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Anatomical and functional brain approach along short abrupt changes in g-levels

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Abstract

To conduct experiments under abrupt changes in g-levels, a single-engine aerobatic aircraft has been used, providing 6-8 seconds of reduced gravity, preceded and followed by 5-7 seconds of hypergravity periods. Due to the specific conditions of the flight and previous findings [1], the hypothesis of the present work lies on the idea that some sensory inputs could have a notorious effect on brain final responses when gravity is altered. Therefore, this study focuses on the evaluation of such hypothesis, based on the analysis of the evolution in time of intracranial activity of limbic, visual and auditory cortices. Five subjects (N=5, age 41±14 years) have flown in parabolic flight with their eyes both open and closed. Electroencephalogram signals were recorded with an Emotive Epoc headset, synchronized with a triaxial accelerometer. The intracranial brain bioelectric activity (standardized current density) throughout the parabola, was calculated by applying Standard Low Resolution Brain Electromagnetic Tomography, and it was analyzed for the limbic, visual and auditory cortices. Intracranial activity of the Temporal, Parietal and Occipital lobes were carried out as well in order to compare the different periods/phases of the flight. Results detected a lower brain activity during the hypogravity phase in all lobes and cortices, only in the case of open eyes. The bioelectrical brain activity along the parabola showed similar patterns in all lobes and cortices, when visual inputs are highlighted. Suppressing the sight, two major behaviors were detected in brain activity: one for temporal lobe and auditory cortex, and second one for the rest of the lobes and visual cortex. It Seemed that, flying with closed eyes, other sensory stimuli were enhanced, in this case the auditory cortex. To confirm the validity of the results two-way ANOVA (factors lobe/phases) and Fisher post hoc test have been applied on mean intracranial activity values in all cases. Spectral entropy evolution in time has been considered as a fast indicator of the sudden extracranial brain activity variation during short g-changes. For open eyes, spectral entropy values indicated a slight decrease at the onset of the hypogravity phase, whereas in case of closed eyes, this change was detected in the last seconds of the parabola, even though these fluctuations were statistically non-significant. Results suggest that some of the sensory inputs can indeed have an impact on brain final response, when gravity conditions are altered.

Keywords: parabolic flight, aerobatic aircraft,, hypergravity, hypogravity, electroencephalogram,

Nomenclature

SEN - spectral entropy
Q - normalized power spectrum
P - power spectrum
N - total number of frequency components

Acronyms/Abbreviations

ANOVA - Analysis Of Variance
EEG - electroencephalogram
B0 - control phase in the laboratory (1g)
B1 - control phase inside the aircraft (1g)
P1 - first hypergravity phase of the parabola
P2 - hypogravity phase of the parabola
P3 - second hypergravity phase of the parabola
sLORETA - Standarized Low Resolution Brain Electromagnetic Tomography

AMUSE - Algorithm for Multiple Unknown Source Extraction
T - temporal lobe
P - parietal lobe
L - limbic lobe
O - occipital lobe
F - frontal lobe
I - insular lobe
A - auditory cortex
V - visual cortex
ms - milliseconds
s - seconds
t – time
g –Earth's gravity (9.81 ms^{-2})

1. Introduction

To conduct experiments under abrupt changes in g-levels, a small aerobatic plane has been used, providing 6-8 seconds of reduced gravity, alternating with 5-7 seconds of hypergravity periods. The aircraft cockpit was transparent, unpressurized, non-thermostated and noisy. Five volunteers were subjected to two types of parabolic flight experiments: firstly, individuals flew with their eyes opened and secondly, with the eyes closed. The aerobatic maneuver consists of 12 parabolas, each of it formed by the three gravity periods mentioned before. The individuals have been flying the first six parabolas keeping all times, the eyes opened (experiment 1) followed immediately by the next six ones with the eyes closed (experiment 2). Due to the specific conditions of the flight and previous findings [1], we hypothesized that some of the sensory inputs could have an impact on brain final response when gravity is altered. Therefore, this study focuses on the evaluation of such hypothesis, based on the analysis of the evolution in time of intracranial activity at limbic, visual and auditory cortices level. Intracranial activity of the Temporal, Parietal and Occipital lobes were as well represented as comparison analysis. Spectral entropy [2] evolution in time has been considered as a fast indicator of the sudden extracranial brain activity variation during short g-changes.

2. Material and methods

The parabolic maneuvers were conducted with the same CAP10B aerobatic plane as described earlier [1, 3, 4]. A parabolic flight maneuver consists of twelve parabolas, each one being composed of three phases: two different intervals of hypergravity, the first and the last period, thereafter P1 and P3, and the corresponding hypogravity interval between them, called P2. A typical parabola is depicted in Fig. 1, describing the three components of the acceleration. Notice that the onset of the hypogravity phase is considered as the common starting time (t = 0). Both hypergravity phases, P1 and P3, are not symmetric in all cases. The first maximum, P1, is about 2.3g in average, while the second, P3, is roughly 1.7g. Also the time associated to P1 and P3 is different, 5 and 9 seconds respectively, while P2 has a typical time of around 6 seconds. The mean values of the residual acceleration, during the hypogravity phase, P2, are 0.13g, 0.003g and 0.05g in the x, y and z axis, respectively.

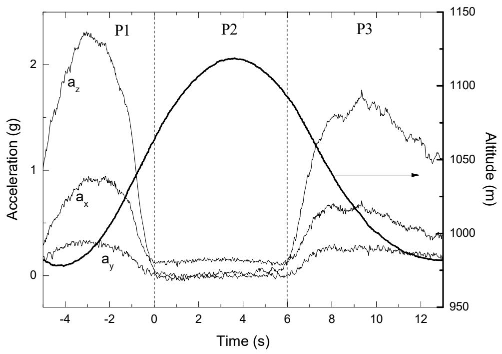

Fig.1 Altitude and acceleration components of a typical parabola.

As a baseline comparison two extra periods or phases were defined: B0 and B1, corresponding to normal gravity conditions (1 g) in the lab and just before the flight, respectively.

For these experiments five right-handed adults (four men and one woman, age 41±14 years) participated. They were under no medication both before and during the flight and had no previous experience in a parabolic flight. As a mandatory prerequisite before the flight, all subjects provided a Class II EASA Aeronautical Medical Certificate and an informed written consent prior to the flight. The experiments were as well granted by the Ethical Committee of Hospital Universitari Joan XXIII, Tarragona, Spain. During the flight the participants, sat weakly strapped at the right side of the pilot and continuously monitored by video to verify their behavior during all the maneuvers. As it has been mentioned earlier, during the first six parabolas the volunteers flew with their eyes opened, and in the last six maneuvers they had the eyes closed and covered with a mask.

The brain activity was continuously monitored by using EMOTIV EPOC Headset of 14-channel (+2 references). More details can be found in Dubert [1].

The recorded EEG data were processed by using Matlab® software. First, the data were filtered between 8-40 Hz and then two Independent component analysis algorithms (Adjust and AMUSE) were applied [5, 6] in order to avoid any contamination with artifacts.

Only the cleanest parabolas have been chosen for further analysis. The averaged extracranial EEG signals were used to evaluate the intracranial activity (that is to say, the estimated standardized current density) by solving the so-called inverse problem using Standardized Low Resolution Brain Electromagnetic Tomography (sLORETA) [7]. To calculate the lead field matrix, the brain anatomy used in the case of BrainStorm package (sLORETA solution) is the so-called Colin27 with 15000 cortical voxels [8].

Analysis of variance, ANOVA, was used for the comparison of the mean values of the intracranial activity. All different tables show the sample mean value, while the value of the 95% confidence interval of the mean appears in parenthesis. To reinforce normality we also used a log-transform in all cases. When the omnibus hypothesis failed, Fisher's Least Significant Difference *post hoc* test was used. The two-tailed level of significance was typically fixed at $p < 0.05$ in all tests. Statistical analyses were performed using Microsoft EXCEL as well as XLSTAT packages.

3. Theory and calculation

A parcellation of the human cerebral cortex is very important for the interpretation of morpho-functional data. An attempt in accomplishing this was described in [9]. The results of this parcellation defined a method for automatically labeling the cortical surface in standard terminology final parcellation. Based on this, five regions of interest (Destrieux atlas in Brainstorm package [8, 9]) have been defined and the intracranial bioelectric activity was then evaluated in each of them (tomographic approach). These regions coincide with the six lobes, frontal (F), temporal (T), parietal (P), occipital (O), insular (I) and limbic (L). As the main goal of this paper was to determine the influence of some of the sensory inputs such as, visual and auditory, on the brain response under short g-levels changes, it has been considered for analysis the brain areas that involve visual and auditory cortices presented in Tables 1 and 2. Notice that the selection was based in above mentioned parcellation. The areas corresponding to the auditory cortex were found in temporal lobe meanwhile the areas associated to the visual were spread along occipital, temporal, limbic and parietal lobes. Consequently occipital, parietal, temporal and limbic lobes were considered for comparison with the selected cortices.

Another possibility to study the EEG background activity is through nonlinear and chaotic methods such as the entropy concept usually used in neuro diseases.

The entropy concept involves randomness and predictability, with greater entropy value, often associated with more randomness and disorder.

Table 1. Visual cortex selected based on Destrieux parcellation

Areas	Code name
Cuneus (superior part)	G_cuneus/ G_cuneus
Sulcus calcarine	S_calcarine/ S_calcarine
Lingual gyrus	G_occipit-temp_med-Lingual_part/G_occipit-temp_med-Lingual
Inferior Temporal Cortex	G_temporal_inferior/G_temporal_inf
Prestriate Cortex	S_parieto-occipital /S_parieto-occipital G_occipit-temp_med-Parahippocampal_part/ G_oc-temp_med-Parahip G_occipit-temp_lat-Or_fusiform/ G_oct-temp_lat-fusiform

Table 2. Auditory cortex selected based on Destrieux parcellation

Areas	Code name
G_temp_sup-Lateral_aspect	G_temp_sup-Lateral
G_temp_sup-Planum_polare	G_temp_sup-Plan_polar
G_temp-sup-Planum-temporale	G_temp-sup-Plan-tempo
G_temp_sup-G_temp_transv_and_interm_S	G_temp_sup-G_T_transv

Spectral entropy estimates the changes in the amplitude component of the power spectrum of the EEG, using the amplitude components at each frequency of the power spectrum as the probabilities in the entropy calculations

According to Mirzaei [2] the spectral entropy, SEN, is applied to the power spectrum of extracranial signals. Therefore, in present work, it has been calculated the normalized power spectrum, Q(f):

$$Q(f) = \frac{P(f)}{\sum_f P(f)} \tag{1}$$

where P(f) is the power spectrum at the frequency f averaged for all channels

The spectral entropy has been defined as:

$$SEN = -\frac{1}{\log(N)} \sum_f Q(f) \log(Q(f)) \tag{2}$$

where N is the total number of frequency components.

A high spectral entropy value (~ 1) implies a higher spectral flatness or maximum irregularity of the signal, whereas a low spectral entropy value gathers the energy in a single frequency bin (~ 0) indicating a complete signal regularity [2, 10].

In the present paper spectral entropy values were calculated along the whole parabola (hypergravity / hypogravity/ hypergravity) taking into account the power spectrum corresponding to each second, therefore is obtained the evolution in time of this variable. Usually spectral entropy is used as an intuitive parameter for the detection of possible power spectrum variations both in time and frequency range, thus in this case, was used to detect the possible significant variations between all the three phases of the parabola.

In order to value the significant differences between all the variables, ANOVA analysis has been applied. [1]

4. Results and discussion

Table 3 summarizes the mean intracranial activity for both phases and cortices and for the two experiments.

Table3. Mean intracranial activity per phases and lobes (A m x10^{-10})

Phases	B0	B1	P1	P2	P3
Lobes			open eyes		
T	2.13(0.5)	2.97(0.6)	4.25(1.1)	3.79(1.0)	4.08(0.9)
A	2.27(0.5)	3.10(0.6)	4.59(1.2)	4.09(1.1)	4.39(1.0)
O	1.66(0.4)	2.53(0.6)	3.49(1.0)	3.07(0.8)	3.39(0.8)
V	1.79(0.4)	2.60(0.5)	3.70(0.9)	3.29(0.8)	3.56(0.7)
L	1.65(0.3)	2.31(0.4)	2.96(0.7)	2.73(0.7)	2.91(0.6)
P	1.73(0.4)	2.4(0.6)	3.35(0.8)	3.04(0.8)	3.29(0.7)
			closed eyes		
T	2.11(0.5)	2.35(0.5)	2.21(0.7)	1.93(0.6)	2.26(0.7)
A	2.22(0.5)	2.43(0.5)	2.33(0.6)	1.99(0.5)	2.34(0.6)
O	1.76(0.5)	1.95(0.5)	1.90(0.6)	1.68(0.5)	2.02(0.6)
V	1.92(0.4)	2.09(0.4)	2.06(0.5)	1.81(0.4)	2.15(0.5)
L	1.69(0.4)	1.97(0.5)	1.79(0.5)	1.61(0.5)	1.92(0.6)
P	1.83(0.5)	2.08(0.5)	1.92(0.5)	1.71(0.5)	2.00(0.58)

*values x10^{-10}

In order to identify the significant differences in the activity two-way ANOVA analysis was performed. In both experiments the ANOVA results indicated the existence of statistical significant differences in the data considered (open eyes experiment, F= 362.25, $p<0.0001$ and closed eyes experiment, F=114.94, $p<0.0001$). Fisher post hoc test results indicated that there were significant differences between all phases except the two hypergravity ones, P1-P3, in the case of first experiment. Considering the second experiment, closed eyes, this above equality was observed only comparing the control period, B1 to second hypergravity periods, P3. Mean intracranial activity by lobes was statistically different for both experiments except comparing the occipital to parietal lobes in case of open eyes trial. As an example, Figs. 2 and 3 plot the temporal evolution of absolute intracranial activity averaged over 100 ms along the whole parabola. This evolution corresponds to the brain activity of a single volunteer. Fig. 2 shows clearly a decreasing trend in the hypogravity phase, P2, whereas this trend was not observed in the case of the closed eyes experiment (Fig. 3).

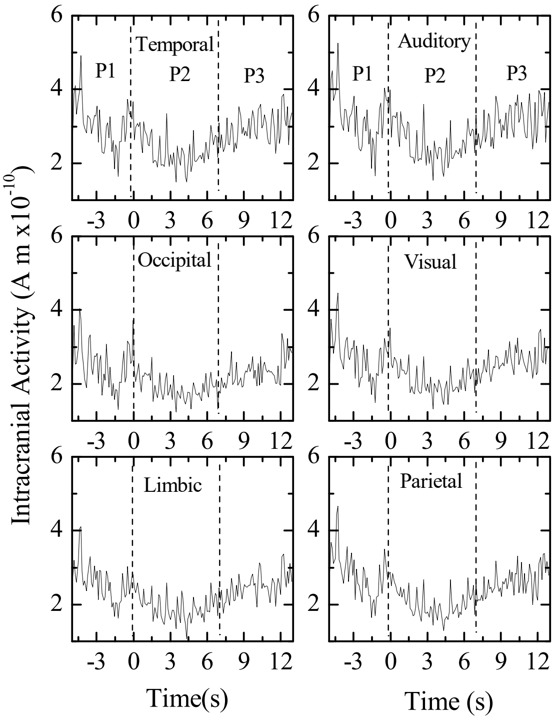

Fig. 2. Intracranial activity along a parabola with open eyes.

Data showed a more pronounced SEN variation at the beginning of the parabola (whole P1, transition from first hypergravity to hypogravity phase and beginning of P2) when the volunteer flies with open eyes. This dispersion was reduced in the last seconds of the parabola (middle-end of P2, transition from P2 to P3 and entire P3 period). When flying with the eyes closed, the above behavior was inverted: higher flatness in the evolution was observed at the beginning of the parabola and a greater variation at the end of it. Even though different behavior was sensed, it should be noted that these variations were not significant from statistical point of view (open eyes experiment, F= 0.06, $p<0.95$ and closed eyes experiment, F=0.20, $p<0.82$).

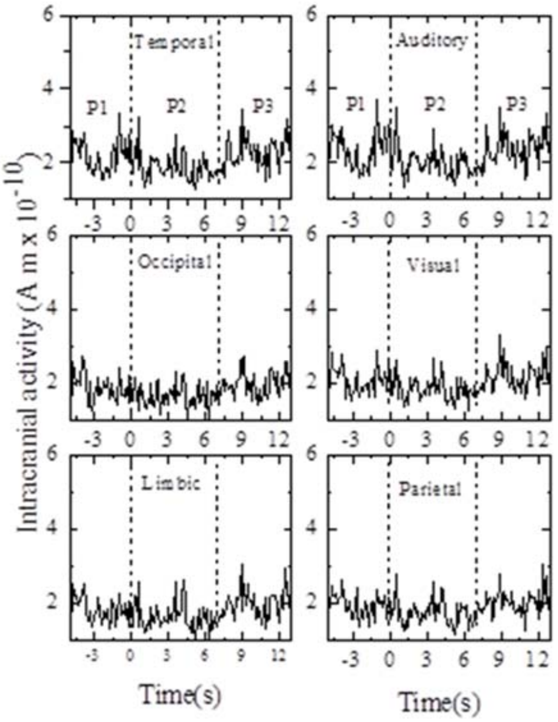

Fig.3. Intracranial activity along the parabola with closed eyes.

As a complementary information of the extracranial activity, Fig. 4 presents the spectral entropy along a parabola for the two cases analyzed.

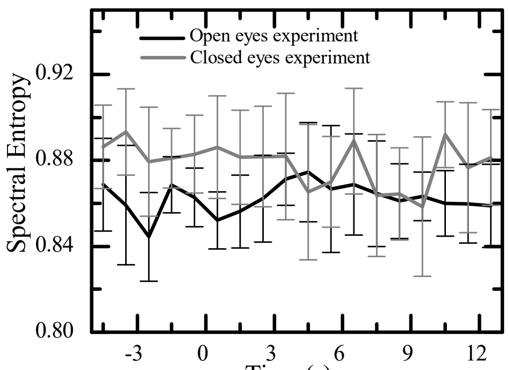

Fig. 4. Spectral entropy evolution along the parabola.

5. Discussion

As it has been mentioned earlier, a correct Destrieux [9] parcellation of the brain connects the visual cortex not only with the occipital lobe but as well with temporal, parietal and limbic ones. This straight connectivity was demonstrated in many studies [11, 12] supporting the idea that these connections are more complex and articulated than initially was thought. The present work confirmed the existence of such tight interrelation between the specified above lobes and cortices. Therefore, Fig. 2 reveals the same pattern of the brain intracranial activity for all temporal, auditory, occipital, visual, limbic and parietal lobes when the subjects were tested with their eyes opened. It was detected lower absolute standardized current density values in hypogravity compared to the two hypergravity periods in all the lobes. It might be associated with a decrease in brain activation during hypogravity period, as well confirmed by other authors [13]. They found a significant decrease in brain activity, specifically in β2 band, in 0g conditions compared to 1g inflight ones. They related these changes to emotional reactions connected to the feeling of weightlessness. Notice that the onset of hypogravity phase (t=0) was clearly detected in all plots. This behavior may be due to the presence of visual inputs which greatly influence the brain response diminishing the impact of other stimuli such as auditory.

When the sight was suppressed (second experiment) two different behaviors were observed (see Figure. 3). The first one was a distinguished focus on the intracranial activity of the temporal lobe and auditory cortex; whereas the second behavior was observed in the brain activity evolution associated to the rest of the lobes in relation with visual stimulation. Considering the onset of hypogravity for all signals, a clear appearance of a wide complex of peaks around t=0s in the temporal lobe and auditory cortex has been discovered, whereas in the occipital, limbic, parietal and visual lobes that effected was less evident. Moreover, the auditory cortex was found to be limited to the temporal lobe [9]. Taking into account the second behavior, the standardized current density distribution of the brain signals for all phases was lower comparing to the one found in the first experiment. This could be correlated with the sight suppression, which in this case, could have little influence in lessening the auditory stimulus effect on the brain responses.

Spectral entropy, as a quick and intuitive parameter for the detection of possible power spectrum variations both in time and frequency ranges; has proven not to be effective in discriminating different behaviors between phases for all individuals and both experiments.

This study has two main limitations. It has a short number of individual cases but as a EEG time quantitative signal analysis it traduces in such an amount of data. The second limitation is that EEG recording system uses only 14 electrodes, but we consider that figure enough to obtain a general idea of the intracranial brain activity while optimizing the signal recording.

6. Conclusions

The present work has shown that the use of small aerobatic aircraft to conduct parabolic flights is a practical and inexpensive way to perform pilot studies. When an individual is subjected to the conditions of a single-engine aerobatic aircraft parabolic flight a higher brain bioelectrical activity could be detected between first hypergravity and hypogravity phases in all lobes and cortices, only in the case of open eyes. Moreover, the bioelectrical brain responses showed different behaviors depending if the visual inputs are involved or not. The intracranial activity connected to sensory cortices (visual and auditory) and with lobes had similar patterns, for both types of experiments. The visual stimuli seemed to dominate the bioelectrical brain responses in all the lobes in case of open eyes experiment, whereas in the second experiment the auditory inputs looked like prevailing only in the temporal lobe.

These results suggest that the different sensory inputs have an important effect on the brain final response when gravity is altered.

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