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The brain electrical activity in different G situations

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FOREWORD

This article will be published as an Academy Transactions Note in the ACTA ASTRONAUTICA.

AVANT-PROPOS

Cet article paraîtra comme une "Academy Transactions Note" dans les ACTA ASTRONAUTICA.

VOORWOORD

Dit artikel zal verschijnen als een "Academy Transactions Note" in de ACTA ASTRONAUTICA.

VORWORT

Dieser Artikel wird wie einer "Academy Transactions Note" in die ACTA ASTRONAUTICA erscheinen.

Summary

The electrical activity of the brain (EEG) has been recorded during parabolic flights in trained astronauts and non trained volunteers as well. It was quantified with the Fast Fourier Transform method. The EEG analyzes evidenced more asymmetry between the two brain hemispheres in the subject who suffered from motion sickness than in the others. In addition, a first attempt was made to calculate the dimensionality of "chaotic attractors" in the EEG patterns as a function of the different g-epochs of 1 parabola. This method allows to discriminate between deterministic and stochastic events and to indicate trends. Only very preliminary results are given here.

Résumé

L'activité électrique cérébrale ou électroencéphalogramme (EEG) a été enregistrée pendant des vols paraboliques chez des astronautes ayant subi un entraînement approprié et chez des volontaires non entraînés. L'EEG a été quantifié par la méthode de transformation de Fourier (FFT). Les analyses ont mis en évidence une asymétrie plus marquée entre les deux hémisphères cérébraux chez le sujet qui souffrait du mal du mouvement (nausées) que chez les autres. De plus, une première tentative de calcul de la dimensionalité des "attracteurs chaotiques" de l'EEG fut faite pour une des paraboles en fonction des différentes valeurs de G (gravité). Cette méthode, qui permet de faire une distinction entre les évènements déterministes et chaotiques, indique essentiellement des tendances. Des résultats très préliminaires sont rapportés ici.

Samenvatting

De electrische activiteit van de hersenen (het electroencefalogram of EEG) werd tijdens parabolische vluchten bij getrainde astronauten en niet getrainde vrijwilligers opgenomen. Het EEG werd gekwantificeerd door de "Fast Fourier Transform" methode. De analyzen hebben een meer uitgesproken asymmetrie tussen de twee brain hemisferen aangetoond bij de proefpersoon die aan het "motion-sickness" syndroom onderhevig was dan bij de andere. Bovendien werd een eerste poging om de dimensionaliteit van de chaotische attractoren in het EEG tijdens één van de parabola te bepalen in functie van de verschillende G (zwaartekracht) perioden gedaan. Deze methode die een onderscheiding toelaat tussen deterministische en chaotische gebeurtenissen, stelt voornamelijk neigingen vast. Slechts zeer preliminaire gegevens worden hierbij meegedeeld.

Zusammenfassung

Die elektrische Aktivität des Gehirns (EEG) wurde während parabolischen Flüge von trainierten Astronauten und von nichttrainierten Volontären registriert. Durch Anwendung ader "Fast Fourier Transformation - FFT" ist nachher das EEG in einer numerischen Form umgestaltet.

Die Analysen haben gezeigt dass die Asymetrie zwischen beiden Hälften des Gehirns bedeutender ist bei dem Individuum das an Bewegungsschmerzen (Würgen) leidete als bei den anderen.

Ein ersten Versuch um die Dimension des "chaotic attractors" von dem EEG bezüglich der Schwere (g) während eines parabolischen Fluges wurde ferner ausgeführt. Solche Methode, die eine Unterscheidung zwischen determinischen und chaotischen Ereignissen ermöglicht, verwirklicht hauptsächlich Tendenzen. Sehr vorläufige Ergebnissen werden hier vorgestellt.

THE BRAIN ELECTRICAL ACTIVITY IN DIFFERENT G SITUATIONS.

de Metz K.(1), Quadens O.(1) and De Graeve M.(2)

INTRODUCTION

The man-space program insists on the aspects "productivity" and "autonomy" of the astronauts. The past decades have also seen increased recognition of the impact of environmental factors in determining the performance capabilities of man. Therefore, monitoring a number of central nervous system (CNS) parameters in different task performance conditions becomes central to the program. In zero-g it is still aimed at establishing a data-base. The brain electrical activity as measured with the electroencephalogram (EEG) can be correlated with states of consciousness, recognition of stimuli, work load intensity and other brain functions. Aberrant neurophysiological changes should serve as early warning signs indicating counter measures for health related problems.

The duration of the different g-situations during parabolic flights is limited. Therefore it restricts the study of the EEG variations to the waking-state only.

METHODS

The EEG recordings were taken during one of the parabolic flight campaigns at the Centre d'Essais en Vol (CEV) in Bretigny (France).

The data were recorded with a portable Medilog-recorder. The filtered and digitalized data (128 Hz) were stored on regular audiocassettes. The cassettes were decoded with a Medilog replay unit 9200 and the data were transfered to a file for frequency-amplitude analysis and further statistical processing. A clock was incorporated with the recorder. The clock was synchronized with that of the accelerometer to insure a precise correlation of the time course of the EEG with the g-variation. Due to the limitations of time and possibilities available, we have used a configuration of 4 bipolar recordings: Fp1-C3, C3-O1, Fp2-C4 and C4-O2.

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A program was developed allowing to select a number of 4 or 8 second epochs from which, by means of Fast Fourier analysis, a frequency-amplitude spectrum (0.25-64Hz) was calculated. For three subjects, the total flight was divided in epochs of 4 seconds and the frequency-amplitude spectrum of each one of the epochs was calculated. The spectra were divided into the 4 classical EEG frequency bands: delta (0.5-4Hz), theta (4.25-8Hz), alpha (8.25-13Hz) and beta (13.25-32Hz). The power in each of the bands was calculated and the result is a histogram, showing the evolution of the different EEG-frequency bands as a function of time. Examples are given in figs.1 and 2. The periods during which the subjects were seated and relaxed, with eyes closed, are indicated on top of the figures.

To investigate the changes of the EEG as a function of g, a number of epochs were selected. In consecutive order:
4 epochs of 4 seconds each during 1g (just before the transition to 1.8g), 1 epoch of 4 seconds, the duration of which corresponds with the transition of 1 to 1.8g;
4 epochs of similar duration during 1.8g; 1 such epoch corresponding to the transition between 1.8 and 0g;
5 epochs of 4 seconds each during 0g; 1 such epoch corresponding to the transition between 0 and 1.8g;
4 epochs of 4 seconds each during 1.8g; 1 such epoch corresponding to the transition between 1.8 and 1g and
4 epochs of 4 seconds each during 1g (just after the transition from 1.8 to 1g).

In this study, the epochs of motor activity were not taken into account. Only the artefact-free resting epochs during which clear alpha waves appeared in the EEG, were analyzed. For this reason, out of the seven recordings taken from five different subjects, only three were meeting these requirements. Thus, 15 parabolas were selected for subject 1, 13 parabolas for subject 2 and 5 parabolas for subject 3.

Each epoch of 4 seconds provides a frequency-amplitude spectrum. Since the epochs were selected in the same way for each of the parabolas, the power in the different frequency bands for each epoch was averaged over the different parabolas. This method provided for each subject an averaged course of the power in each band during the parabolas. It allowed to calculate the standard deviations, and the t-test provided us with the level of significance of the differences in the EEG activity between the left and the right hemisphere on one hand, between the various g-situations on the other hand.

In a previous set of experiments, one of us has analyzed the recordings made during a similar parabolic flight campaign in two subjects. One of them was subject 1 of the present study, the other was also a trained astronaut. The recorder was a 4 channel Medilog-recorder, which stores the analog signal on an audio-cassette. This signal was re-read with an Oxford PB-2 replay unit. After conversion with a Data-Harvester analog-to-digital converter, the data were further processed by computer. The sample frequency was 80 Hz. After Fast Fourier transform, the frequency-amplitude spectra were situated within a range of 0-40 Hz. The recordings were bipolar (parieto-occipital leads on both right and left hemispheres). Different frequency-bands were selected, namely: 5-8Hz (thetaband), 9-11Hz (alphaband), 32-34Hz (part of the beta-band). But the recorder had no clock and the location of the 0-g acrophase on the EEG could be calculated for 6 parabolas only. For technical reasons the experiments were to be runned again.

The classification of the EEG behavior of the brain system by means of power spectra is but a first step towards quantification. Abraham and his coworkers pointed out that such a classification does not lead to an unambiguous discrimination between signals which are merely deterministic and those which are the result of stochastic events (1). Babloyants et al. raised similar questions concerning the features of the EEG during the different sleep stages. They described the EEG patterns by determining the number of variables necessary to define the system responsible for them. This method allowed them to calculate the dimensionality of the attractors for two of the EEG sleep stages (2).

We made thus an attempt to use such techniques to assess, in a very preliminary way for subject 1, wether the EEG evolves from one kind of behavior to another as a function of different gravity situations. The data are indicative only, since they have used 1 epoch of 4 seconds in the 5 different G conditions during 1 parabola.

RESULTS

The power spectrum of the main EEG frequency bands during wakefulness include mainly the alpha-, beta- and theta waves. The alpha waves are typical for quiet wakefulness and appear invariably when the subject closes his eyes. The beta waves are predominant during periods of intense arousal and anxiety. The theta waves have been related to periods of attention. Therefore an increase in the alpha waves is normally correlated with a decrease in the beta- and the theta waves. This out of phase correlation is the case with the power spectra recorded from the occipital areas of the brain in subjects 1 and 2. It is most obvious in subject 1 (fig.1) and is present but less pronounced in subject 2. Subject 1 did not suffer from motion sickness whereas subject 2 did. Nevertheless, both subjects belong to a group of people whose EEG is characterized by well individualized alpha activity, especially in the occipital areas of the brain, which combine, during quiet wakefulness, the presence of the 8 to 12 Hz waves and a weak manifestation of fast beta activity.

-- fig.1--

One of the subjects (subject 3) however, belongs to another group which includes EEGs with a depressed alpha-rhythm and a pronounced beta activity (fig.2). In the subject, the variations of the power in the different frequency bands are synchronous and in-phase. These in-phase variations of the alpha-, beta- and theta bands point to the absence of the system or axons responsible for the alpha waves. This subject suffered only mildly from motion sickness.

--fig.2--

In subjects 1 and 2, the power increases in the alpha band and decreases in the beta- and theta bands only when the eyes are closed. On the other hand, the onset of the parabolas does not seem to alter the course of the power within the different frequency bands. In subject 3, no correlation is detected between the EEG power and the opening or the closing of the eyes. Since the alpha rhythm is the one which disappears as a function of eye opening, the absence of this 'arrest reaction' with this subject is not surprising. However, with the onset of the parabolas, peaks of power appear in the three frequency bands, the periodicity of which approximates that of the parabolas (fig.2). We do not know at present to which part of the parabola the periodic increase of power in the different frequency bands corresponds. This can be calculated. The appearance of the beta and theta waves should correspond to a phase in the parabolas where attention increases. But the subject admitted that he had opened his eyes repeatedly during the parabolas.

The differences in the EEG characteristics between the three subjects as a function of incoming information point to the existence of independent neurogenic mechanisms underlying the different EEG frequencies.

A more detailed and time related analysis of the EEG in function of the various g-conditions during the parabolas evidenced additional features. Here, we include the slow, 0.5 to 4Hz deltawaves.

In subject 1, significant differences appeared during the parabolas between the two hemispheres in two of the four frequency bands only. They are restricted to the deltaband of the occipital and the betaband of the frontal areas of the brain (table 1). In the betaband, the power was higher in the left hemisphere than in the right one (between 0.01 and 0.1), whereas the opposite was true in the deltaband (between 0.01 and 0.1). The subject was trained to participate in parabolic flights.

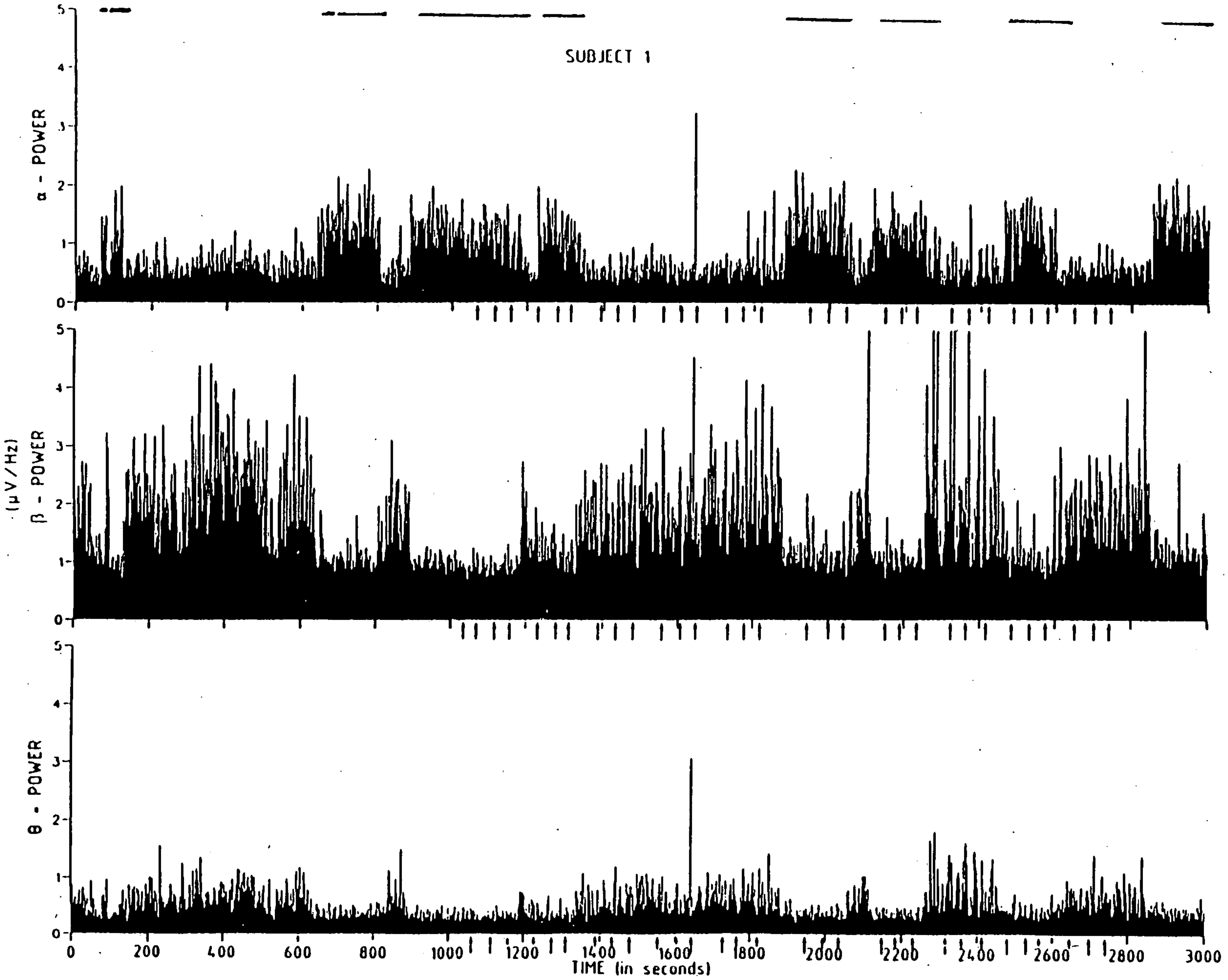


Fig. 1.- Power in the alpha-, beta and thetabands for subject 1. The fat lines at the top of the figure indicate the periods when the eyes are closed. The parabolas are indicated with arrows on the time axis.

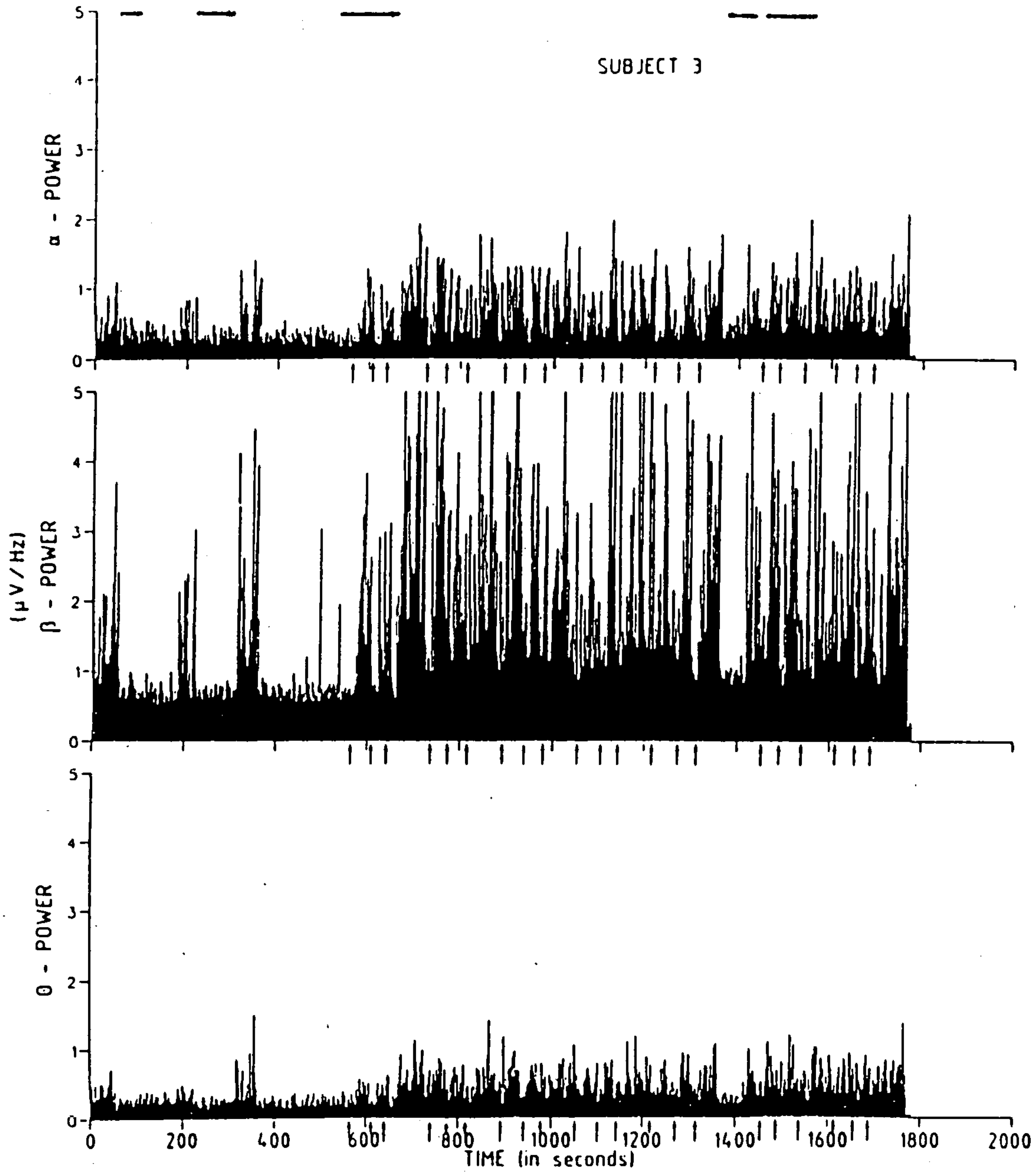


Fig. 2.- Power in the alpha-, beta and thetabands for subject 3. The fat lines at the top indicate the periods with eyes closed. The parabolas are indicated with arrows on the time axis.

--table 1--

In subject 2, significant differences appeared in all of the 4 frequency bands. The asymmetry was found in the occipital areas, the power being higher in the left than in the right hemisphere (between 0.01 and 0.1)(fig.3, table 1). Subject 2 was not used to participate in parabolic flights and was suffering from motion sickness at times during the flight. Before take off he had been medicated to prevent it (Scopdex).

--fig.3--

The EEG of subject 3 was almost devoid of alpha waves. No real asymmetry was detected in any of the EEG frequency bands. The subject had also been medicated.

The recordings made previously by one of us also evidenced an asymmetry between the two hemispheres, especially in the higher frequency range, in both subjects.

For subject 1, we made an attempt at discriminating between "deterministic chaos" (1) and randomness in the EEG signals. Therefore, we have used the formula with which Babloyants et al. have calculated the dimensionality of the attractors of the EEG during sleep. It has been shown that 'from a unique time series X (t), a set of variables describing the dynamics of the function could be defined. These variables are obtained by shifting the original time series by a fixed lag r (r=m t where m is an integer and t is the interval between successive samplings). These variables span a phase space which allows the projection of the system to a low dimensional subspace of the full phase space.

In the phase space, the instantaneous state of the system is characterized by a point, a sequence of such states followed in time defines the phase space trajectory. If the dynamics of the system is reducible to a set of deterministic laws, the system reaches in time a state of permanent regime. This fact is reflected by the convergence of families of phase trajectories towards a subset of the phase space. This invariant subset is called an attractor' (2).

The existence of an attractor and the evaluation of its dimensionality may be achieved in the following manner where C(r) may be referred to as the integral correlation function of the attractor

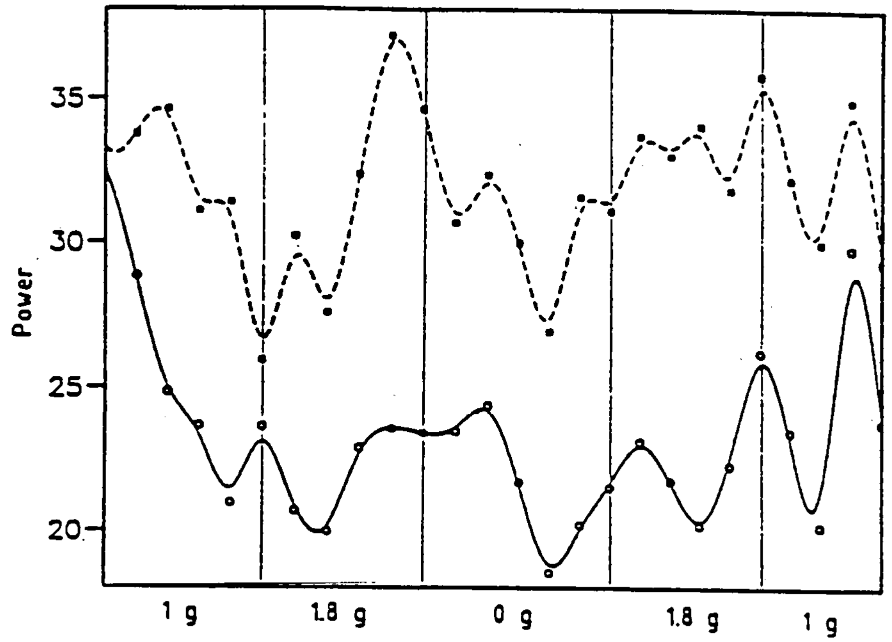
$$C(r) = \frac{1}{N^2} * \sum_{i \bullet j}^{N} \Theta(r - | Y_i - Y_j |)$$

	Subject 1		Subject 2	
band	anterior	posterior	anterior	posterior
delta	L = R	L < R	L = R	L > R
theta	L = R	L = R	L = R	L > R
alpha	L = R	L = R	L = R	L > R
beta	L > R	L = R	L = R	L > R

TABLE 1.- Comparison of the power in the different EEG frequency bands between the left (L) and the right (R) hemisphere of the anterior and the posterior parts of the brain.

SUBJECT 2

alphaband



betaband

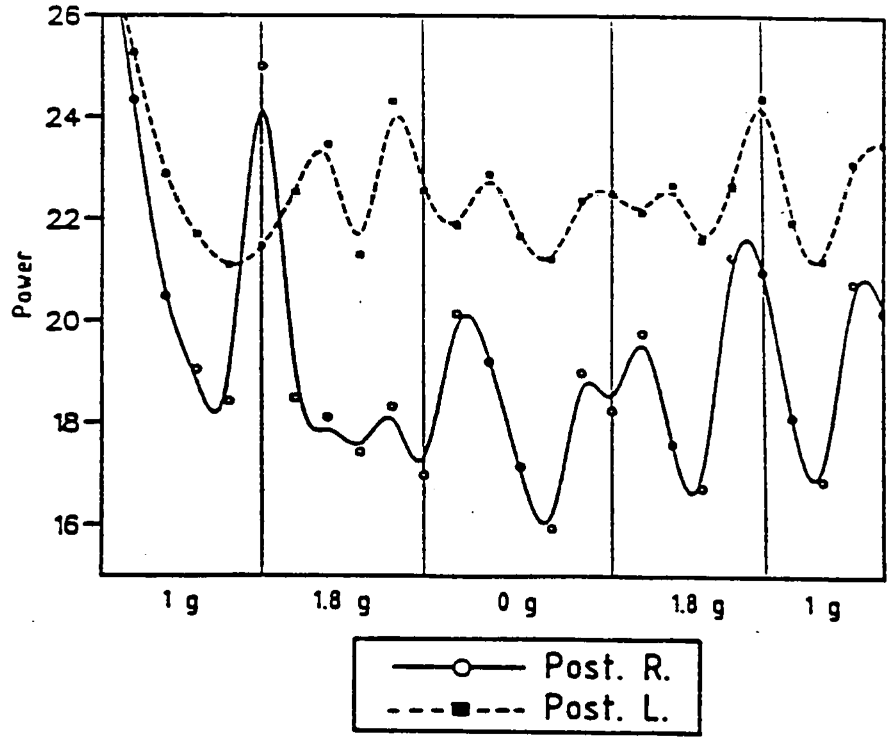


Fig. 3.- Evolution of the power in the apha- and the betabands (posterior area of the brain) for subject 2. The level of significance varies from 0.01 to 0.1.

r= variable

N represents the number of points selected in the experiment.

θ is the Heaviside function. $\theta(x)=0$ if $x<0$ and $\theta(x)=1$ if $x>0$

x is the reference point from $x(t)$ which is a point of phase space whose coordinates are $[x_0(t_i),\ldots,x_c[t_i+(n-1).\tau]$

--fig.4--

The slope of log C(r) versus log r gives the dimensionality d of the attractor (fig.4), where n represents the imbedding dimensions and d the number of parameters needed to describe the system. If the d versus n dependence is saturated beyond a relatively small n, the system represented by the time series possesses an attractor. The saturation value d is regarded as the dimensionality of the attractor represented by the time series.

Our results are however preliminary and many more data are required to establish the presence of chaotic attractors in hypergravity. So far, let us notice that d is moderately decreased at 1.8g, which corresponds to the ascent of the plane, immediately after take-off. It increases when zero-G is reached and decreases again, even more slightly, at 1.8g which corresponds to the descent of the plane, after the 0g acrophase. Surprisingly, in this one parabola the d values are similar in 0- and in 1g. Let us remind that these g changes last for 20 seconds or so only during the parabolas.

DISCUSSION

Changes in the EEG during space-flights have been documented during the Spacelab 1 flight (3), in the Gemini flights (4) and with Russian cosmonauts as well.

Our results are at variance with those of Bodrov and Fedoruk (5). These authors used the 'right ear coefficient' (not further described but evidently derived from a dichotic listening task) in order to investigate the brain activity in pilots who were exposed to flight factors. They found that an asymmetry in this parameter was associated with high tolerance to motion sickness. They also showed that the extent of asymmetry is positively correlated with the functional state of the pilot and his task performance.

In our study a lateralisation of the activity in the EEG frequency bands was found indeed. However its relation to the tolerance of the subjects to flight factors is uncertain. In our experiments the asymmetry was limited to the higher frequency beta waves in the subjects with

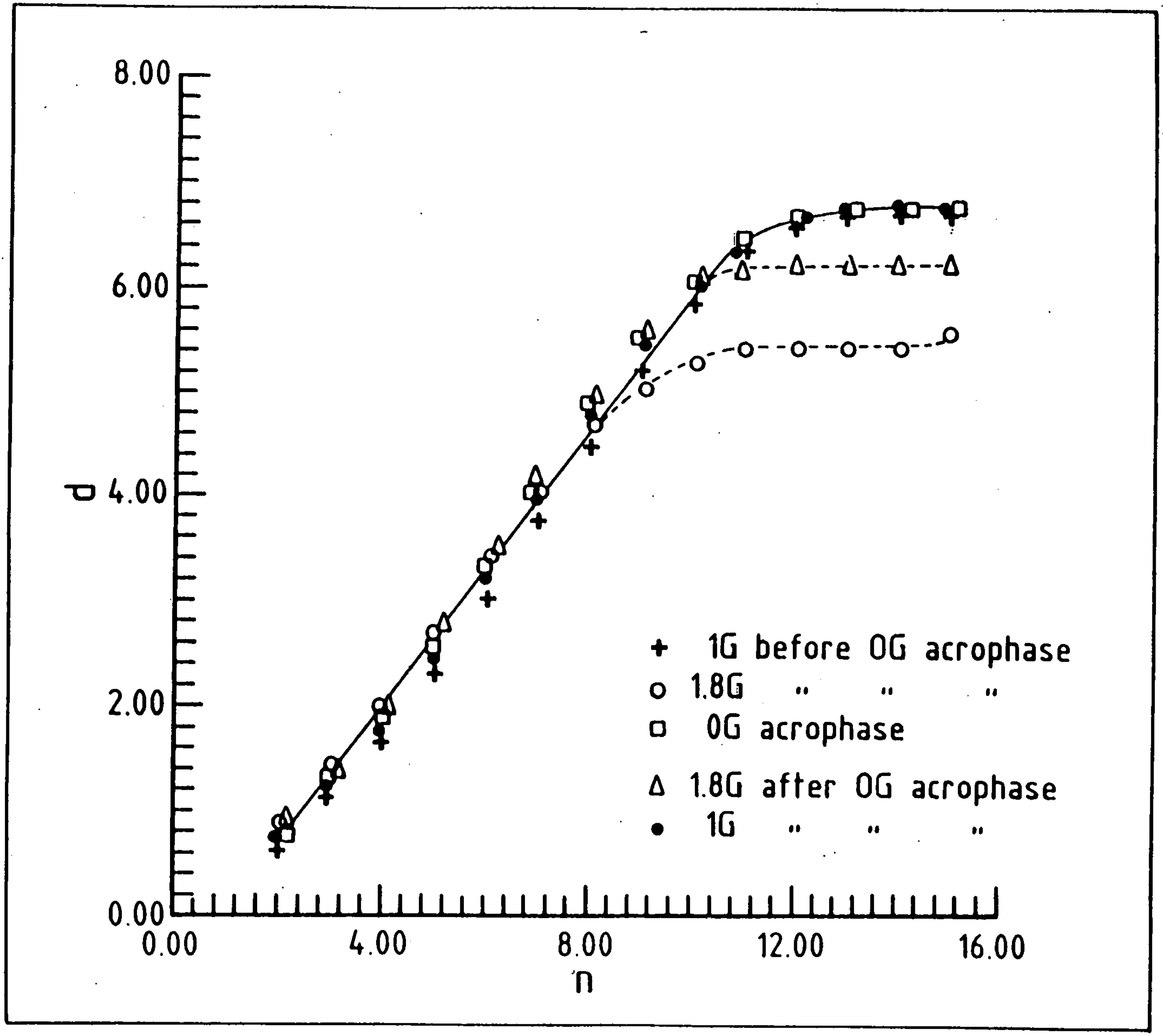


Fig. 4.- The dependence of dimensionality d on the number of phase space variables n for a subject in different g conditions during one parabola.

the highest tolerance to motion sickness. The asymmetry was spreading to all frequency bands in the subject with lower tolerance. The difference in the neurological endpoints may account for the differences in the results.

A comparison between the mean values of the power in the different bands as a function of various g-levels did not evidence significant correlations. The short duration of the consecutive g-values may be responsible for it. The variation of power during the parabolas suggest that changes did occur but that the F.F.T. techniques do not allow to measure them with precision. An increase in the power of the thetaband in weightless conditions was however detected by R. Adey during the Gemini-flights (4). The same observation was made by one of us during the Spacelab 1 flight (3). In space flight, the exposure to microgravity is, unlike the parabolic flights, of long duration. Alterations in physiological parameters are expected not only as a function of vestibular stimulation during acceleration but also as a function of changes in cerebral hemodynamics due to the redistribution of blood flow in microgravity.

In subject 3, the power of the alpha frequency band was significantly decreased in every g-condition. This appears to be an individually stable feature of his brain electrical activity.

To investigate the interindividual differences more thoroughly, we could have analyzed the data with the method descibed by Creutzfeldt et al. (6). This method is based on a computerized segmentation of the different parts of the EEG. For now we focused on the evaluation of the EEG as a function of time and on a statistical analysis to evaluate differences between the two hemispheres only.

A number of studies suggest that the brain EEG organization is predominantly genetic in nature. They show that the essential features of electrocortical organization can be regarded as indicators of the neurophysiological level of human individuality (7). Therefore, it appears that longitudinal EEG studies are required for each candidate astronaut, such that he may be used as his own control.

The method of discriminating between deterministic chaos and randomness in the EEG signals, which uses only small data sets, looks promising. Fig.4 only aims at illustrating the possibilities of this method. It provides a quantitative means of following the brain system of a space traveller as it evolves in different g-conditions. Technically, such an EEG analysis strains the computer resources but it meets the need to obtain quantitative data on the brain activity of astronauts working and sleeping in space.

The EEG data-base in microgravity remains poor. The complexities of multichannel records, the frequent and inadvertent detachment of the electrodes, the irregularity in the occurence of artefact free periods and particularly the differences between the subjects as illustrated by the above results, have discouraged fine interpretation of a gamut of behavioral states that might range from quiet wakefulness to the extreme focusing of attention.

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