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The ALTEA/ALTEINO projects: studying functional effects of microgravity and cosmic radiation

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Abstract

The ALTEA project investigates the risks of functional brain damage induced by particle radiation in space. A modular facility (the ALTEA facility) is being implemented and will be operated in the International Space Station (ISS) to record electrophysiological and behavioral descriptors of brain function and to monitor their time dynamics and correlation with particles and space environment. The focus of the program will be on abnormal visual perceptions (often reported as "light flashes" by astronauts) and the impact on retinal and brain visual structures of particle in microgravity conditions. The facility will be made available to the international scientific community for human neurophysiological, electrophysiological and psychophysics experiments, studies on particle fluxes, and dosimetry.

A precursor of ALTEA (the 'Alteino' project) helps set the experimental baseline for the ALTEA experiments, while providing novel information on the radiation environment onboard the ISS and on the brain electrophysiology of the astronauts during orbital

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flights. Alteino was flown to the ISS on the Soyuz TM34 as part of mission Marco Polo. Controlled ground experiments using mice and accelerator beams complete the experimental strategy of ALTEA. We present here the status of progress of the ALTEA project and preliminary results of the Alteino study on brain dynamics, particle fluxes and abnormal visual perceptions.

Keywords: The ALTEA/ALTEINO projects; Functional effects of microgravity and cosmic radiation

1. Introduction

The interaction between the functional state of the astronauts brain and the space radiation environment has become a focus of investigation for evaluation of future space travel. This is particularly important with the increasing length of human operation on board the International Space Station (ISS), and in the perspective of manned journeys to Mars, with an expected duration exceeding one year outside of the earth's magnetic shield. A conspicuous example of these effects is the abnormal visual perception (*"light flashes",* LF), reported by the astronauts since the Apollo program.

These anomalies occur most often during dark adaptation (Pinsky et al., 1974, 1975). Evidence in accelerator controlled experiments (Charman et al., 1971; Tobias et al., 1971; Charman and Rowlands, 1971; McAulay, 1971; McNulty, 1971; McNulty et al., 1972; Budinger et al., 1972; McNulty and Pease, 1978) and measurements in space (Osborne et al., 1975; Bidoli et al., 2001; Avdeev et al., 2002; Casolino et al., 2003) link this phenomenon to cosmic, probably HZE, particles impacting on the eye. Many related issues, in particular the biophysics of this phenomenon, remain open. The retina appears involved in the perception of LF, yet the brain cortical regions dedicated to vision may be affected by particles as well and anecdotal evidence suggests an effect of heavy ions on the optic nerve. Documented electrophysiological effects of particles on the brain may be related to as yet undetected functional impairment and would raise questions regarding crew safety especially during emergencies. Cumulative effects, possibly overlooked in the past due to the absence of detectable prolonged or irreversible symptoms, still warrant detailed investigations. ALTEA is funded by the Italian Space Agency (ASI) and the Italian National Institute for Nuclear Physics (INFN).

2. Experimental approach

The ALTEA project features three parallel experimental strategies: (1) a study project on animals (mice) in accelerators (ALTEA-MICE), (2) a preliminary project on humans in the space environment (Alteino), and (3) a fully developed space project (ALTEA).

Human studies on LF were performed in the early 1970s under controlled experimental conditions in accelerators (Charman et al., 1971; Tobias et al., 1971; Charman and Rowlands, 1971; McAulay, 1971; McNulty, 1971; McNulty et al., 1972; Budinger et al., 1972; McNulty and Pease, 1978). In these experiments (unacceptable today for ethical reasons), the eyes of human volunteers were exposed to the beam line of the accelerator, with controlled pulsed radiation and a descriptive report of subjective perceptions. As a first important implement, ALTEA will provide objective measurements of the electrophysiological correlates of LF perception and of the interaction between particles and neural structures in the retina and/or visual cortex. The subproject ALTEA-MICE will investigate the effects of heavy ions on the visual system of mice in an accelerator, under controlled experimental conditions (rationale and state of progress of the ALTEA-MICE project are presented elsewhere in this volume). Objective measurements of the effects of particles on visual brain structures will include an advanced EEG mapping system in both the ALTEA and Alteino space experiments.

Alteino (a development of our SilEye particle detectors used on the MIR station in the 1990s (Bidoli et al., 2001; Avdeev et al., 2002; Casolino et al., 2003)) has been hosted in the Russian modulus of the ISS since April 2002. Its purposes are the first EEG data recordings in concomitance with LF perception and particle flux measurement in the ISS (with nuclear discrimination up to Fe). Alteino is providing novel data on cosmic ray particles (reported elsewhere in this volume) and is a useful test for the ALTEA experiment.

Two additional issues are addressed by the ALTEA experiment. In the previous SilEye projects on the MIR station, the particle detectors covered only a minimal percentage of the solid angle and therefore of the particles impinging in the brain. ALTEA covers most of the astronaut's head with its six double detectors, and will permit a 3-D reconstruction of the energy released in the brain by the particles, with discrimination among nuclear species. In addition, ALTEA will monitor the functional state of the astronauts' visual systems and its compliance with the environment conditions in space (such as microgravity) in order to interpret the biophysical mechanisms generating anomalous perceptions due to particles. This is accomplished by the addition of a visual stimulator to the ALTEA equipment.

3. Alteino

The Alteino is composed of two devices: an Advanced Silicon Telescope (AST) and a 14-channel EEG, with a pushbutton to signal LF perception. The AST was implemented from the SilEye and SilEye2 detector system built by our group for use in the MIR station (and therefore named SilEye3 in several instances) and consists of eight planes, each one incorporating 32 silicon strips (2.5 mm pitch). The planes are alternately oriented along the X and the Y view. Two plastic scintillators S_1 and S_2 (1 mm thick) are located at the top and at the bottom of the silicon stack to provide the trigger.

Two sheets of Mylar (50 μm each, sandwiching an aluminum foil (70 μm)) lie between each scintillator and the adjacent silicon plane. The displacement of the foils is symmetric from the top to the bottom and vice versa. Each silicon plane is 8×8 cm^2 and 380 μm thick. The scintillator area is 7.6×7.6 cm^2; the total distance between scintillators (15.6 cm) results in a (bidirectional) geometric factor of 23.8 cm^2 sr.

The AST detects particles releasing energy from 0.4 to 1200 MIP (minimum ionizing particles; 1 MIP = 330 keV/μm for a 380 μm thick silicon chip). The trigger is configured with the logical AND of the signals of the two scintillators S_1 and S_2. The trigger gives the hold signal to the preamplifiers (peaked at 1 μs) and begins the multiplexed acquisition of the $(32 \times 8 = 256)$ channels and their analog to digital conversion. Permanent data storage is performed on PCMCIA cards, periodically substituted and sent to Earth after each measurement sequence. Each card of 660 MB holds about one month of data. EEG data is acquired at 256 Hz and stored on 64 MB PCMCIA cards

3.1. Alteino: the experimental protocols

Alteino has been launched with Soyuz TM34 on April 25, 2002 and set up in the ISS Russian module. Two experimental protocols were conducted: (1) the AST was activated for continuous measurement of particle data (without human monitoring) in order to obtain nuclear-discriminated information about the ISS radiation environment. During the Marco Polo Mission, measurements were performed for six days, with a total of 131 h; (2) the astronaut wore the EEG cap including the 14 pre-gelled electrodes and sat near the AST, holding the pushbutton with one hand to signal the perception of a LF. EEG and AST were then both turned 'on' and acquisition started in parallel, with the astronaut wearing a cloth mask for progressive dark adaptation. This protocol was designed as a pilot search for electrophysiological correlates of LFs and the experimental tuning of software and hardware for the forthcoming ALTEA experiment. Results from the first protocol are presented elsewhere in this volume. Some very preliminary data from the second one are shown below.

3.2. Alteino: the electrophysiological approach

A total of 44 LF events were reported during a 7 h and 41 min observation by the astronaut, with rate of 0.09 ± 0.02 LF/min, consistent with our previous findings with the SilEye2 experiment (Avdeev et al., 2002; Casolino et al., 2003). No significant increase of rate was observed while passing through the South Atlantic Anomaly. Electrophysiological (EEG) events, potentially related to LF, are expected to occur within a time window preceding pushbutton signalling by the astronaut, consistent with the protocol requirements and with the predicted reaction time to sudden stimuli in space. These events are also expected to meet several criteria which are still under definition based also on preliminary Alteino data analyses. The possible structure of an electrophysiological event related to a particle passage in the retina end/or brain, is exemplified in Fig. 1 where the EEG signals from 12 recording channels are shown superimposed in a 3 s epoch. During these 3 s one LF has been reported as indicated by the pushbutton mark at the bottom. Each one of the 12 EEG signals describes the time behavior of the potential resulting from cortical activity and measured from one scalp location. The collection of 12 traces therefore describes the dynamics of the potential measured over a large portion of the cortex. Starting about 1.4 s before the pushbutton mark, the potentials show a clear spatial structure that *might* indicate an electrophysiological event potentially linked to particle passage and the signalled LF. Detailed analyses based on the criteria under definition mentioned above are in progress and will help define strategies to search for electrophysiological transient events correlated with

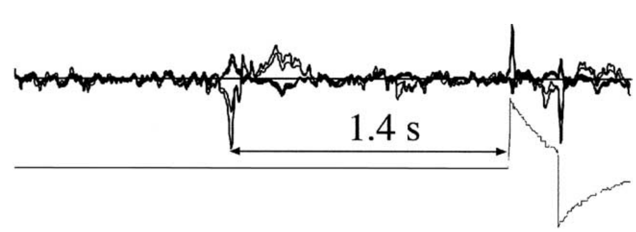

Fig. 1. Example of a candidate electrophysiological event linked to the perception of LF. Superimposed EEG records (3 s) from 12 recording locations on the scalp. The LF is signalled by the pushbutton pressure (lower trace).

LF, possible candidates of electrophysiological signatures of particle passages.

4. ALTEA

The ALTEA facility includes six particle detectors (implemented from the detectors used in the SilEye experiments), a 32-channel EEG system, a visual stimulator and a pushbutton.

The particle detector (SDS: Silicon Detector System) is composed of six identical particle telescopes [SDU (Silicon Detector Unit)] mounted on a helmet-shaped holder also supporting the visual stimulator (Fig. 2). Each SDU is a six-plane particle telescope: the planes are alternately oriented in the two *X* and *Y* directions. On each plane there are two 8×8 cm^2 silicon chips, 380 μm thick, placed side by side, with a 3.75 mm horizontal gap between them. Each chip is divided into 32 strips. Therefore each pair of *X* and *Y* planes features a 32×64 strip grid.

Between an *X* plane and the corresponding *Y* plane there is a vertical gap of 4 mm, while between two *XY* planes there is a vertical gap of 37.5 mm. The geometrical factor (bidirectional) for one SDU is 160 cm^2 sr. The energy of detectable particles ranges from $\approx$5 to 2400 MIP (minimum ionizing particles: 1 MIP $=$ 330 keV/μm for 380 mm thick silicon chip). The energy resolution is 0.6 MIP for each channel of the 12 bit ADC. The EEG system is a 32 channel device, with possible acquisition rates ranging from 128 to 16,384 Hz per channel. The visual stimulator unit (VSU) is composed by two color LCD-TFT oculars XGA 1024×768 pixels at 60 Hz Field of view: 35° diagonal (21 °V V 28 °H) Luminance 5-50 FL; Contrast 40:1 256 colors out of a 16 million colors palette. The total video memory is 2 Mb. Synchronizability of the systems (EEG, VSU and SDS) is within 1 ms. These instruments can be used separately or in any combination, permitting several different experiments (in physics, dosimetry, psychophysics, electrophysiology, cognitive neurophysiology).

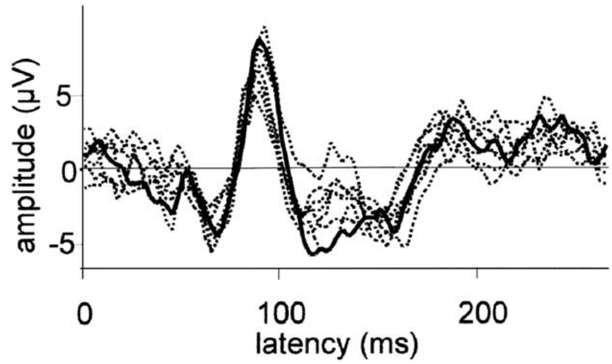

Fig. 3. Comparison of visual responses detected from standard (dashed lines) and new electrodes (solid line).

Electrodes requiring no preparation of the skin or semiliquid gels but that can guarantee comparable impedance and dynamics of standards are under development. The first tests are encouraging. In Fig. 3 are shown the human cortical responses to visual (contrast) stimulation as recorded by a standard electrode (dashed lines, several repetitions) and by a newly designed gel electrode (PMMA-LiClO$_4$-l,2-diethoxyethane doped with nanometric acidic Al$_2$O$_3$) (solid bold line) (Romagnoli et al., 2001).

4.1. ALTEA: the experimental protocols

The ALTEA scheduled protocols are comparable to those of Alteino. The first *(DOSI)* will perform long-term measurements of charged particles inside the ISS without human monitoring; the second *(CNSM)* is aimed at a complete study of the effects of particles on retinal and brain structures in space.

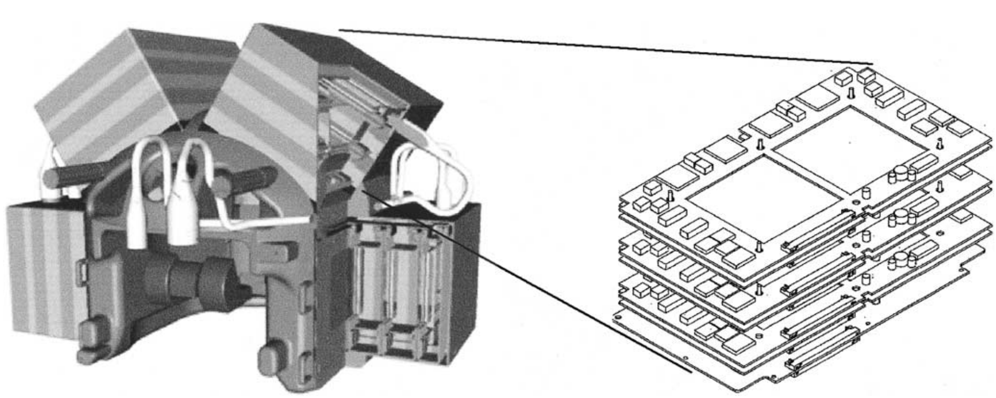

Fig. 2. Left: the helmet shaped holder and the six SDUs (frontal not shown) visual stimulator and harness are also visible. Right: a view of the six double planes in each SDU.

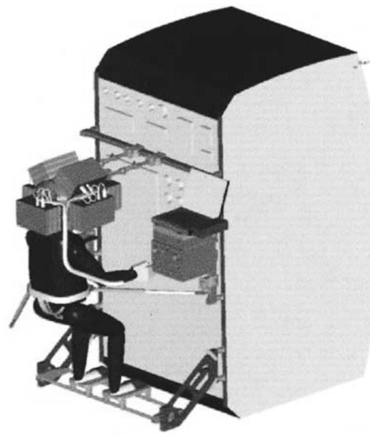

Fig. 4. Schematic of the ALTEA detector mounted on the express rack in the ISS during the manned experiment. During the unmanned experiment the helmet will be turned 90° so to face the rack and protrude the least.

4.1.1. Setup

The ALTEA hardware will be deployed and mounted on the assigned express rack as shown in Fig. 4. The electronics and lap top unit (LTU) will be positioned on the LTU holder.

4.1.2. DOSI

The helmet with telescopes and visual stimulator will be tilted 90° using the pivoting holding arms in order to reduce the protrusion inside the cabin to an acceptable extent for continuous measurements throughout the increment (four to five months of measurement according to current programs). In this protocol the acquisition, with periodic measurements of the pedestals for optimal calibration, is performed automatically by the LTU software.

4.1.3. CNSM

The astronaut will wear the electrode cap, connect it to the LTU, and check the electrodes impedance. Then he/she will move the helmet in the extended position, slide into it, lower the visual stimulator (goggles) to a proper position for visual stimulation, and begin dark adaptation. A second astronaut will launch the program for the concurrent acquisition of particle and EEG data. The same software drives the visual stimulator according to preselected conditions at the beginning, at the end and in the middle of each session (one orbit of 90 min). A total of six sessions are scheduled. An agreement to move ALTEA to the Russian segment of ISS and operate it for longer periods is in progress.

The concurrent acquisition of particle and EEG data will detect the number of particles traveling through each different region of the brain per unit of time, perform nuclear discrimination and calculate the amount of energy delivered to neural tissues. Combining this information with the electrophysiological data and the time of occurrence of LF will provide insights of the possible mechanisms of the effect of particles on brain structures. The retinal/brain responses to standard visual stimulation will allow one to monitor the functional state of the visual system during the experiment.

5. Conclusion

Parallel investigations of the effects of particles on retinal and brain mechanisms completed in space with humans, and in controlled ground-based experiments with accelerators and mice, will permit an assessment, in part, of the resulting possible risks due to transient and cumulative functional changes during long manned flights.

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