References and Notes

1. E. H. Weber, *De Subtilitate Tactus* (1834), in *E. H. Weber: The Sense of Touch*, H. E. Ross and D. J. Murray, Transl. (Academic Press, London, 1978), pp. 59–62.
2. A. H. Holway, J. E. Smith, H. J. Zigler, *J. Exp. Psychol.* **20**, 371 (1937).
3. H. E. Ross, in *21° Convegno Internazionale Scientifico Sullo Spazio* (RIENA, Rome, 1981), pp. 173–182.
4. We found the Weber fraction for the discrimination of polar moment of inertia to be at least 0.70 for cylinders of comparable mass and polar moment of inertia to the test spheres.
5. H. E. Ross and M. F. Reschke, *Percept. Psychophys.* **31**, 429 (1982).
6. H. E. Ross, *Acta Astronaut.* **8**, 1051 (1981).
7. T. Engen, in *Experimental Psychology*, J. W. Kling and L. A. Riggs, Eds. (Holt, Rinehart & Winston, New York, 1971), p. 17.
8. D. W. Rees and N. K. Copeland, *Discrimination of Differences in Mass of Weightless Objects* (WADD Tech. Rep. 60-601, Wright-Patterson Air Force Base, Ohio, 1960).
9. L. R. Young, C. M. Oman, D. G. D. Watt, K. E. Money, B. K. Lichtenberg, *Science* **225**, 205 (1984).
10. A more detailed account of this work is planned for a dedicated issue of *Experimental Brain Research*. This project was supported by a grant to H.R. from the Medical Research Council and a fellowship from the Leverhulme Trust. The apparatus was constructed by RAE & IAM (Farnborough), ESTEC (Netherlands), and the University of Stirling. Our thanks are due to all the crew and backup crew of STS-9, and for the support provided by ESA and NASA.

* To whom correspondence should be addressed.

27 March 1984; 23 May 1984

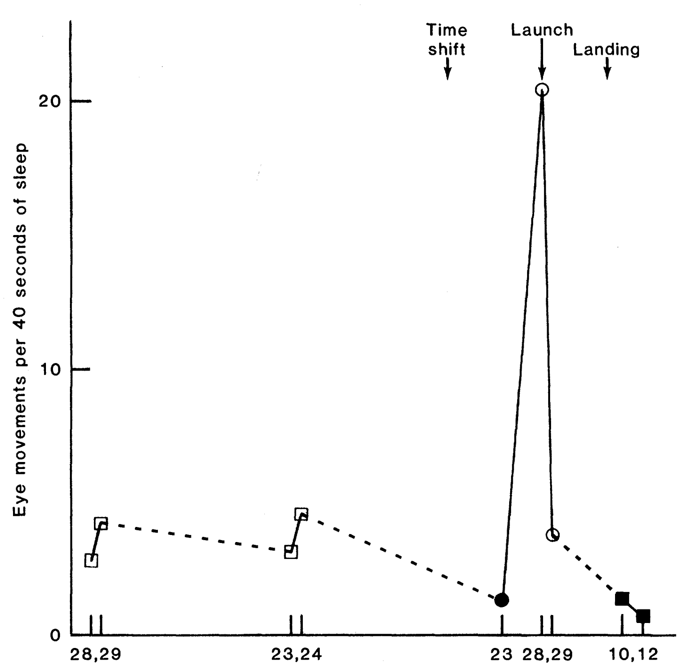
Eye Movements During Sleep in Weightlessness

Abstract. *The number of eye movements during sleep increased during the first sleep period in zero gravity but returned to normal by the second night. These rapid-eye-movement functions in flight may be the first variations of an oscillatory system. The ratio of the higher and lower eye movement frequencies oscillates within normal-gravity limits.*

Experiment 1ES030 was performed to record eye movements and the associated muscle activity during sleep on the Spacelab 1 flight. Measurements were made with Medilog electrophysiological tape recorders. Eye movements during sleep differ from those during wakefulness in frequency and amplitude. A further differentiation between wakefulness and sleep was obtained by recording movement artifacts with an electromyograph (EMG). In the evaluation of the Spacelab data, two variables were to be taken into account: a 12-hour time shift for the payload specialist (PS1) who carried out this experiment and zero gravity. Therefore, baseline measurements were made during sleep 120, 60, and 30 days before flight (days F − 120, F − 60, and F − 30). Measurements were also made during sleep on day F − 5. A 12-hour time shift started for PS1 2 weeks before the launch, the rationale being that most biological rhythms take 1 to 2 weeks to adapt to such a shift. Measurements were also made 2 and 4 days after recovery (days R + 2 and R + 4), but it must be realized that the effects of return to gravity were compounded with the effects of a return to local time. For various reasons, it was feasible to record the sleep parameters only during the early part of the mission. The electromyogram and electro-oculogram were recorded satisfactorily and the rapid eye movement (REM) sleep epochs were clear.

Observations. During the first sleep epoch (night 0) in space, the number of eye movements increased dramatically compared with any of the pre- or post-flight nights, but it returned to normal by night 1 (Fig. 1). Similar fluctuations were seen in the percentage of REM sleep as a function of total sleeping time. On night 1, REM sleep increased to 50 percent, whereas it is normally between 20 and 25 percent of total sleeping time. The abrupt increase is not pathological. Instead, it reflects a temporary imbalance of the REM mechanisms which include other autonomic variables such as heart rate and blood pressure. In pathological conditions, REM sleep decreases rather than increases. However, an increase in REM percent has been found in association with nausea and vomiting during the waking state. Total sleeping time was only 3 hours during the first night in space, but during the second night it increased to 6 hours, which corresponded to the average baseline level.

It has been shown that REM sleep is a sensitive indicator of how information is learned (*1*). This is true even for the rat (*2*). In humans, the informations may be internal (hormonal and metabolic) or external (for example, the learning of a new computer language) (*3*). During REM sleep, eye movement frequencies higher than 1 per second are specifically correlated with learning, whereas lower fre-



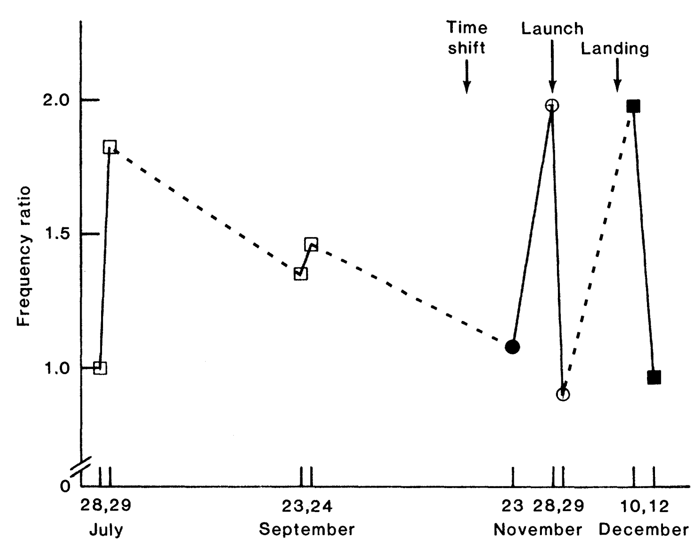


Fig. 1 (left). Number of eye movements per 40 seconds of sleep at various times. Fig. 2 (right). Ratio of eye movement frequencies higher than 1 per second to those lower than 1 per 2 seconds at various times.

quencies are distributed like random noise. The ratio of these frequencies is relatively stable (*4*) and expresses the synergetic function of the brain (*5*).

In flight, the ratio of eye movement frequencies higher than 1 per second and those lower than 1 per 2 seconds shows fluctuations which remain within the normal range (Fig. 2). It is of interest that the inflight fluctuations were repeated after return, showing that the variations in gravity were integrated without distinction between increases and decreases in gravity.

The increase in REM discharges on flight night 1 was unexpected. Given the stress of the launch, a decrease was expected instead (*6*). However, the payload specialists for the Spacelab 1 mission had undergone a long period of preparation. They had been thoroughly trained to perform various experiments and they were able to adjust their instructions to novel circumstances. The results are consistent with the view that the change to zero gravity provides information which the brain of PS1 integrated positively. The same was true after landing for the change to normal gravity, but Fig. 2 shows an apparent delay of 1 day in the integration of this new information. The effects of the 12-hour time shift together with the effects of the return to normal gravity may have been responsible for the delay.

There is no doubt that there is a link between eye movements during sleep and those during wakefulness (which were recorded in other experiments on the Spacelab 1 mission). However, the specific link is not yet known. The present results may provide hypotheses for future research.

O. QUADENS

University of Antwerp, Antwerp, Belgium

H. GREEN

Clinical Research Center, Harrow, England

References and Notes

1. O. Petre-Quadens, *Acta Med. Belg.* **69**, 769 (1969).
2. V. Bloch, in *Neural Mechanisms of Learning and Memory*, R. Rosenzweig and E. L. Bennett, Eds. (MIT Press, Cambridge, Mass., 1976), p. 583.
3. B. Chevalier *et al.*, in *Proceedings of the 6th European Congress on Sleep Research* (Zurich, 1982), p. 166.
4. O. Petre-Quadens and C. Hoffman, *Adv. Physiol. Sci.* **17**, 55 (1981).
5. O. Petre-Quadens, in *Sleep*, L. Popoviciu *et al.*, Eds. (Karger, Basel, 1978), p. 126.
6. ——, *Totus homo* **12** (No. 10), 14 (1980).
7. Experiment 1ES030 was a joint project between the Clinical Research Center at Harrow, supported by the British Medical Research Council, and the University of Antwerp Neurophysiology Laboratory, sponsored by the Belgian National Science Foundation (NFWO). We thank Dr. H. Wolff and Dr. F. Stott for their valuable assistance.

27 March 1984; accepted 23 May 1984

Radiobiological Advanced Biostack Experiment

Abstract. *The radiobiological properties of the heavy ions of cosmic radiation were investigated on Spacelab 1 by use of biostacks, monolayers of biological test organisms sandwiched between thin foils of different types of nuclear track detectors. Biostacks were exposed to cosmic radiation at several locations with different shielding environments in the module and on the pallet. Evaluations of the physical and biological components of the experiment to date indicate that in general they survived the spaceflight in good condition. Dosimetric data are presented for the different shielding environments.*

Humans in spaceflight are exposed to two important sources of potentially detrimental effects: (i) the cessation of the gravitational stimulus to which they are normally adapted and (ii) ionizing cosmic radiation. On the earth people in industrial countries are exposed and possibly adapted to an average radiation dose-equivalent estimated as 2.4 millisieverts (mSv) per year (*1*), whereas measurements in the near-earth orbits of Skylab yielded exposure levels between 200 and 800 mSv per year (*2*). It is not this quantitative increase in intensity that merits special attention, however, since according to current radiation protection standards even this several hundredfold increase would not prohibitively limit man's sojourn in space. It is the radiobiological quality of numerically minor components of the cosmic radiation field which uniquely distinguishes it from the terrestrial radiation environment and which, since the beginning of manned spaceflight, has prompted the special attention of radiation biologists (*3*).

In the context of radiation protection the radiobiological quality is expressed in terms of a dimensionless quality factor, Q, by which the amount of physically absorbed radiation as measured in grays (1 Gy = 1 joule/kg) is to be multiplied in order to yield the biologically relevant dose-equivalent in sieverts (*4*). The physical quantity by which ionizing radiations of different quality are conventionally distinguished is the spatial density of ionizations engendered in the irradiated material, which in turn can be expressed by their linear energy transfer (LET), usually given in keV per micrometer of tissue or MeV-cm^2 per gram. The densely ionizing heavy ions [also called HZE (high charge and energy) particles] and the disintegration stars of nuclear reactions induced in irradiated matter present an obstacle to a comprehensive and consistent assessment of the radiation hazards in manned spaceflight. The LET of the cosmic heavy ions extends to such large values, where both the spatial and temporal pattern of energy deposition become extremely inhomogenous, that the very definition of absorbed dose as a measure of radiation exposure and also the concept of the quality factor become inapplicable (*5*). The pragmatic approach of setting aside these fundamental conceptual difficulties and converting the physically measured macroscopic spatial and temporal "averages" of "absorbed dose" distributions over LET into biological "dose-equivalents" by means of accepted Q(LET) relations (*6*) remains problematic, since (i) the data base on which these relations rest does not cover the ionization densities typical of cosmic heavy ions, (ii) LET alone does not provide a unique measure of radiation quality, and (iii) a unified theoretical understanding of radiation quality, which might allow extrapolations, has yet to be achieved. These problems were recognized in a report of the U.S. National Academy of Sciences on HZE particle effects. The report (*7*) concluded that in order to assess the radiation hazards of these HZE particles to man, the experimental knowledge of their radiobiological effects must be advanced by spaceflight experiments and ground-based experiments at suitable particle accelerators (which at that time just became operational). Also, in order to be relevant for this purpose, these experiments must permit evaluation of the radiobiological effects of single HZE particles on individual biological cells.

The advanced biostack experiment on Spacelab 1 is part of a research project designed to contribute toward this goal through spaceflight and comparative accelerator experiments. The physical and biological components of the advanced biostack experiment are listed in (*8*), together with the contributing coinvestigators. The requirement for observing the effects of single HZE particles on individual biological cells was realized for the first time in the biostack experiment on Apollo 16 (*9*). Basically, the experimental design consists of a sand-