of test performance before the flight; declines from this peak level during the flight would then be considered as possibly microgravity-related. For estimating cognitive functions we introduced the use of computer based psychometric measurements, an advanced assessment technique which has proved increasingly attractive in experimental psychology and clinical neurology [6, 7].

3. Methods

3.1. Technology

COGIMIR is a computer based psychometric device based on MEL (Micro Experimental Laboratory, 6), a commercially available integrated software system for experimental research. MEL generates visual stimuli, measures reactions, stores experimental specifications and is also equipped with an advanced system for data analysis. Its high flexibility allows the production, change and adaptation of different experimental tests in relatively short time. MEL was installed and run on the hard disk of DATAMIR (total size 3 MB). To run the experiment, a subtest had to be chosen from a menu and was then presented on a 158 x 228 mm monochrome screen. Reactions to stimuli were recorded via a keyboard; for most tests only one or two keys were designated for answering stimuli.

3.2: Tests

Test designs and stimuli followed classical tasks of experimental and clinical psychology. Six tests were selected to tap non-specific (SREACT, CREACT, ARROWS) and specific (LINE 1, LINE 2, TIMEST, SPATLO) cognitive functions (Table 1). One of the central questions of the experiment was whether microgravity induced altered sensory integration had any impact on visuospatial processing as assessed by LINE 1, LINE 2 and SPATLO.

Table 1. Tests Used in COGIMIR

Name	Test function	# Stimuli	Duration (sec)
SREACT	simple reaction time	24	90
CREACT	choice reaction time	48	90
ARROWS	mental flexibility	48	180
LINE 1 & 2	visuospatial perception	64	480
SPATLO	spatial working memory	30	180
TIMEST	time estimation	24	360
Total experiment time			23 min

Tests were presented over a 30 minute period in a fixed sequence and with short optional breaks before every new task. To avoid learning effects, stimuli appeared in random order. Reaction times (RT, milliseconds) and accuracy scores (AC, percentage correct) were recorded and evaluated for every single stimulus. During the design period all tasks were repeatedly administered to two populations in Innsbruck and Moscow whose age and education matched both flight candidates FV and CL. Based on this pilot study several changes and improvements were made concerning the functionality of the final test versions. Also, the proper degree of test difficulty had to be found in order to avoid floor or ceiling effects. The two tests measuring two-dimensional visuospatial processing (LINE 1 and LINE 2) are introduced in Fig. 1. They are modified versions of a clinical test tapping parietal lobe functions [8].

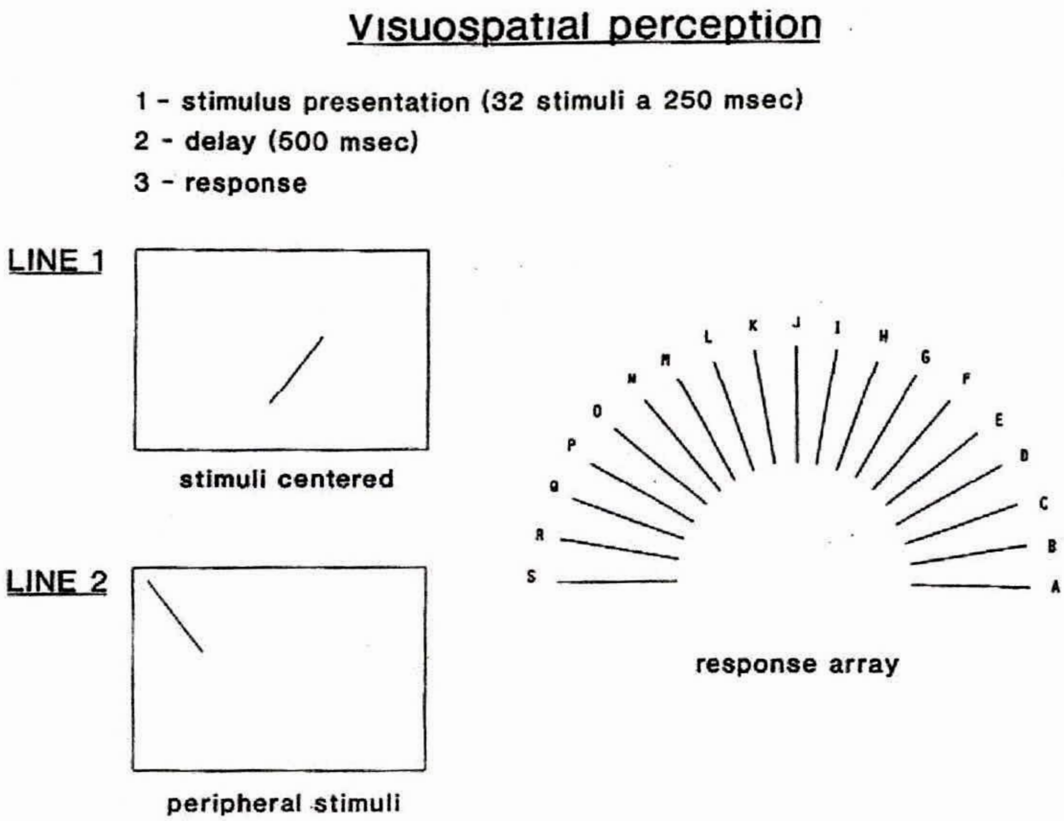

Fig. 1. Line orientation tasks. Stimuli are single lines (length 25 mm) presented tachistoscopically (250 msec) in 19 different angular directions. After a delay period (500 msec) subjects respond by identifying the target line on the response array and by pressing the appropriate letter. Stimulus sequence is randomized, each stimulus is presented twice, vertical and horizontal lines (letters S, J and A) are excluded from the study

3.3. Procedure

For test execution both trainees were instructed to favour accuracy over speed. To reach the maximum performance level (high accuracy scores and short reaction times) FV and CL were made familiar with the tasks in approximately 30 test sessions over a period of eight months. In both subjects this training increased ACs about 20% to 30% and reduced RTs by 60% to 70%. For the actual experiment (performed by FV) a single-case sequential testing procedure was used with 4 preflight, 3 flight and 3 postflight measurements. Preflight sessions (reference measures) were recorded on day 54, 30, 28 and 6 before takeoff. Additional training sessions were also continued during the preflight period. Despite the length of this recording period preflight results were homogenous documenting that FV had reached a stable condition at a high performance level. Flight sessions were recorded on day 1, 3 and 6 of FV's visit on the orbital complex; postflight test dates were on day 1, 2 and 5 after landing.

4. Results

All preflight, flight and postflight data were averaged; the three resulting groups were compared using a nonparametric one-way analysis of variance (Kruskal-Wallis test). Overall, there were no significant group differences on any variable. Minor performance fluctuations were recorded on several test sessions of ARROWS, SPATLO and CREACT throughout the whole experiment. On TIMEST, a tendency to underestimate longer time periods (6, 8 and 10 seconds) became evident on flight days 3 and 6 which also continued for two days after the landing. These fluctuations indicate trends of changing cognitive performance, they, however, did not reach statistical significance. Figures 2 and 3 give an example for the analysis of computer-derived behavioural data.

5. Discussion

A first analysis of the psychometric data obtained from the AUSTROMIR flight shows that FV's cognition remained essentially unchanged during his six-day visit in space. Selective measurements indicated that nonspecific (attention, psychomotor performance, mental flexibility) and specific (time estimation, visuospatial perception, spatial memory) mental abilities were performed without major change in speed or accuracy. Inflight data revealed only slight, nonsignificant fluctuations as compared to the pre- and postflight state. Fluctuations in this range may be interpreted as trends of altered cognitive processing or as adaptation; they also indicate that the test material of COGIMIR was sufficiently sensitive to those factors of a space mission which may exert influence on cognition, among them microgravity, stress, isolation or other microgravity triggered secondary events. However, the absence

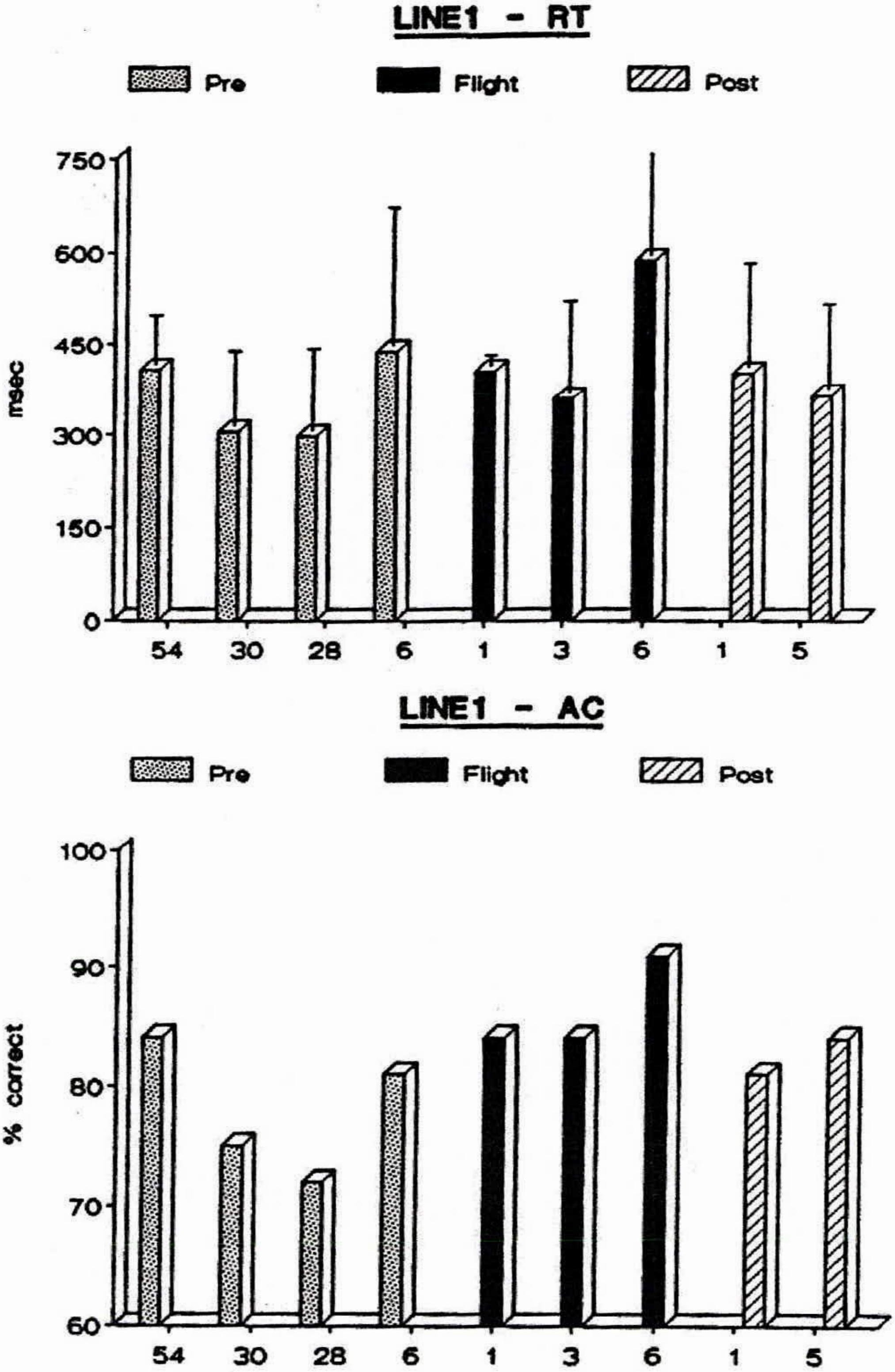

Fig. 2

Figs. 2 and 3. Reaction times (upper panels) and accuracy scores (lower panels) of experiment LINE 1 and LINE 2. Bars represent average scores of 4 preflight, 3 flight and 2 postflight test sessions. Digits below x-axis indicate day of testing period. Overall, RTs and ACs fluctuate only slightly during the observed periods. Non-

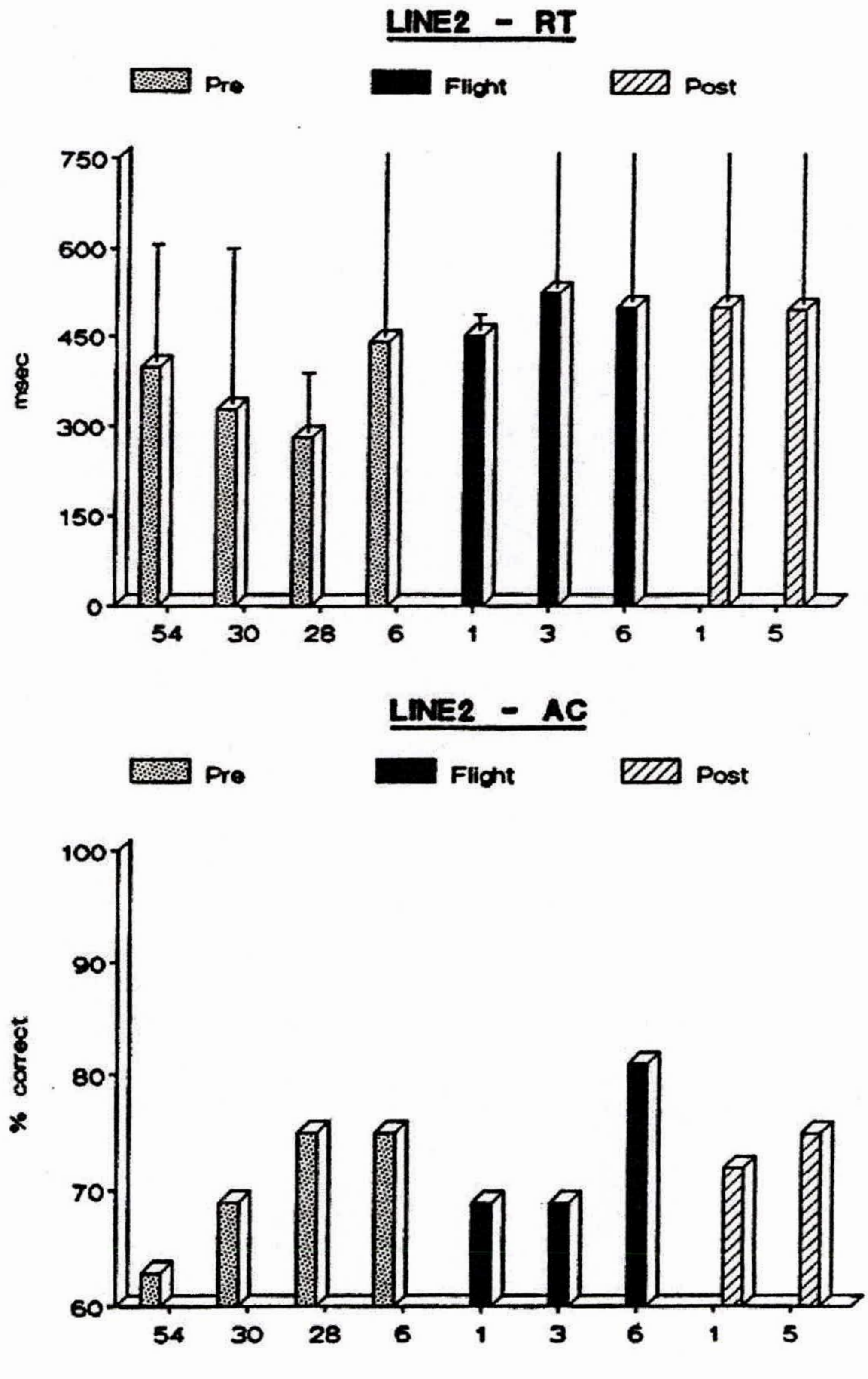

Fig. 3

centered stimuli (LINE 2) are processed less accurately than centered stimuli (LINE 1), whereas RTs differ only marginally. Note that proper evaluation includes the simultaneous judgement of both correlating scores (RT and AC) of cognitive changes in this experiment can certainly not be generalized; the data amount of this study is relatively small, was obtained in a single-case study, during a short flight, and collected from an alltime healthy, well trained and highly motivated subject who showed no evidence for motion sickness in space. Additional measurements performed in long duration flights will provide better evidence.

Yet, these data prove that the present methodology, quite different from paper-and-pencil tests or psychological questionnaires, allows for an exact assessment of "hard" psychological data during space missions. Precise measurements along two performance dimensions (speed and accuracy) and good flexibility are among the advantages of using computer and software technology for research purposes. At present cognitive and experimental psychology have developed many specific test procedures for so-called "higher" cognitive functions; most of these procedures can be adapted and put to use on computer. Future extensions of the system will include the use of acoustic stimuli, voice-onset measurements and a synchronization with biological monitoring systems, e.g. measuring event-related brain potentials. In addition to the assessment of inflight performance computer based psychometrics can easily be adapted to evaluate qualification of flight candidates, to test the cognitive status of flight personnel in preflight periods or the effect of specific training procedures on a subject's cognitive processing.

There is no objection to employ MEL or comparable systems outside space. In fact, computer based psychometrics have been established in a wide range of applications in our clinic, a neurological department with a research group specializing in neuropsychology. Presently experimental studies are done to explore the degree of functional laterality in healthy male and female brains using the tachistoscopic techniques of a lexical decision paradigm. Other research topics are the impact of working conditions on cognition; they include measurements of sustained attention, psychomotor speed and mathematical abilities of workers engaged in night shifts and medical doctors doing stress jobs on intensive care units. Clinical studies serve various aims, among them the exploration of bradyphrenia in Parkinson's disease, the problem of impaired time estimation in brain damaged patients, the cognitive outcome of subarachnoidal bleedings or Lyme disease after successful treatment. Thus, links between space life science research and neuropsychology seem tight and productive. A future approach, probably the most beneficial in its medical application includes the development of therapeutical, computer based aids for cognitive rehabilitation. These treatment procedures will be specially designed to serve the large cohort of brain damaged patients with deficits in language, memory, reading, calculating and other disabling cognitive impairments. This step will shift the computer aided "cognitive" devices from a purely experimental and diagnostic to a therapeutical tool in neurological rehabilitation.

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