# Brain activity changes induced by open and closed eyes during low-g maneuvers

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## Summary

*The present work reports and discuses the changes in brain bioelectrical signals induced on normal subjects by open and closed eyes during their first parabolic flight in a small aerobatic plane. A parabolic flight maneuver is characterized by gravity changes from 1g to ~3g (first hypergravity phase, P1) to ~0.05g (hypogravity phase, P2) to ~ 2g (second hypergravity phase, P3) to 1g (inflight phase, B1). EEG signals have been obtained using a 14 channels EMOTIV EPOC device. Digital preprocessing techniques have been applied in order to properly clean all the experimental signals. Standardized Low Resolution Brain Electromagnetic Tomography (sLORETA) allowed obtaining intracranial activity. Statistical analysis of this intracranial activity was performed by using analysis of variance techniques (ANOVA). If ANOVA results were significant, post-hoc analyses were carried out. The results clearly show a decreasing of the intracranial activity during the hypogravity phase with open and closed eyes. Concerning mean values, significant differences have been detected between the hypogravity, P2, and both hypergravity phases, P1 and P3. Significant differences have also been detected for open eyes, by lobes. To check if intracranial activity presents significant differences along the phases, Even Related Potential, ERP, analyses were carried out. For both open and closed eyes tests, sLORETA images show statistical significant differences in the Brodmann areas 18 (Left Occipital Lobe) and 39 (Right Temporal Lobe) between B1-P2, respectively.*

## 1. Introduction

Lately, great attention has been directed towards the possible effect of hyper/hypogravity on human body due to increase interest in life outside Earth. Parabolic flights are suitable methodologies for providing short periods of high/low gravity [1 – 4]. To perform experiments under these conditions, a small CAP10B single-engine aerobatic plane has been used in the present case. This platform provides 6-8 seconds of reduced gravity of, at least, 0.05g on average. Before and after each low gravity interval, hypergravity periods of 5-7 seconds with at the most 2.5-3g load are required [5, 6]. On the other side, as the flights are local, the CAP10B platform can repeat the parabolic flight a number of times during a single day campaign with less than 20 minutes of delay between the take-off and the corresponding hypogravity window. In summary, the proximity and accessibility of the plane as well as the reasonable price of the experiments induced us to select the above platform to perform the experiments. The CAP10B plane cockpit is transparent in all directions, unpressurized and significantly noisier compare to big airplanes such as the ZeroG Airbus 300 (ESA), the G-Force One (NASA), the ZeroGllyushin 76 MDK (RSA) or the GulfStream II (JAXA).

The post-processing of the electroencephalographic signals obtained in the context of the CAP10B low-g maneuvers helped to cover the aim of the present research mainly focused on the study of the neurophysiological differences between the visual and the propioceptive systems. To do so, we conducted two types of experiments, with opened and closed eyes subjects. This study should then be included in a more global framework on aerospace medicine.

## 2. Methods

### 2.1. Parabolic flights

Systematically the CAP10B aerobatic plane took off from the Aeroclub Barcelona-Sabadell and directed to an uninhabited area near the airport to begin the parabolic flights. The approximate rising height was of one thousand meters and the flight duration was about forty minutes, describing ten parabolas. In some special cases the pilot interrupted the experiment due to detection of hot rising convective currents which, by its intensity, could have affected the stability and quality of the parabolas, in terms of acceleration levels.

### 2.2. Subjects

The subjects under study were right-handed adults, men and women, being under no medication both before and during the flight and had no previous experience in parabolic flight. As a mandatory prerequisite before the flight, they successfully underwent a clinical check (Class II EASA Aeronautical Medical Certificate) and provided their written consent to make this activity. During the flight the participants, making low-g parabolas with open and closed eyes, sat strapped at the right side of the pilot and did not report any kind of motion sickness at all. Unfortunately these kind of small platforms do not allow investigating other positions as, for instance, standing or lying in the supine or prone position. In addition, the subject was constantly monitored by video to synchronize their activity with the EEG signal, in order to correct it.

### 2.3. Data acquisition devices

To mechanically characterize the flight we use a Pololu AltIMU-10 inertial measurement unit having a three-axis linear accelerometer and an altimeter. Acceleration sensor

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had a 12 bits data digital output with a 2 mg resolution in a full-scale of ± 4g. The altimeter had a digital resolution of 24 bits getting a resolution in altitude about 2 meters. All the data were recorded at forty samples per second. Simultaneously a GPS receiver engine module, EM406A board, supplied the position of the plane at one sample per second.

To continuously monitor the brain EEG changes all along the flight an EMOTIV EPOC Headset was used. This device is a 14-channel (+2 references) wireless EEG system developed by Emotive Systems. The location of the forteen cephalic electrodes in the MCN International 10-20 system are AF3, AF4, F7, F8, F3, F4, FC5, FC6, T7, T8, P7, P8, O1 and O2 with CMS/DRL references in the P3/P4 locations. The real time brain signals were sampled at 128 Hz using the free software package OpenViBE [7]. This software was also used to store raw data in a portable PC.

### 2.4. Data preprocessing

Due to the high level of artifact contamination in EEG records, mainly generated by the unavoidable mechanical vibrations of the plane and the subject movements, the preprocessing of the fourteen extra-cranial raw signals obtained all along the flight involved a sequence of very delicate steps. Firstly a band pass filter – Butterwoth type - preserving only the frequency range between 8 – 40 Hz was applied to all signals. The objective of this first manipulation is to maintain only the information contained inside the alpha and beta frequency bands discarding the ambient and much of the muscle artifacts [8, 9]. Remember that the four mentioned bands covers, alpha-1 [8-11 Hz], alpha-2[11-13 Hz], beta-1 [13-18Hz], and beta-2 [18-40 Hz]. For the detection and removal of the remaining artifacts (eye blinks, vertical and horizontal eye movements, remaining muscle artifacts, impedance fluctuations ...) we used the ADJUST package [10] followed by the Algorithm for Multiple Unknown Source Extraction, AMUSE, available in the ICALAB toolbox for Signal processing. Both packages work in MATLAB environment [11]. ADJUST has proven to be very efficient in the reduction of eye movements while that AMUSE has proven to be very fast and equally efficient in the elimination of the remaining muscle activity. After the artifact removal, each parabola is baseline corrected in order to minimize slow drifts over time. Six parabolas EEG signals have been averaged and the intracranial activity (equivalently, the estimated standardized current density) was finally obtained solving the so-called inverse problem using Standardized Low Resolution Brain Electromagnetic Tomography (sLORETA) [12]. To calculate the lead field matrix, the brain anatomy used in the case of sLORETA solution (BrainStorm package) is the so-called Colin27 with 15002 cortical voxels [13], while in the case of sLORETA the default MNI115 anatomy has only 6239 grey matter voxels at 5 mm resolution.

### 2.5. Statistical analyses

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% confident interval of the mean appears in parenthesis (thus, there is a 95% chance that the calculated confidence interval contains the true population mean). In order to accomplish the ANOVA conditions, the presence of outliers are checked prior to discarding them. To reinforce normality we also used a log-transform in all cases. When the omnibus hypothesis failed, Tuke's Honestly Significant Difference, Fisher's Least Significant Difference and Bonferroni *post hoc* tests were used. The two-tailed level of significance was typically fixed at $P < 0.05$ in all tests. To avoid the different degree of conservativeness – equivalent, significant levels - associated to each one of the three mentioned tests, we accepted that there were significant differences in the mean values if and only if a minimum of two of them were accomplished. Statistical analyses were performed using Microsoft EXCEL as well as XLSTAT packages.

To check if intracranial activity presents significant differences along the specified phases, Even Related Potential, ERP, analyses were carried out in two stages. The first one enables to detect the instant when a significant difference in the signals between two phases exists. The second involved the detection of the brain region/s (Brodmann areas) which is/are the responsible of the significant difference. The first step test uses the EEG data while the second step test is based on the consideration of intracranial activity around the instant previously detected. Statistical significance is assessed using a nonparametric randomization test [14]. All the above-mentioned manipulations were conducted with the help of the sLORETA & eLORETA Zero Error package.

## 3. Results

### 3.1. Mechanical results

Fig 1 plots, two typical vertical accelerations associated with the averaged parabolas (open and closed eyes). 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

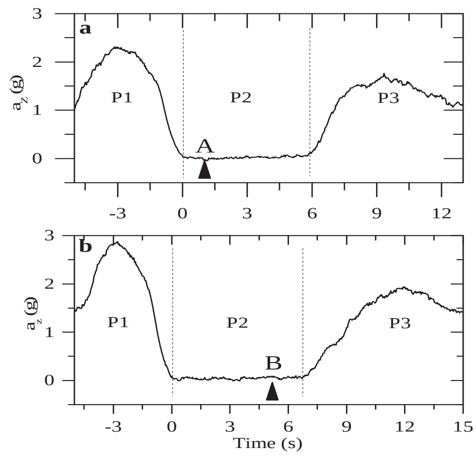


*Figure 1. Vertical acceleration of the averaged parabolas: a) flight with open eyes, b) flight with closed eyes*

In fact, due to the lack of symmetry, P1 and P3 maximum values of vertical acceleration are not equal. The mean value of the residual acceleration during the hypogravity phase, P2, is typically around 0.03g in both cases.

### 3.2. EEG results

Figures 2 and 3 present the temporal evolution of the intracranial activity averaged over 100 ms for the four lobes and for both cases, open and closed eyes respectively. Figure 2 shows that, in all lobes the lower values correspond to the hypogravity phase, P2. This tendency is not clearly recognized in the case of closed eyes (Figure 3).

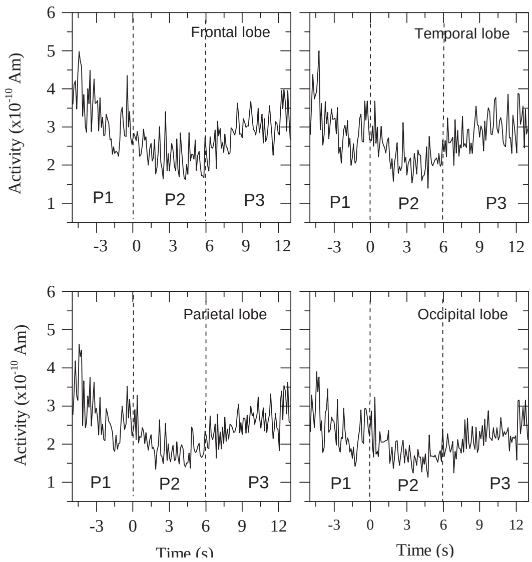


*Figure 2. Intracranial activity along the representative parabola of the flight with open eyes*

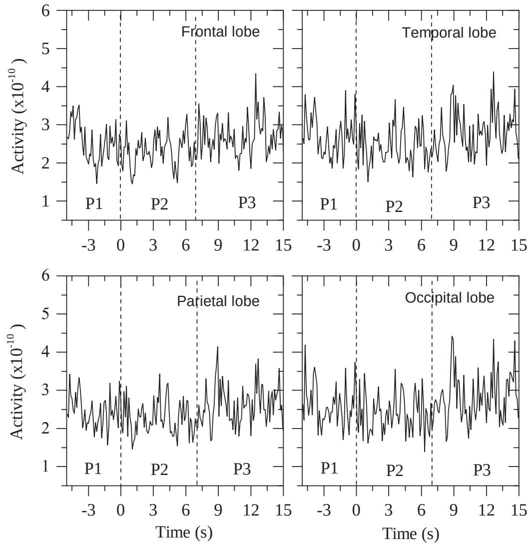


*Figure 3. Intracranial activity along the representative parabola of the flight with closed eyes*

Tables 1 and 2 summarize the mean intracranial activity associated to the different lobes and phases as well B1 inflight phase gathered under 1g conditions, in both experiments. The ANOVA two-way results indicate that there are significant differences between phases with closed eyes but not with open eyes. In addition there are significant differences between lobes with open and closed eyes.

| Lobes / Phases | F | T | P | O |
|---|---|---|---|---|
| B1 | 3.5(2) | 2.1(0.7) | 2.1(0.6) | 1.3(0.7) |
| P1 | 3.3(1.0) | 3.1(0.9) | 2.8(0.9) | 2.5(0.9) |
| P2 | 2.4(0.6) | 2.2(0.6) | 1.9(0.6) | 1.8(0.6) |
| P3 | 2.9(0.7) | 2.9(0.7) | 2.5(0.6) | 2.2(0.6) |

*Table 1: The mean of the intracranial brain activity associated to flight with open eyes. The 95% confident interval of the mean appears in parenthesis*

| Lobes / Phases | F | T | P | O |
|---|---|---|---|---|
| B1 | 2.2(0.8) | 2.2(0.8) | 2.1(0.8) | 1.9(0.8) |
| P1 | 2.6(1.1) | 2.7(1.2) | 2.5(1.1) | 2.6(0.9) |
| P2 | 2.3(1.0) | 2.5(1.1) | 2.3(0.9) | 2.4(0.7) |
| P3 | 2.6(1.1) | 2.7(1.1) | 2.5(1.2) | 2.7(0.7) |

*Table2: The mean of the intracranial brain activity associated to flight with closed eyes. The 95% confident interval of the mean appears in parenthesis*

Post hoc results showed that, comparing the mean intracranial activity values by lobes with open eyes, the values are significant different in the cases of Frontal-Occipital, Frontal-Parietal and Temporal-Occipital. Though, with closed eyes just Temporal-Parietal lobes showed significant differences. Comparing the mean intracranial activity values by phases, the differences were significant between P1- P2, P2-P3 and B1-P1,P2,P3 for closed eyes and insignificant for open eyes.

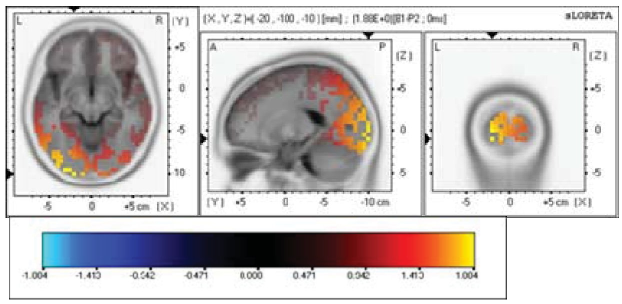


*Figure 4. sLORETA images showing statistical differences (Log of ratio of averages) between B1 and P2 phases in the case of open eyes.*

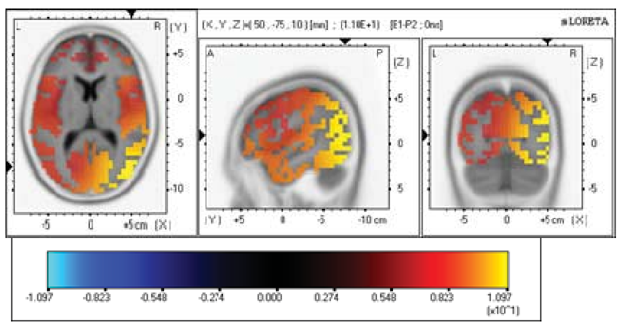


*Figure 5. sLORETA images showing statistical differences (Log of ratio of averages) between B1 and P2 phases in the case of closed eyes.*

For open and closed eyes, ERP analysis indicated that there were no significant differences between specific phases of the parabolas. On the contrary, there exist significant differences between the hypogravity, P2, and

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the inflight base, B1, gathered under 1g conditions during the flights, in both cases.

Figure 4 shows that the significant difference was located in the lingual gyrus (occipital lobe, Brodmann area 18) at a time = 1 second approximately. This time corresponds to point A in Figure 1.a. Figure 5 (B1-P2 for closed eyes) shows that the significant differences are now located in the middle temporal gyrus (temporal lobe, Brodmann area 39). The time associated is 4.8 seconds - see point B in Figure 1.b-.

## 4. Conclusions

The present work has shown that the use of small aerobatic aircraft to conduct parabolic flights is a practical and inexpensive way to conduct pilot studies for medical research. With these small platforms, the attained hypogravity is reasonable (around 0.05 g) and suitable for research purposes, but its characteristic elapsed time within a parabola is short (around 6 seconds, open and closed eyes) when compared to the longer time obtained in larger aircraft (around 20 seconds, only closed eyes). Moreover extra influences in the results were due to the different experimental conditions (plane transparent cockpit, non thermostated and unpressurized environment).These differences allow us to explain the different responses reported in the literature, as specific activity found in the right frontal lobe [15].

Up to now the literature reports discussion based on mean EEG values [9]. In this work we introduce for the first time, temporal evolutions of intracranial activity all along the hypogravity maneuvers and from different lobes considered. It seems that the incorporation of the neural routes, associated with the vision - corresponding to Brodmann areas 17, 18 and 19 - increase the brain activity in all phases of the parabola.

The present ERP analyses, introduced, as well, for the first time in this kind of experiments, indicate that the conditions of the flight greatly influence the neural behavior of the subjects. The different times obtained show that the human perception of the hypogravity is faster when the visual system is involved. This agrees with the fact that the lobes implicated are different, open eyes is related with occipital and closed eyes is related with temporal.

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