Brain Anatomo-Functional Changes Associated with Spaceflights

TRANSLATIONAL RESEARCH INSTITUTE FOR SPACE HEALTH
CAT004

CENTER FOR COGNITIVE AND COMPUTATIONAL NEUROSCIENCE

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ILMENAU UNIVERSITY OF TECHNOLOGY

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Outline

Risk factors associated with Spaceflights

1. Isolation, Radiation, Microgravity
2. SANS / Cognitive performance

Brain Morphological and functional Changes associated with Spaceflights

1. Volumetric Changes
2. Structural connectivity changes
3. Functional MRI

Brain Oscillatory activity changes

1.Brief history of EEG in the Space
2.Potential Technical Issues
3.Alpha power and connectivity changes after spaceflights
4. New avenues and analysis

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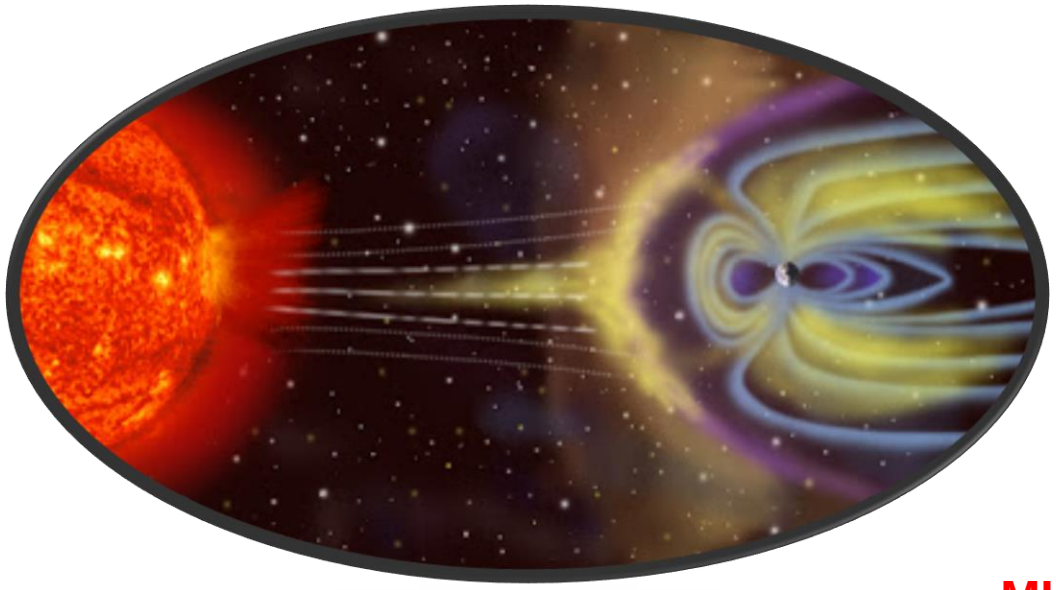
RISK FACTORS

RADIATION

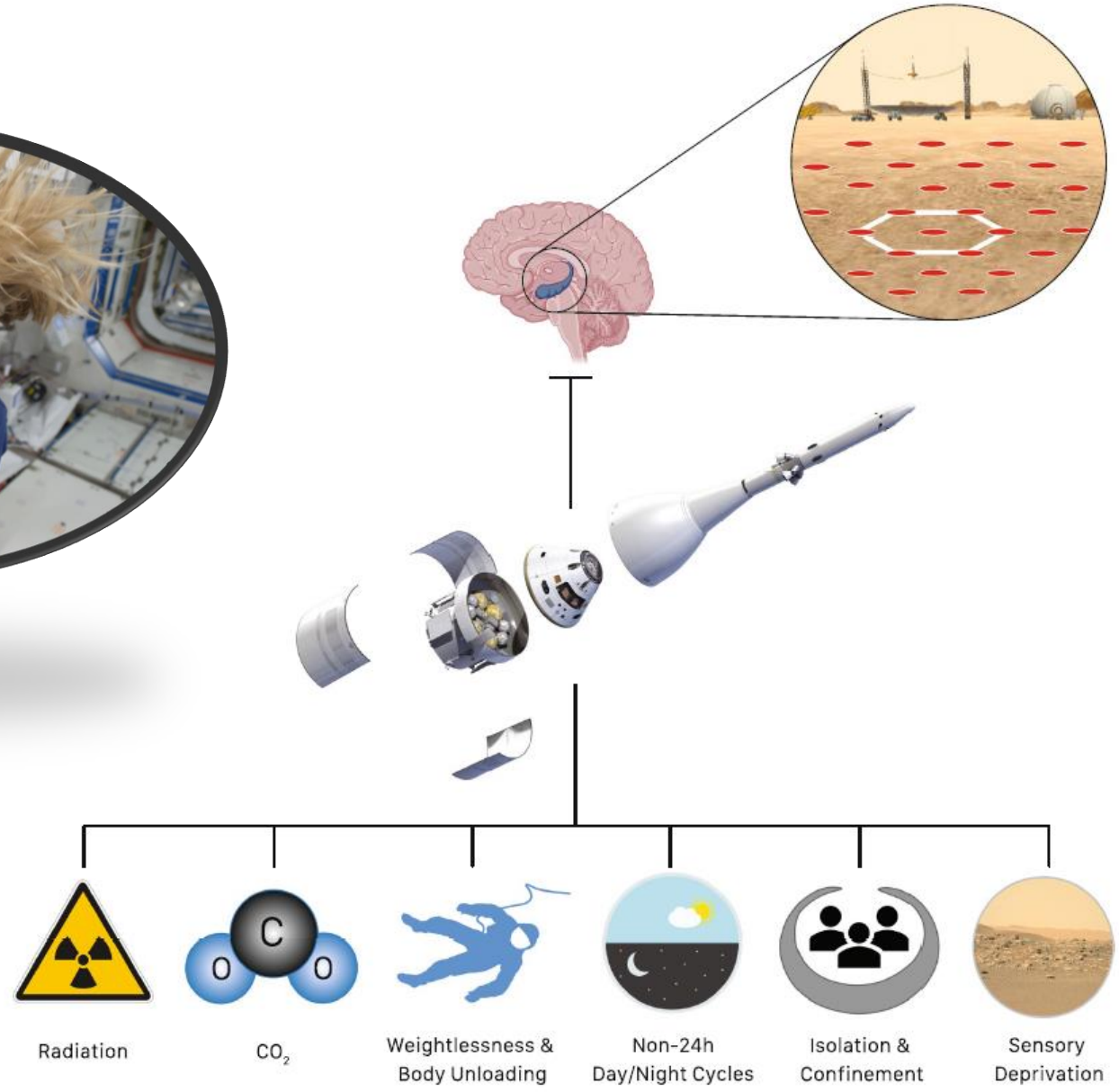


ISOLATION

MICROGRAVITY

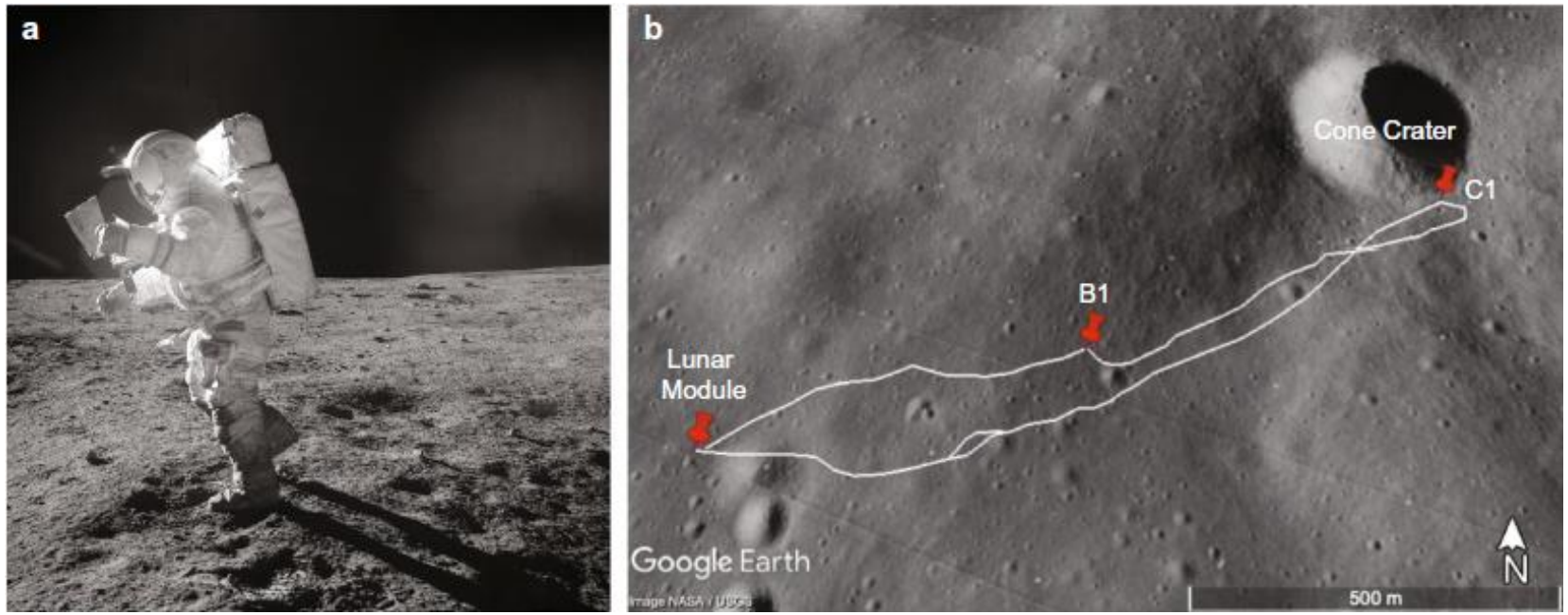
Cognitive Performance

SANS



(Stahn and Kühn, 2021)

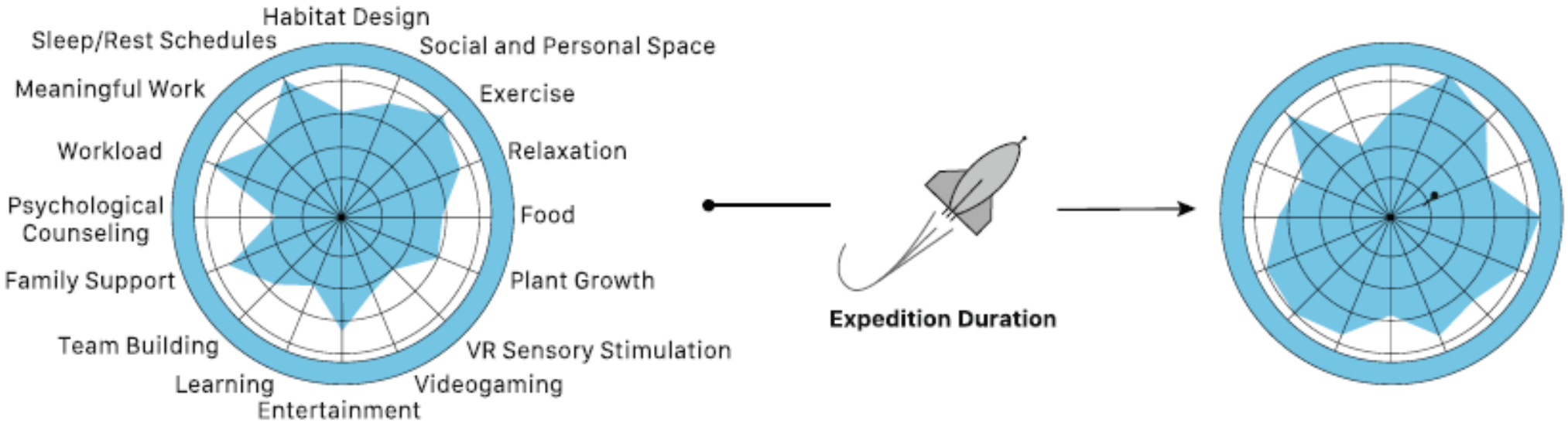
Cognitive performance



Astronauts Ed Mitchell and Alan Shepard had to walk to a crater located within a mile from their landing module. Having nearly reached the target destination, they had to abort the assignment because of spatial disorientation. They were just 30m away from the target cráter.

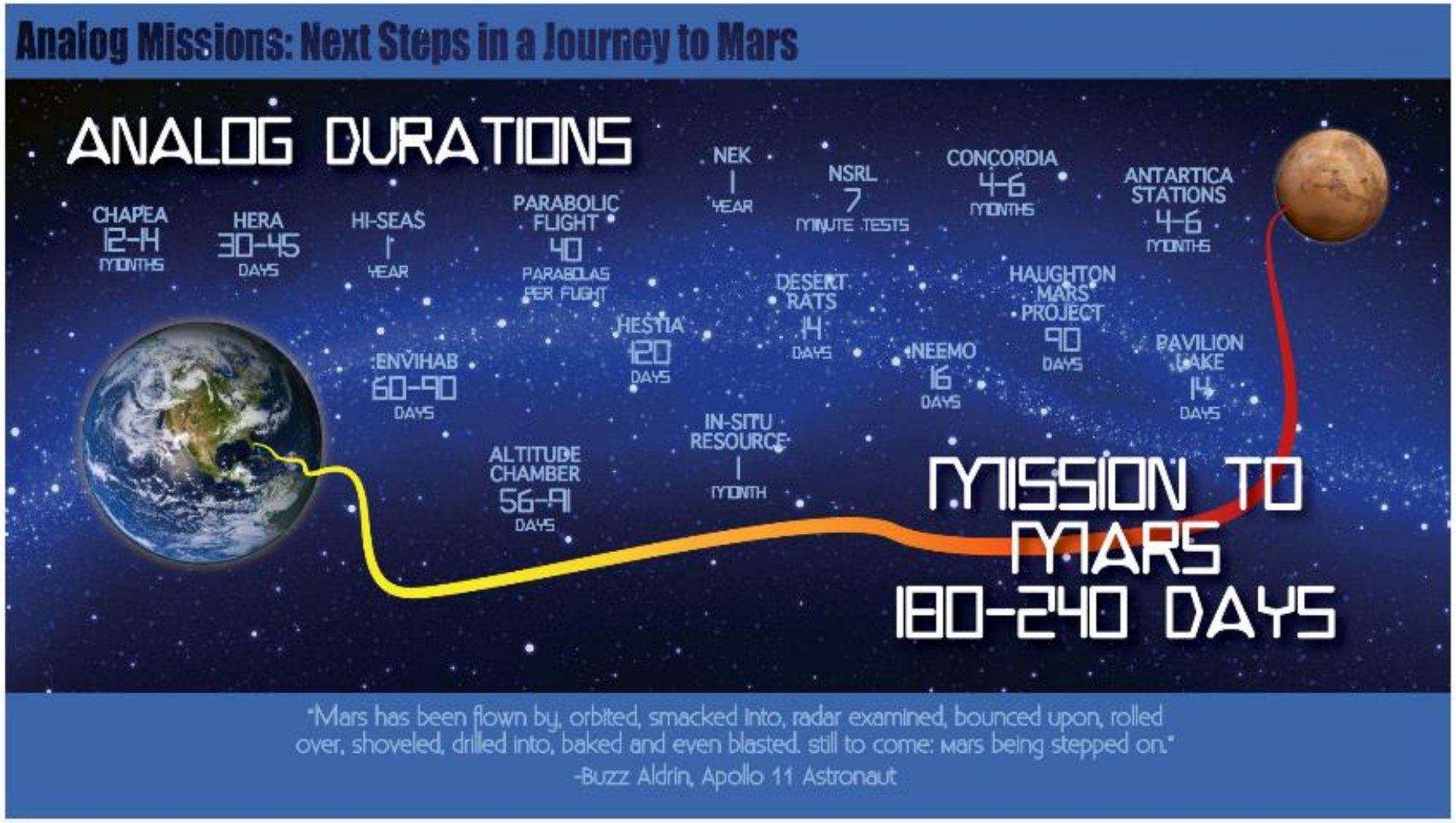
(Stahn and Kühn, 2021)

Countermeasures



(Stahn and Kühn, 2021)

Analog missions



Isolation and Hostile Environments

Isolated and controlled confinement (ICC)

Isolated confined and extreme environments (ICE).

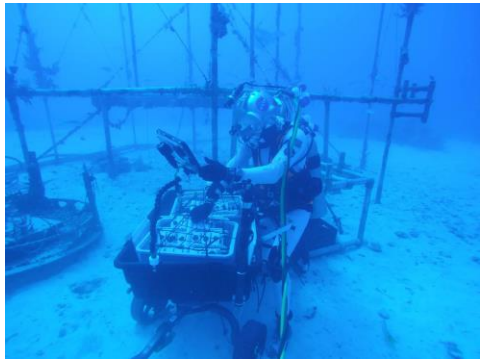
Possible Hazards:

- ❑ Decline in mood, cognition, morale..
- ❑ Sleep disorder
- ❑ Depression
- ❑ Behavioral or cognitive conditions
- ❑ Elevated stress hormone level -> alter immune system

The Human Exploration Research Analog (HERA)

NASA's Johnson Space Center, Houston

NASA Extreme Environment Mission Operations (NEEMO)



Undersea Research Station, Florida

Mcmurdo Station

Palmer Station

ANSMET

Antarctic Stations

Isolation studies

MARS 500

During the Long Way to Mars: Effects of 520 Days of Confinement (Mars500) on the Assessment of Affective Stimuli and Stage Alteration in Mood and Plasma Hormone Levels

Yue Wang[1,2], Xiaolu Jing[3], Ke Lv[2], Bin Wu[2], Yanqiang Bai[2], Yuejia Luo[4]*, Shanguang Chen[5]*, Yinghui Li[2]*

1 National Key Laboratory of Cognitive Neuroscience and learning, Beijing Normal University, Beijing, China, **2** State Key Laboratory of Space Medicine Fundamentals and Application, China Astronaut Research and Training Center, Beijing, China, **3** China Astronaut Research and Training Center, Beijing, China, **4** Institute of Affective and Social Neuroscience, Shenzhen University, Shenzhen, China, **5** National Laboratory of Human Factors Engineering, China Astronaut Research and Training Center, Beijing, China

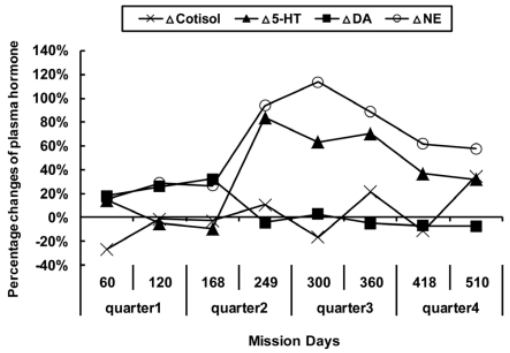


Figure 4. Percentage changes of plasma hormone level compared with baseline (−7 d) over 520 d confinement. Δ5-HT, ΔCortisol and ΔNE fluctuated significantly over the course of confinement ($p<0.05$).
doi:10.1371/journal.pone.0087087.g004

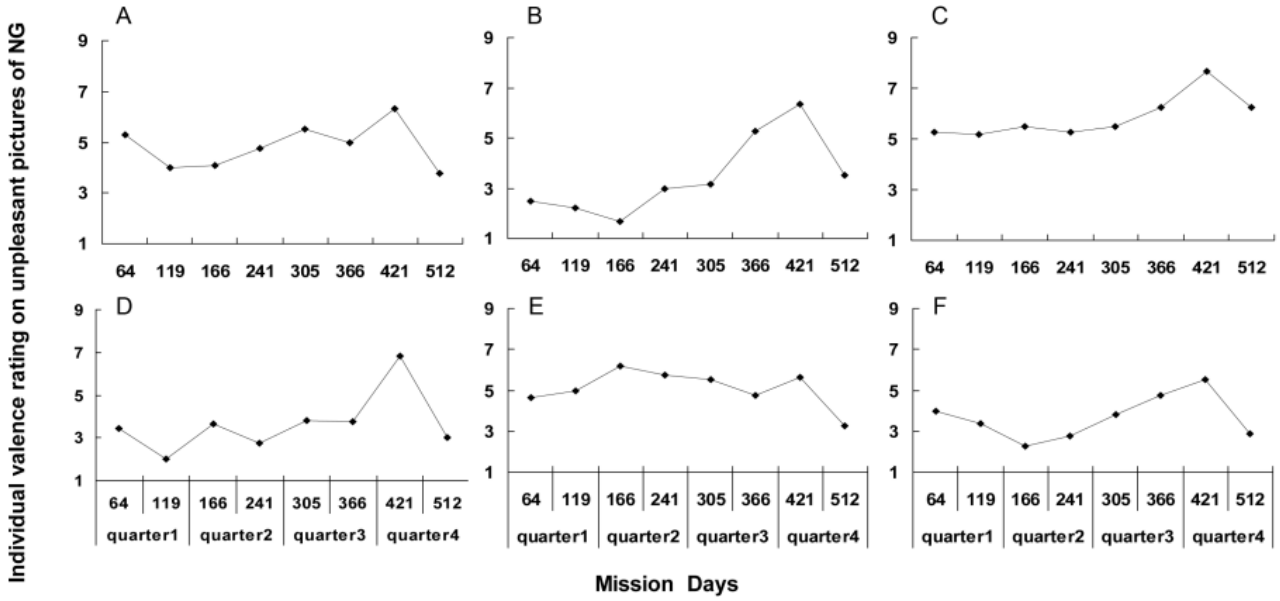
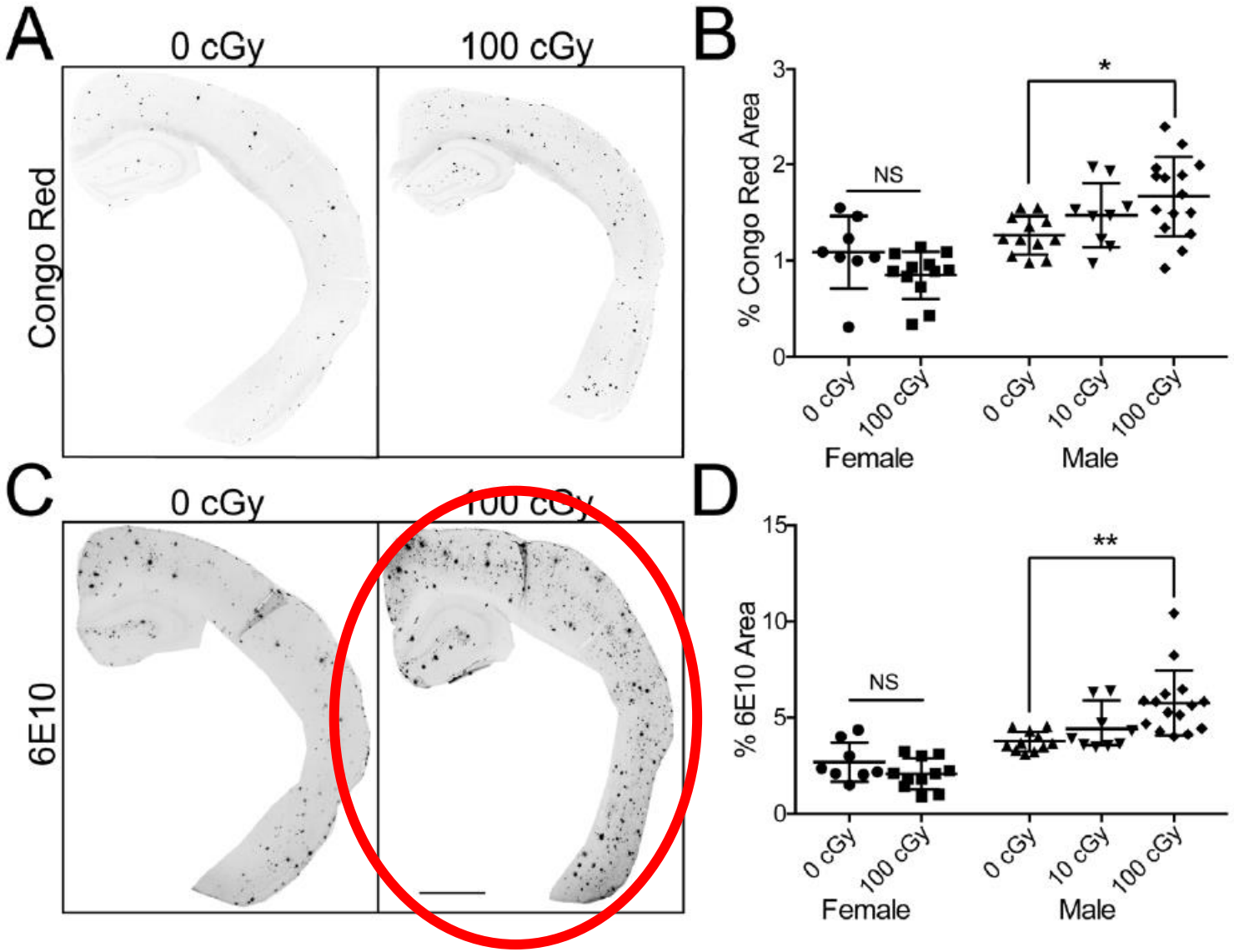
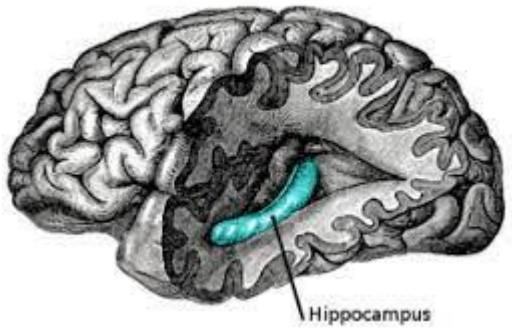


Figure 2. Individual valence ratings of unpleasant pictures from the NG. (A)–(F), valence ratings from each crewmember.
doi:10.1371/journal.pone.0087087.g002

Radiation

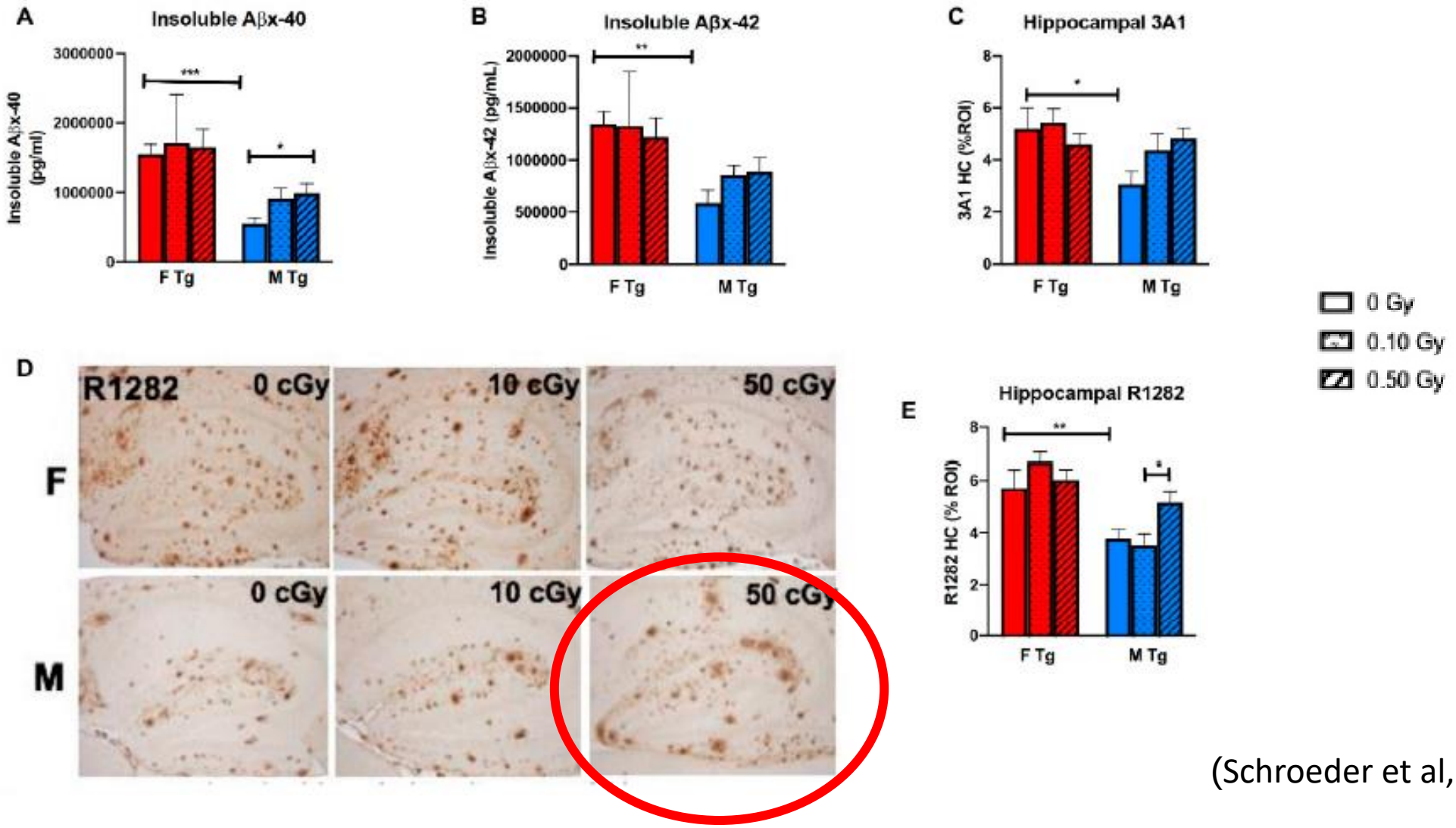


Male animals increased amyloid deposition



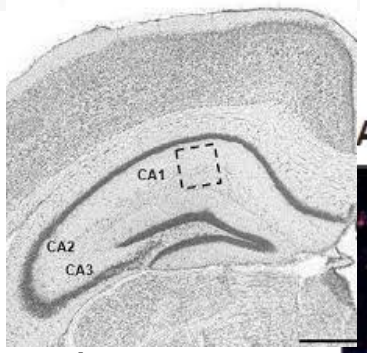
(Cherry et al, 2012)

Radiation

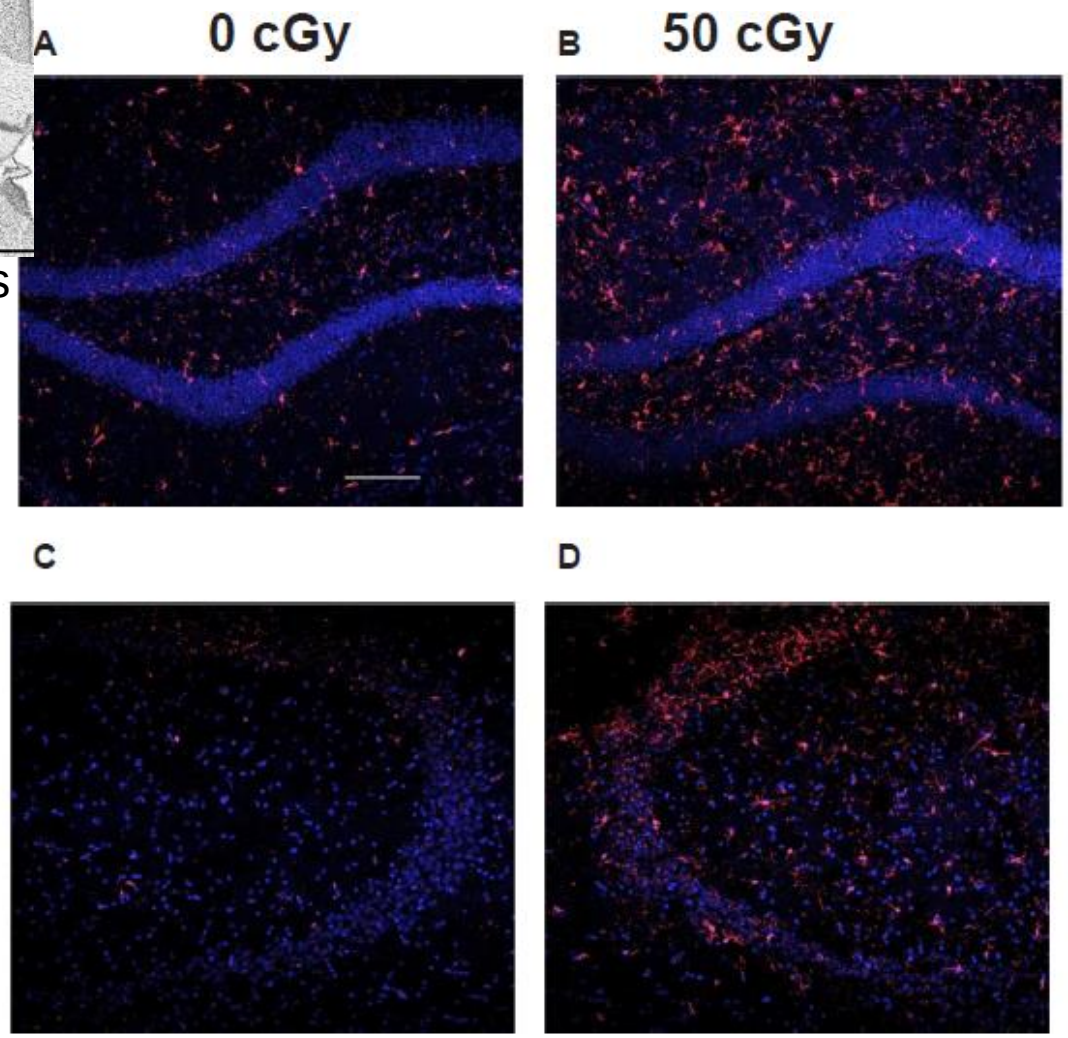


(Schroeder et al, 2021)

Radiation: microglial activation

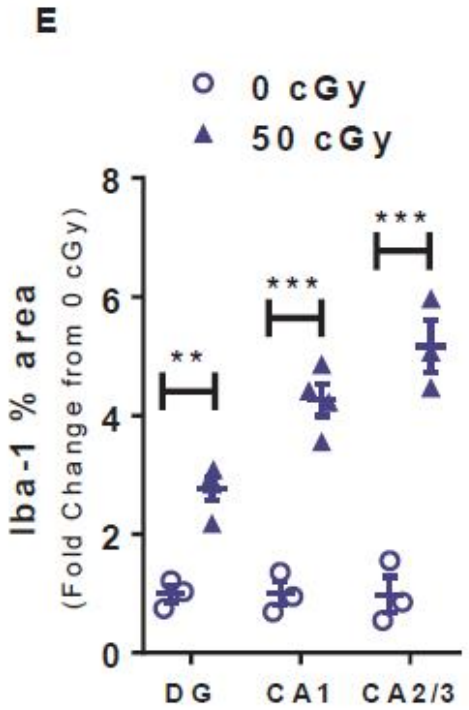


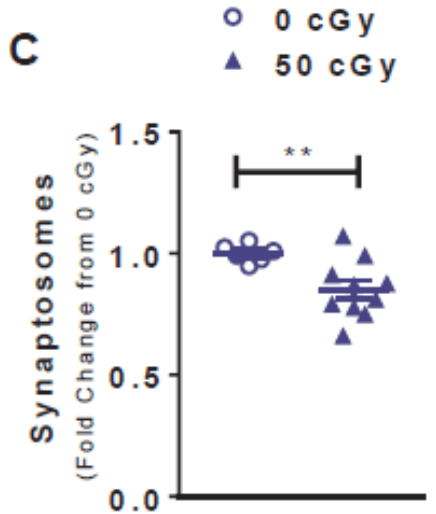
Hippocampus



Just in male animal

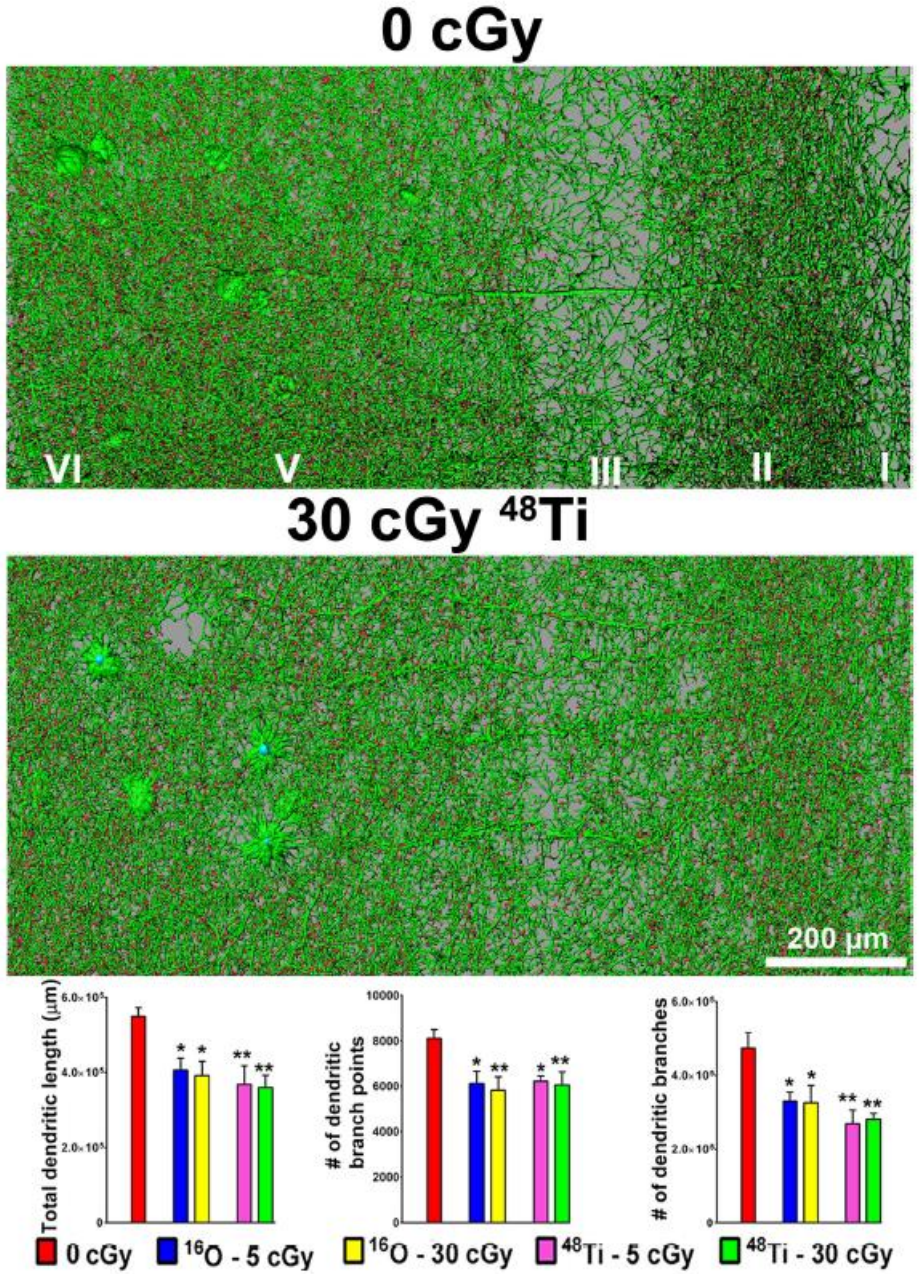
diminished social interaction,
increased anxiety-like
impaired recognition
memory



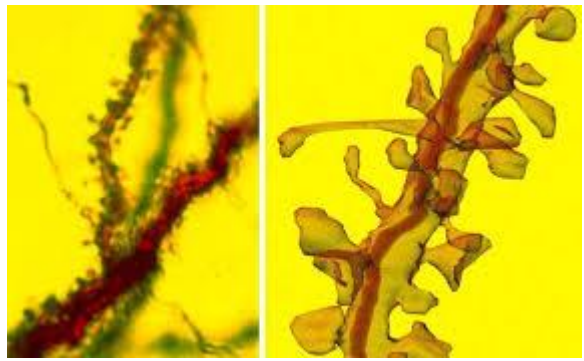


(Krukowskia et al, 2018)

Radiation: dendritic complexity



Reduced dendritic complexity



(Parihar, et al, 2016)

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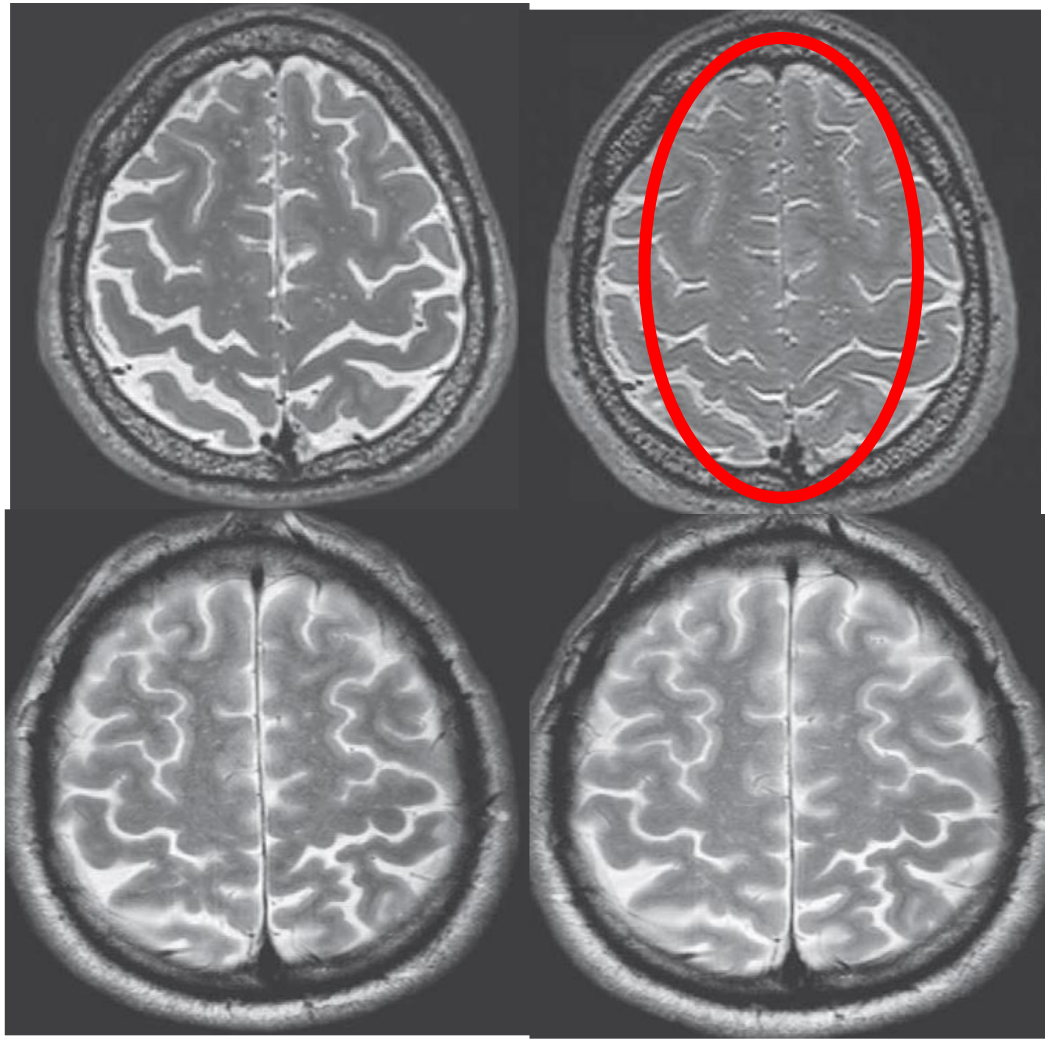
Brain Morphological Changes

Narrowing of the central sulcus occurred in 17 of 18 astronauts after long-duration flights and in 3 of 16 astronauts after short-duration flights



18 Astronauts Long duration

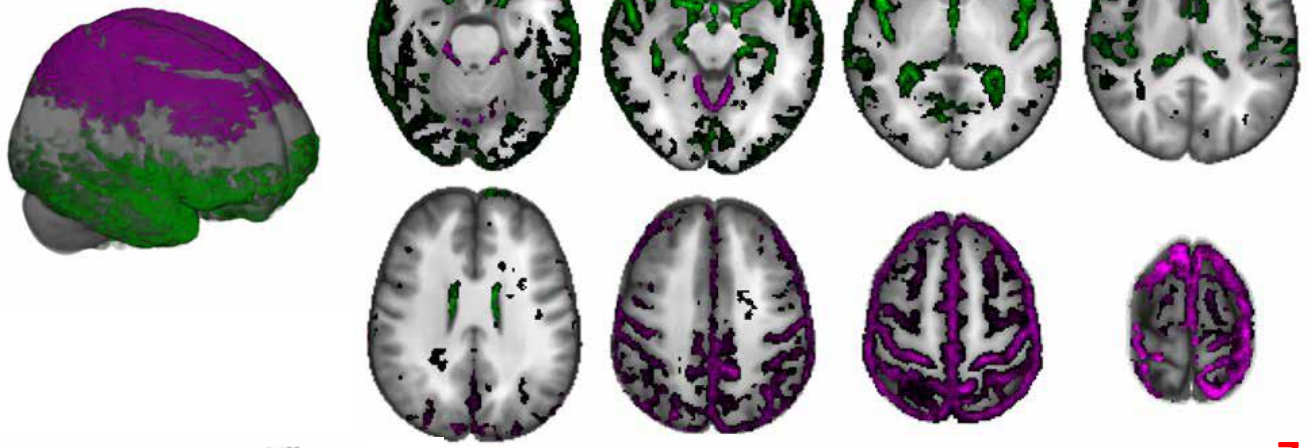
16 short Duration

(Roberts et al, NEJM, 2017)

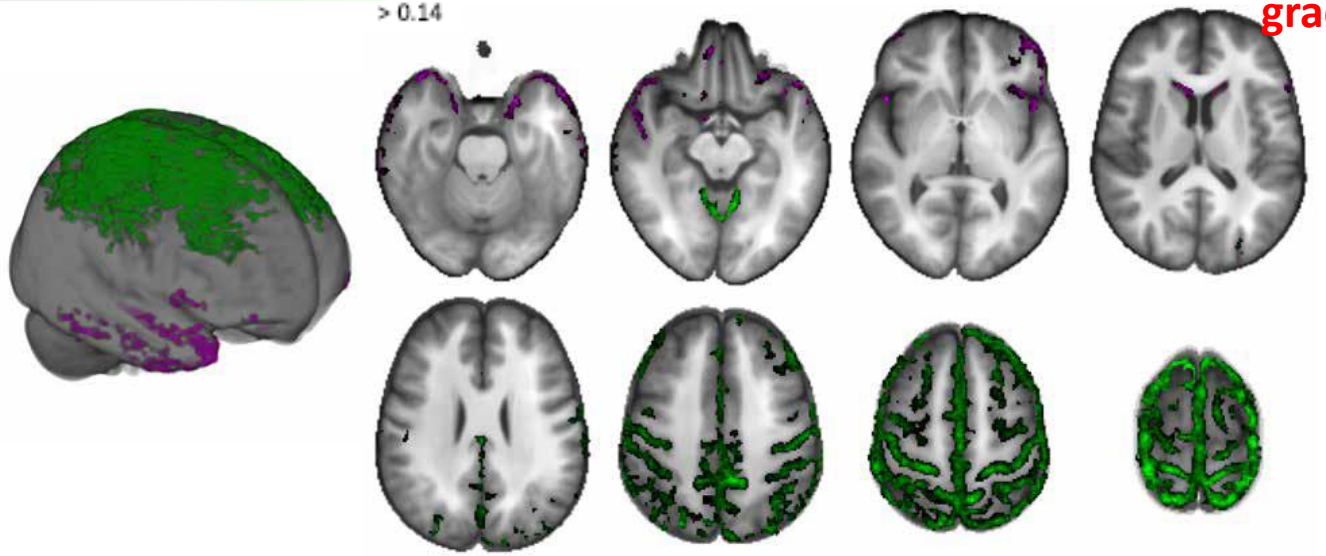
MRI CSF changes

Preflight - postflight

Microgravity-induced upward brain shift inside the skull



Follow-up - Postflight

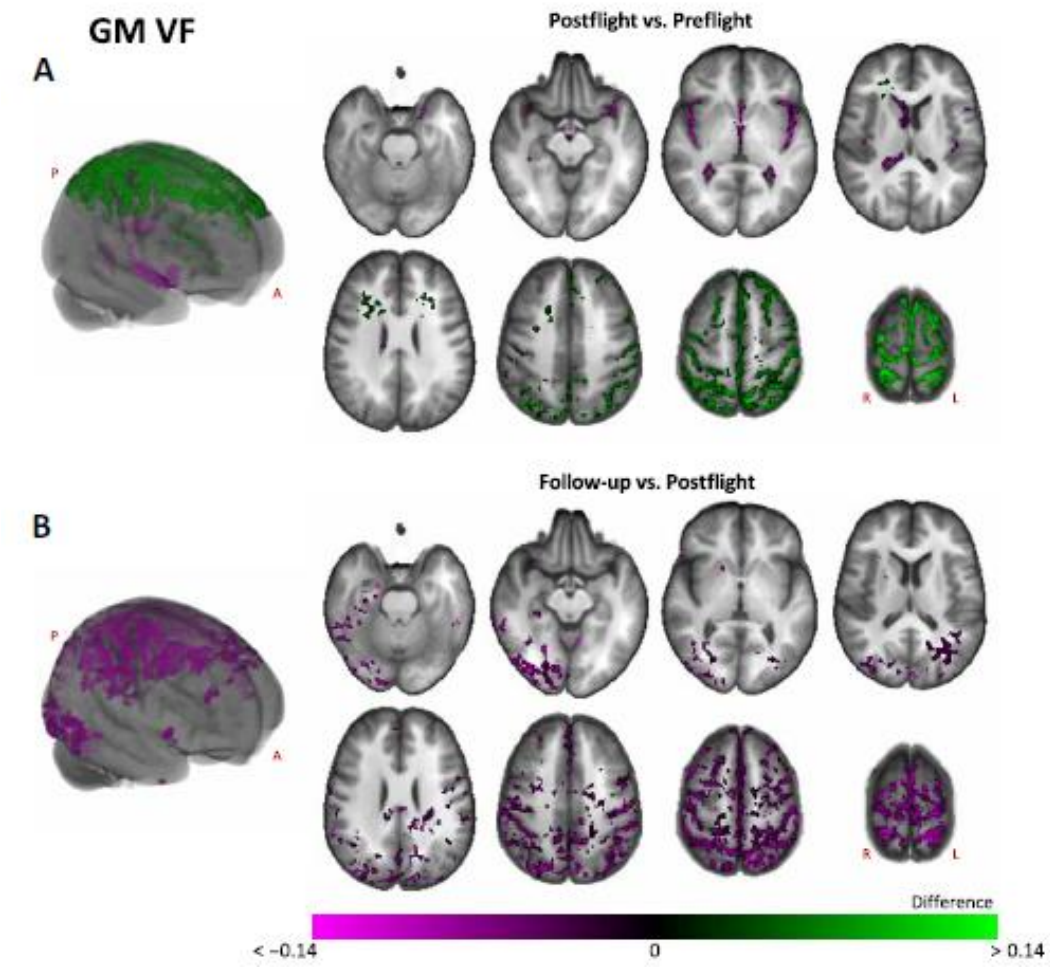


7 months after landing on earth gradual recovery of CSF distribution

(Jillings et al, 2020)

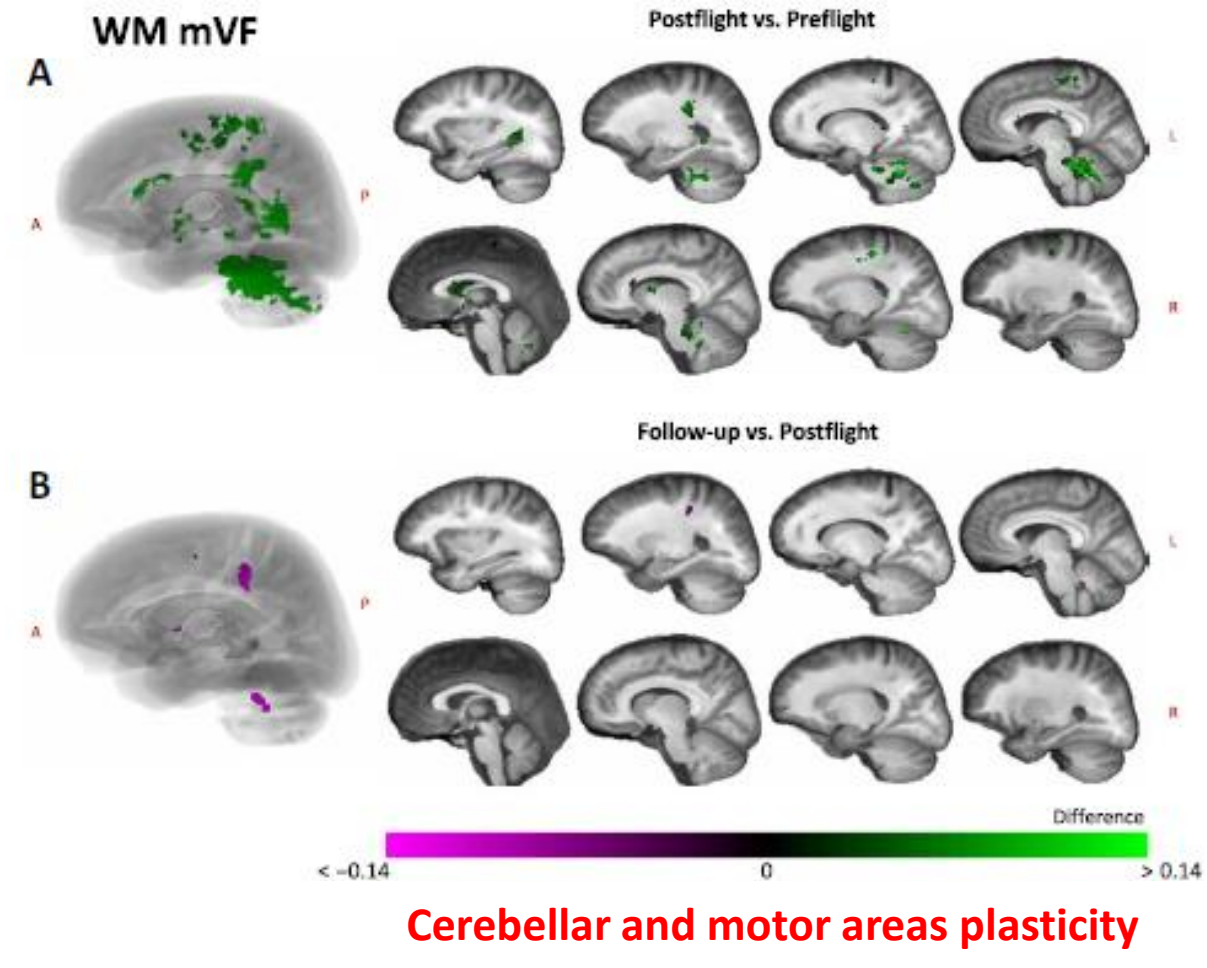
MRI G/W matter changes

Grey Matter Changes



CSF volume decrease in superior region, cause crowding of the GM tissue along the interface with the sulci

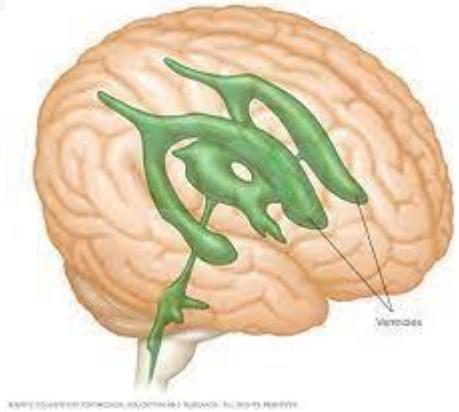
White Matter Changes

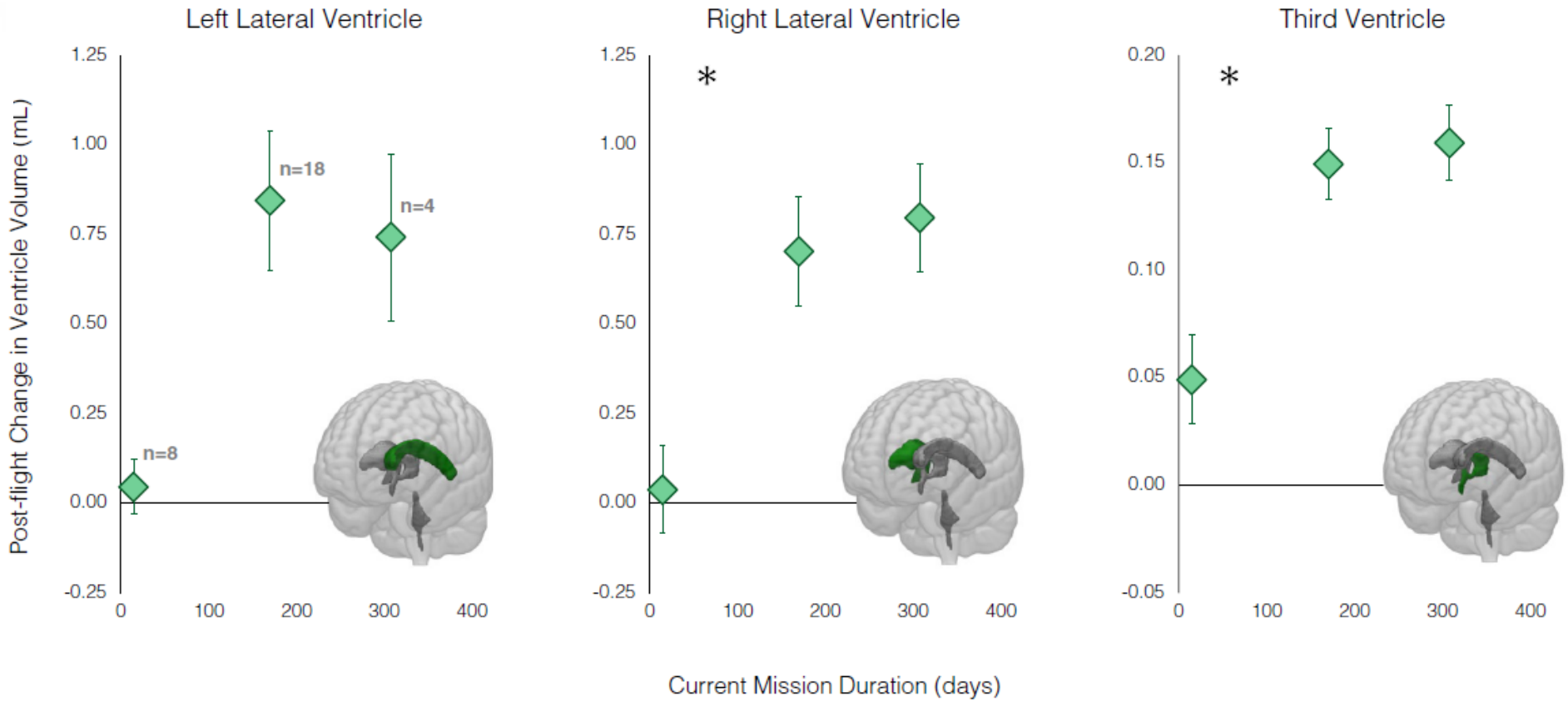


Cerebellar and motor areas plasticity

(Jillings et al, 2020)

Volumetric changes: effects of flight duration and previous flights





(McGregor et al, 2023)

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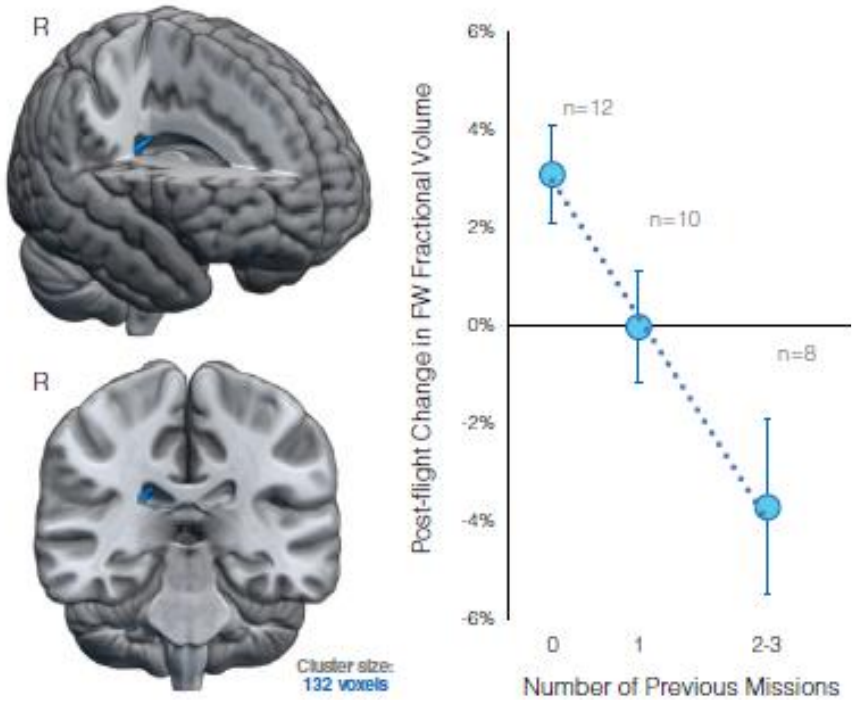
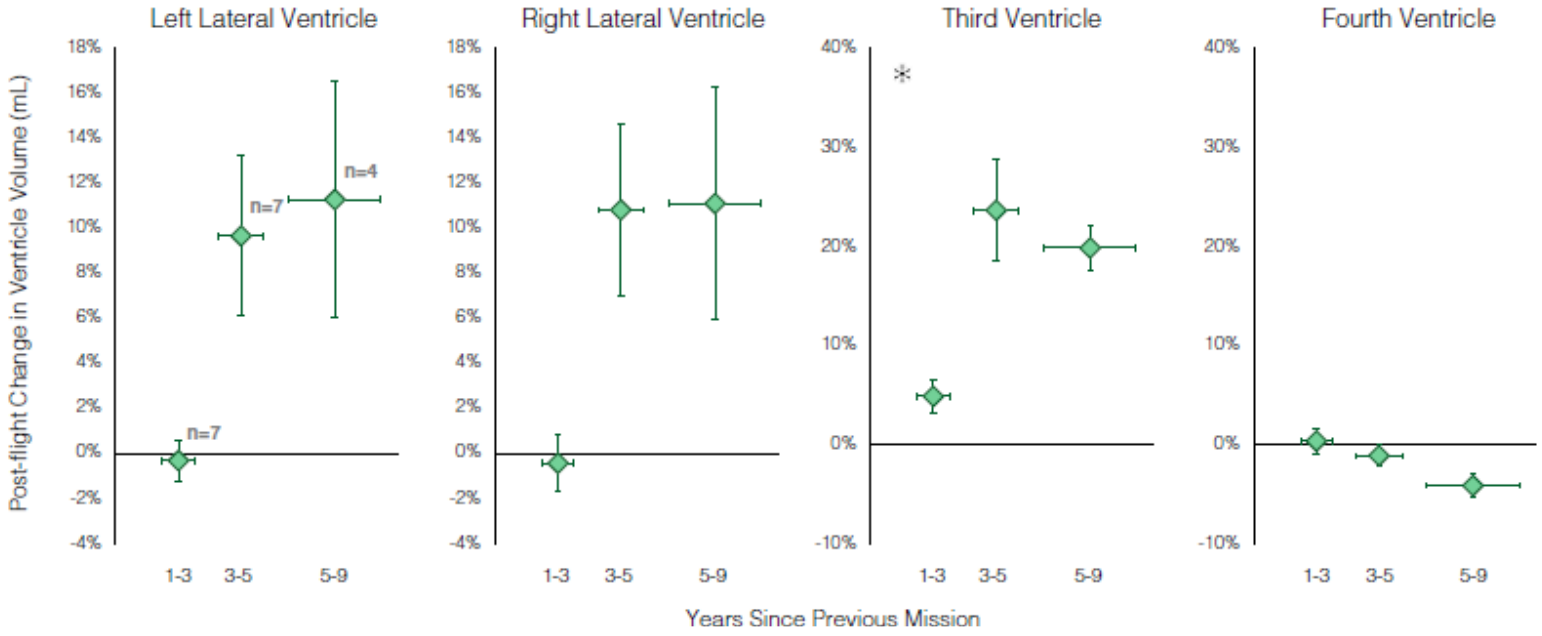


No further increase of volume as a function of previous missions

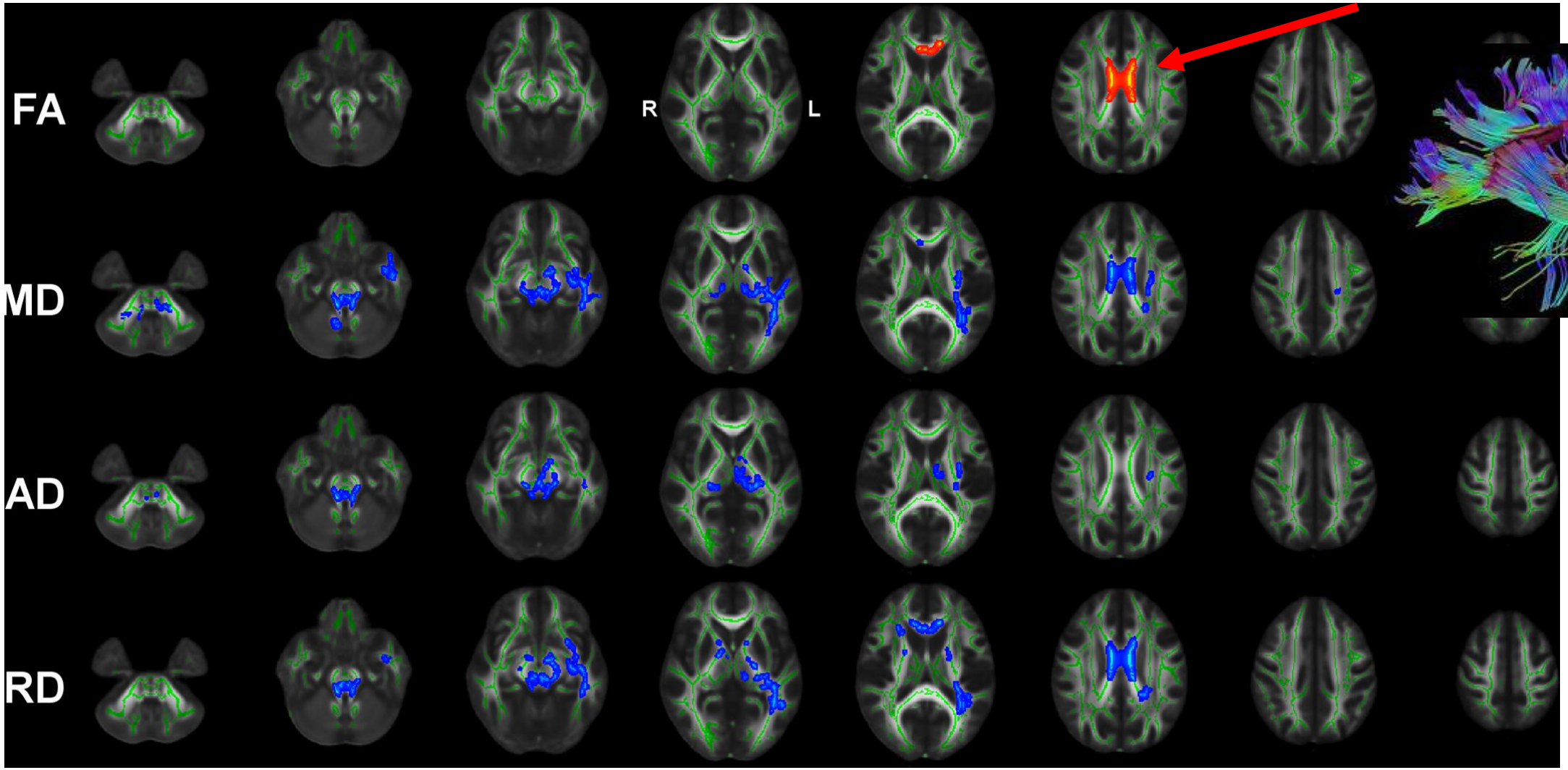


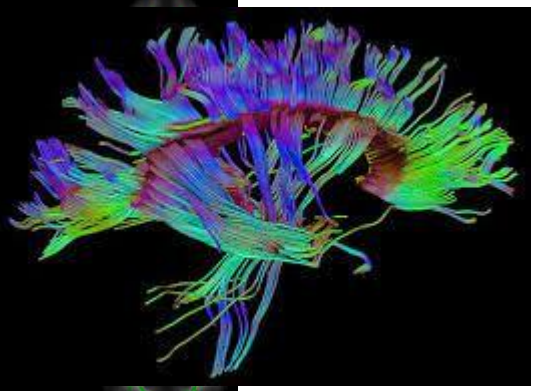
Crewmembers who had 3 years or longer to recover following their previous mission showed ventricular expansion following the current mission

(McGregor et al, 2023)

MRI DTI changes

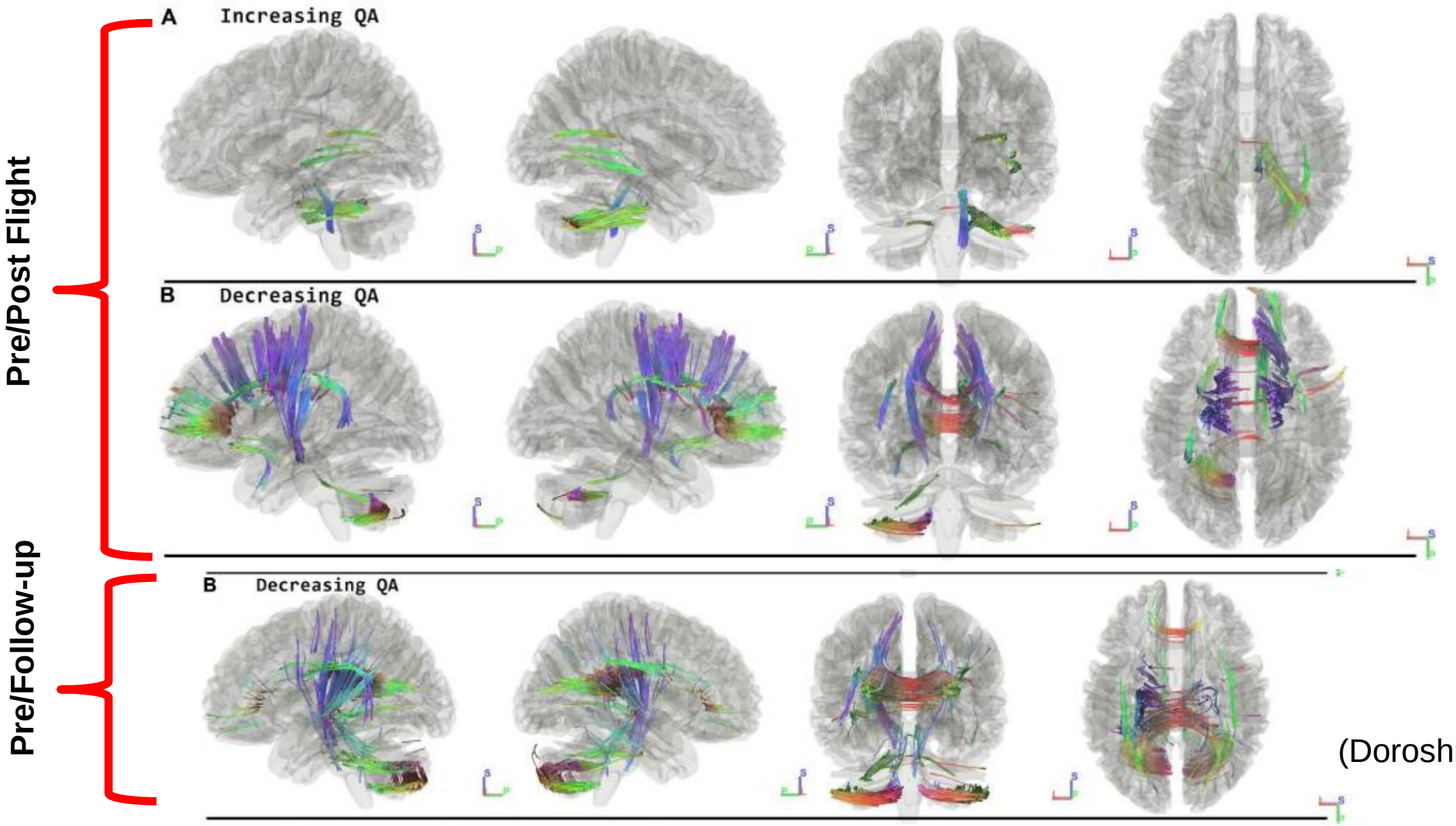
Structural connectivity: 520 days isolation (analog) **Reduction of FA values**





(Brem et al, 2020)

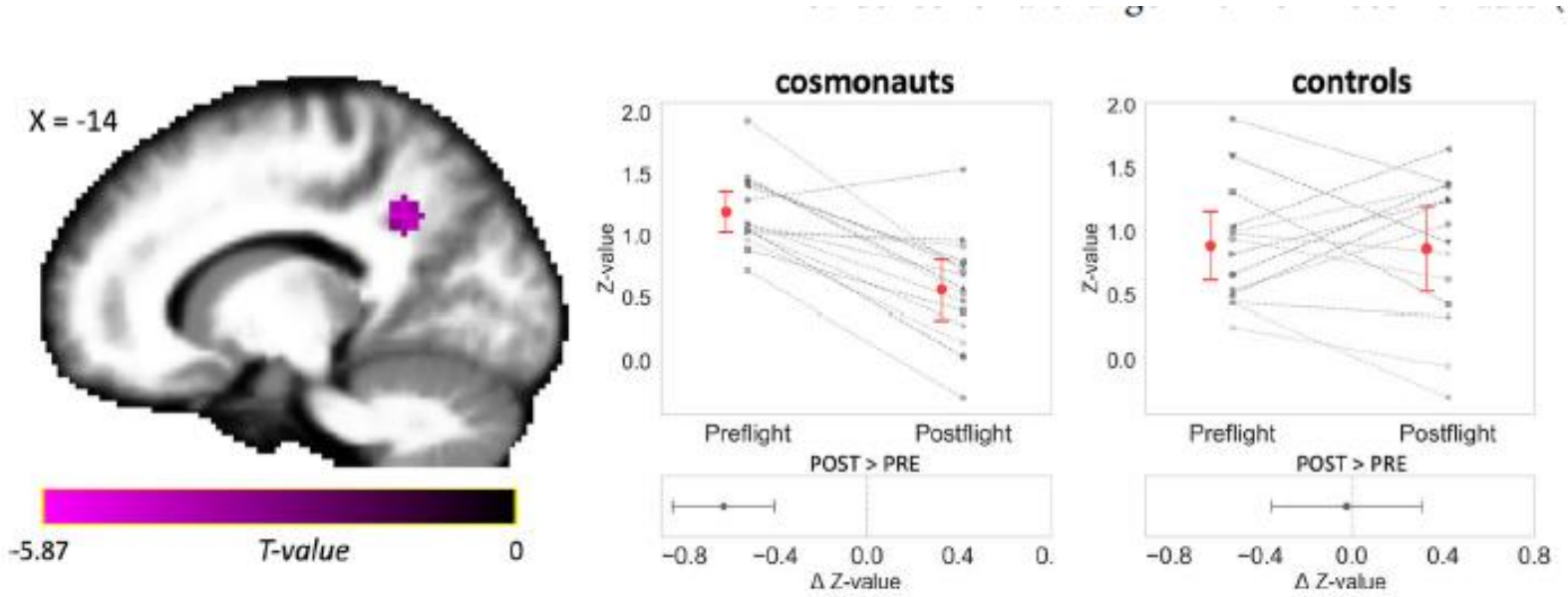
Structural connectivity in 12 Cosmonauts: Six months at ISS



(Doroshin et al, 2022)

MRI Functional connectivity changes

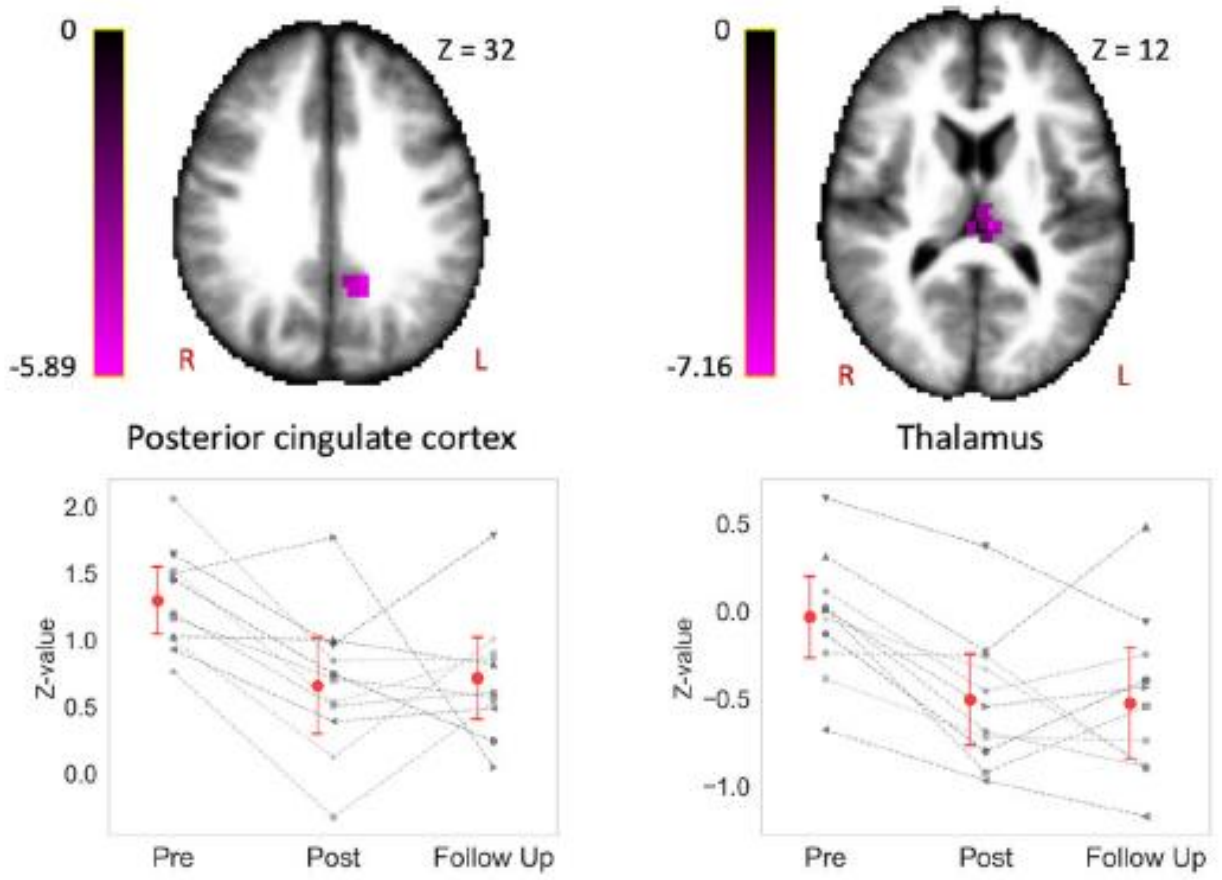
Posterior Cingulate Cortex decreased connectivity postflight



(Jillings et al, 2023)

MRI Functional connectivity changes

Posterior Cingulate Cortex and Thalamus decreased connectivity 7 months after landing



(Jillings et al, 2023)

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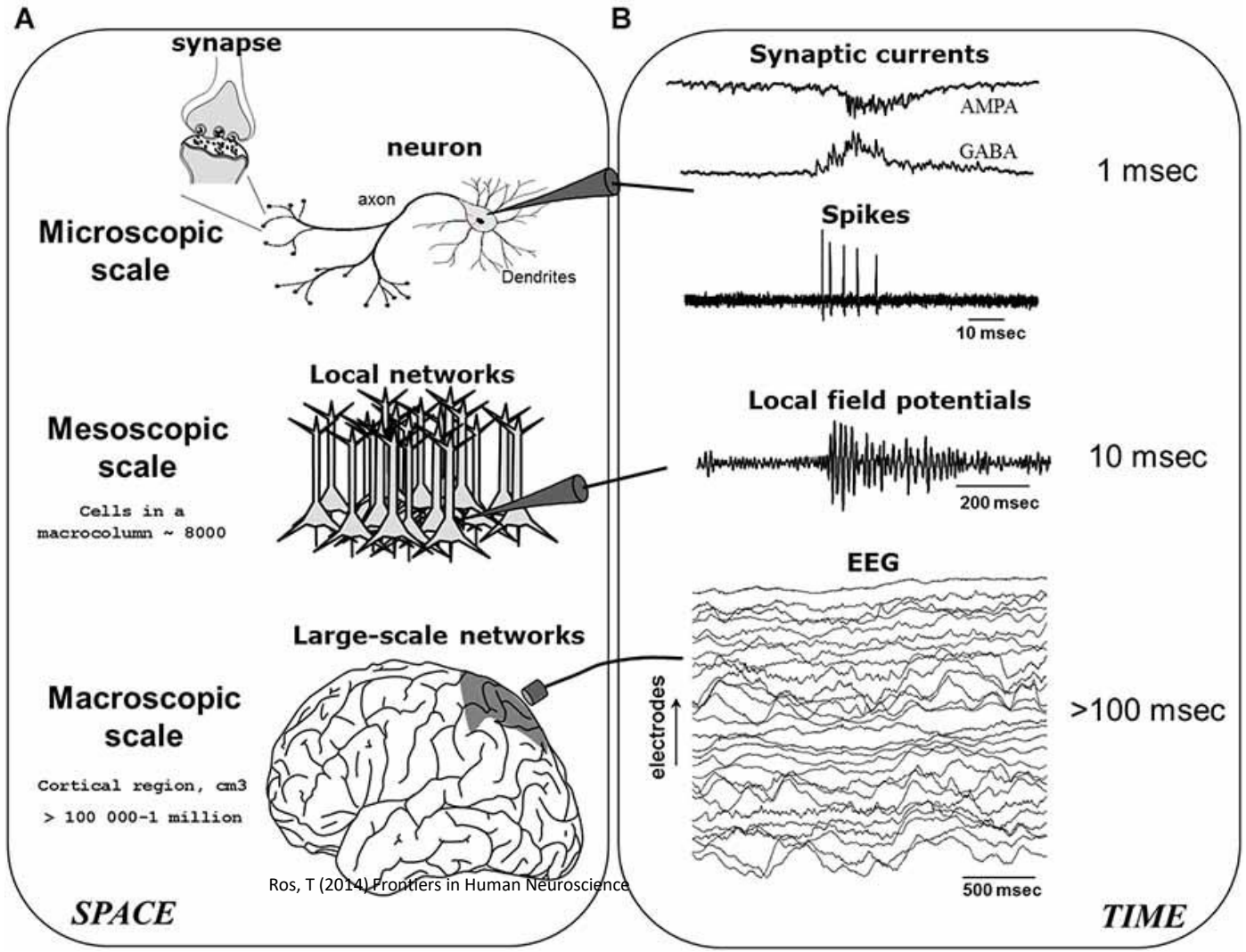
Generación de la actividad cerebral



Ros, T (2014) Frontiers in Human Neuroscience

Oscilaciones y ritmos cerebrales

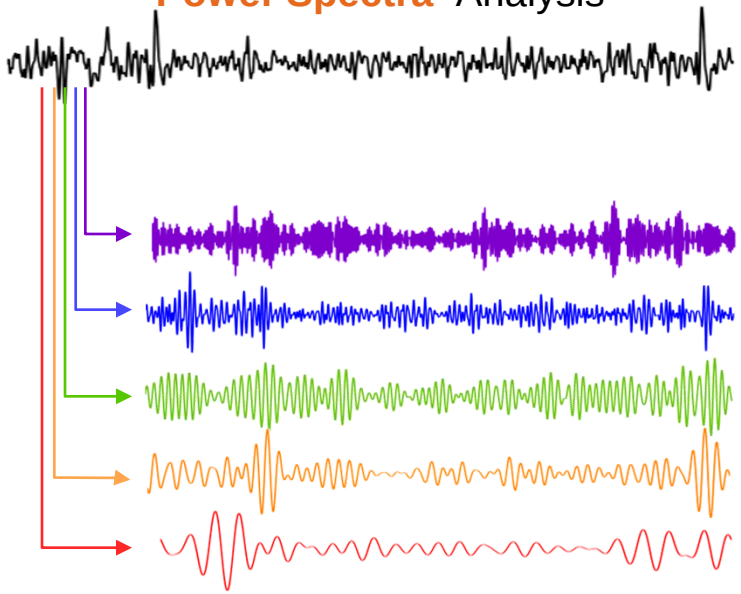
Amplitud

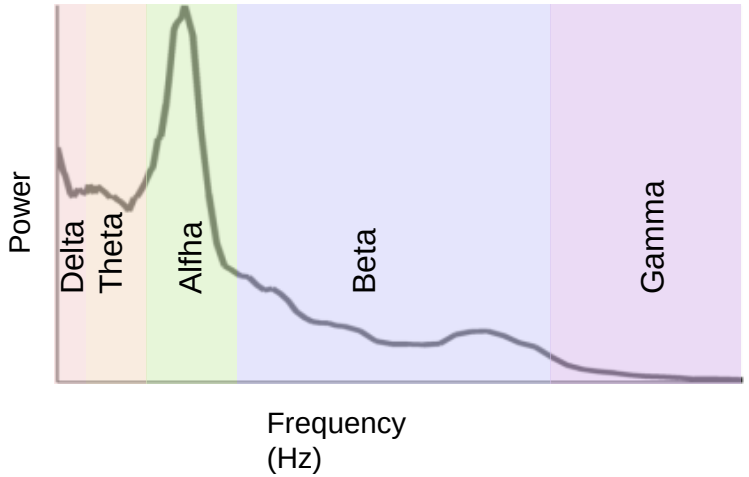
Tiempo

- Amplitud: Es la amplitud máxima que alcanza el oscilador desde el punto de reposo
- Periodo: Es el tiempo que tarda el oscilador en completar un ciclo completo, es decir, en ir desde un punto cualquiera, hasta volver al mismo punto tras completar una vuelta entera.
- Fase: Es la posición de la oscilación en un momento de tiempo cualquiera

MEG

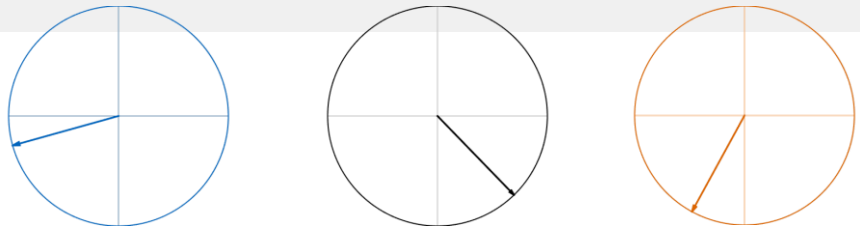
Power Spectra Analysis





Functional Connectivity Analysis

- **Phase** Synchronization
- **Amplitude** Synchronization

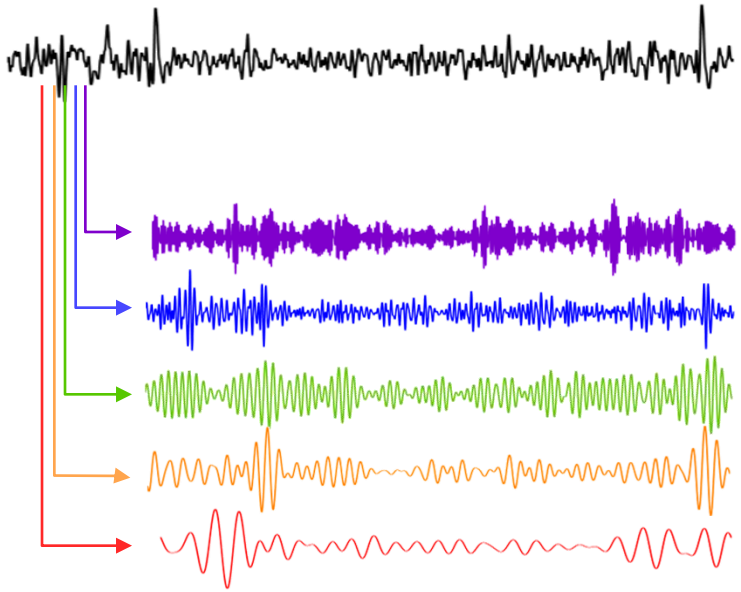


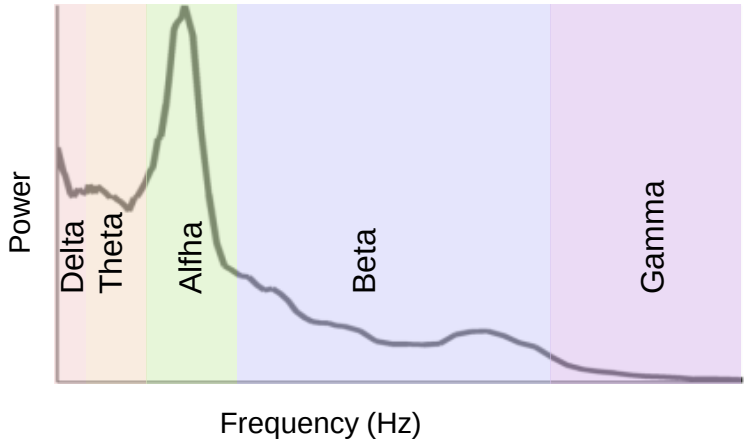
Network Analysis

López-Sanz, 2017 PhD disertation

Why MEG?

Power Spectra Analysis





Functional Connectivity Analysis

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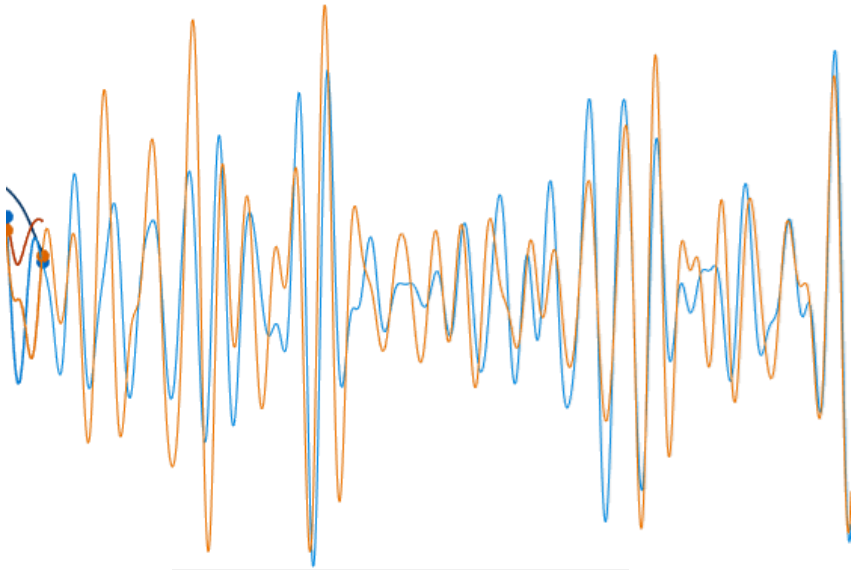
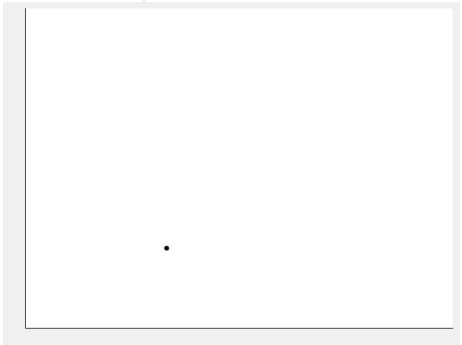
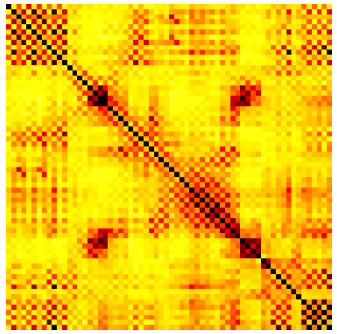
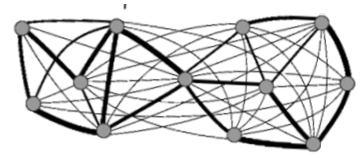




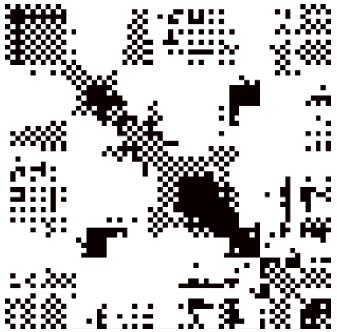
Network Analysis

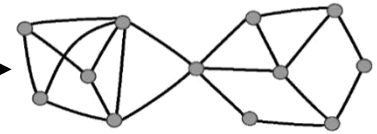




Include **all edges** between nodes with their respectives **weights**

Binarization



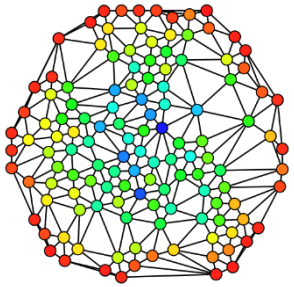


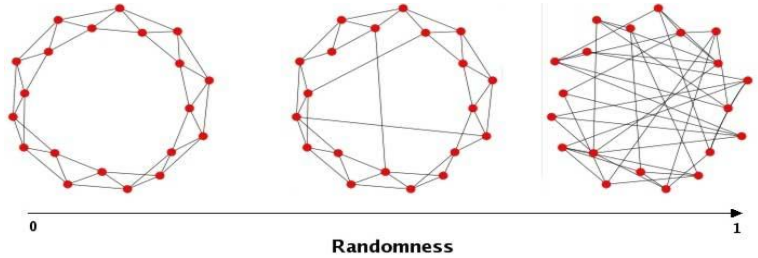
Includes just the **most relevant edges** between nodes **without weights**

López-Sanz, 2017 PhD disertation

M/EEG Conectividad funcional

TEORÍA DE GRAFOS





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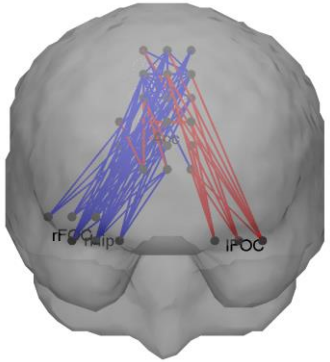
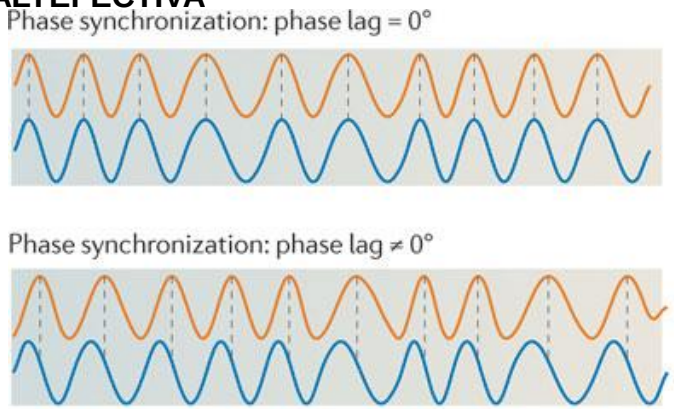
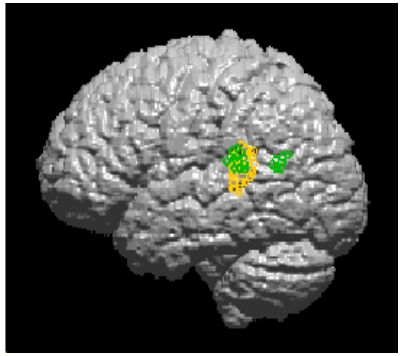
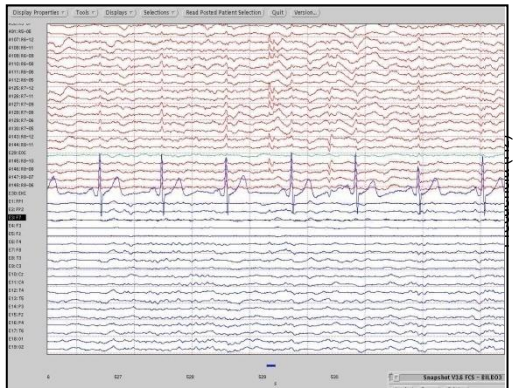




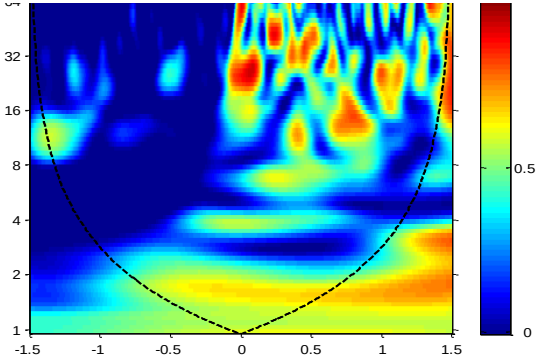
ESPACIO



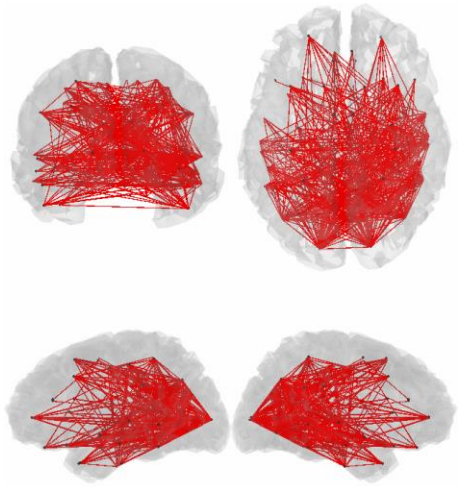
TIEMPO

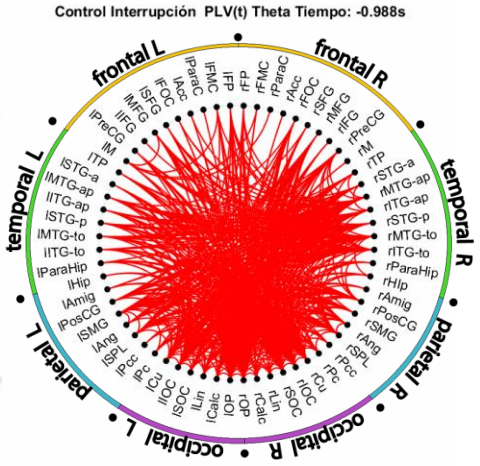


FRECUENCIA

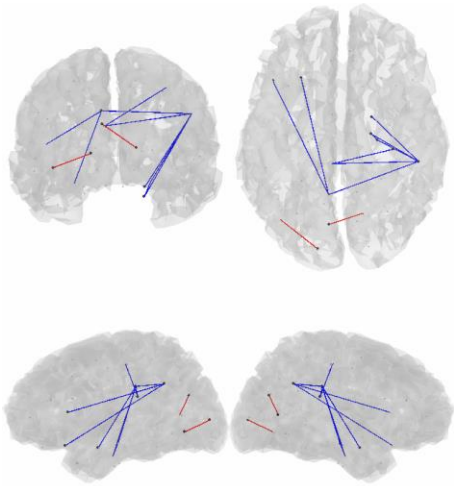


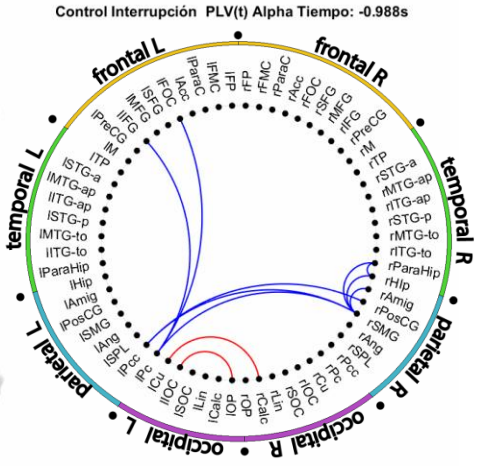
Theta



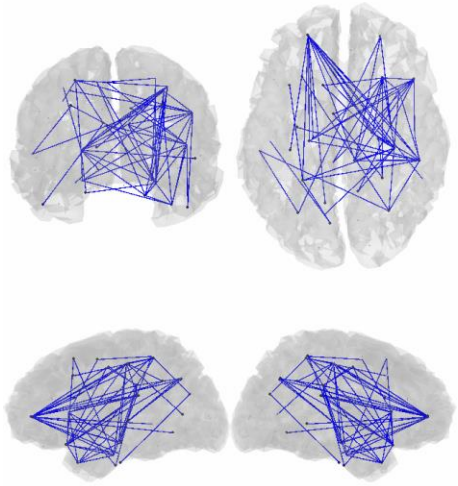


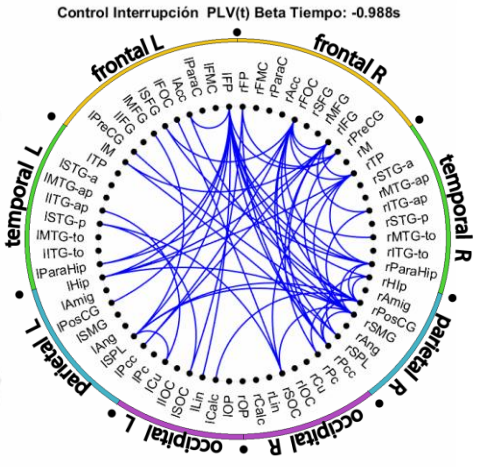
Alpha



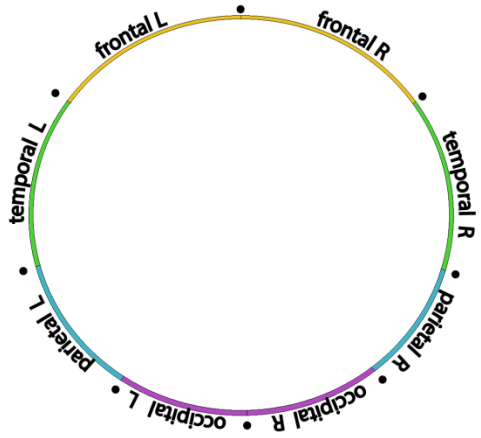


Beta





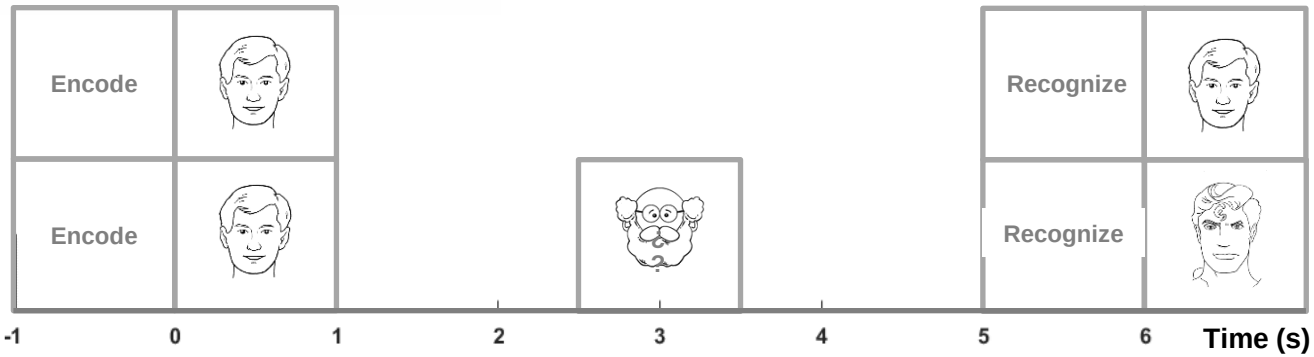
Gamma



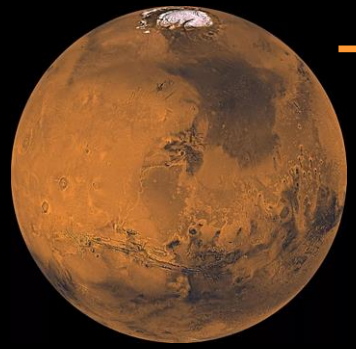
WM Retroactive

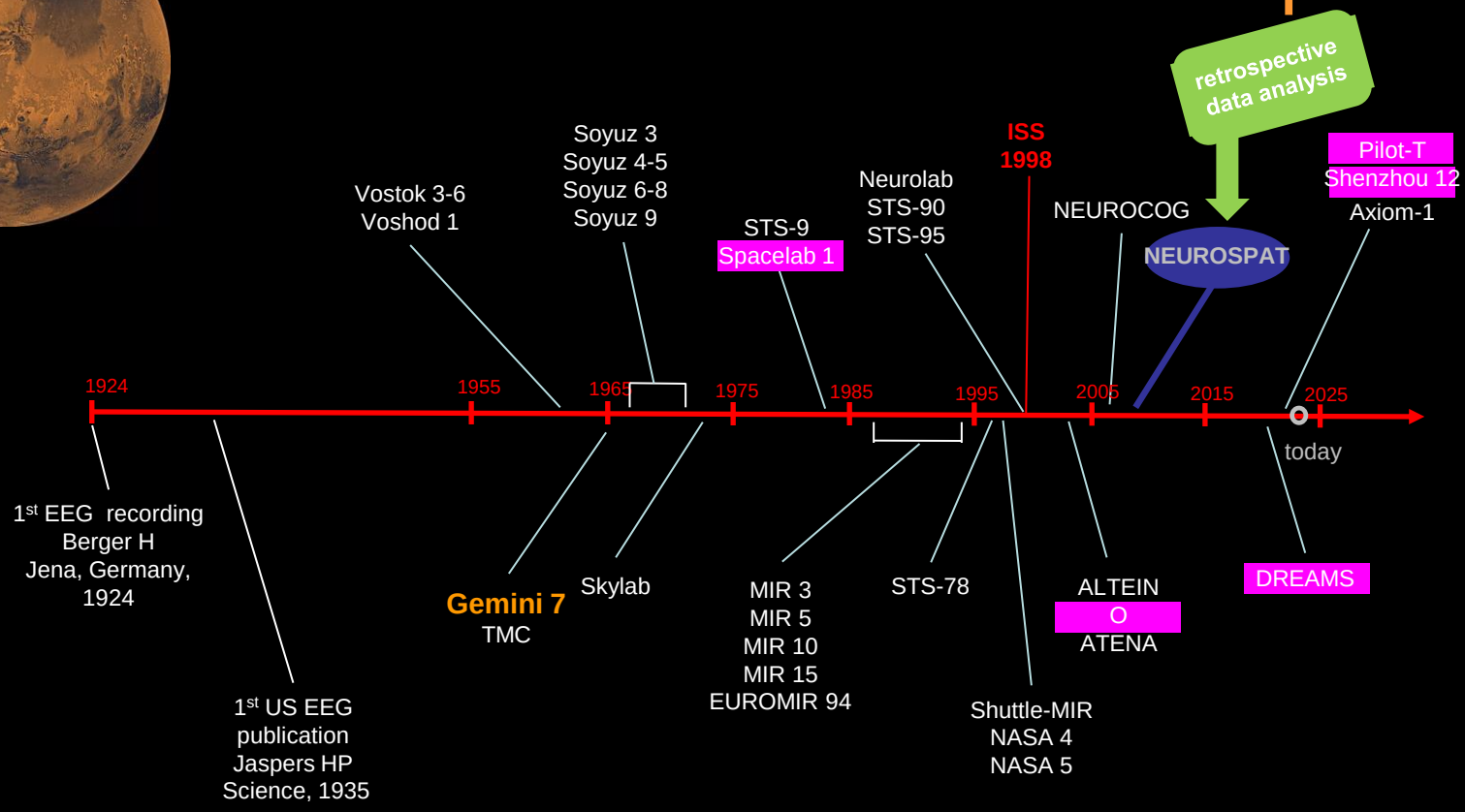
Theta Alfha

Beta Gamma



TIMELINE - EEG in Human Spaceflight





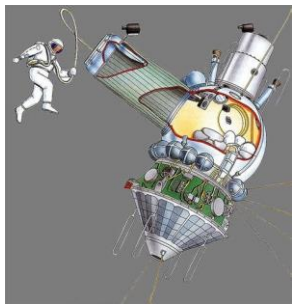
(Funke et al, in progress)

* EEG experiments without reported EEG results in literature

EEG Space recordings timeline

1961 — Vostok

1964 — Voskhod

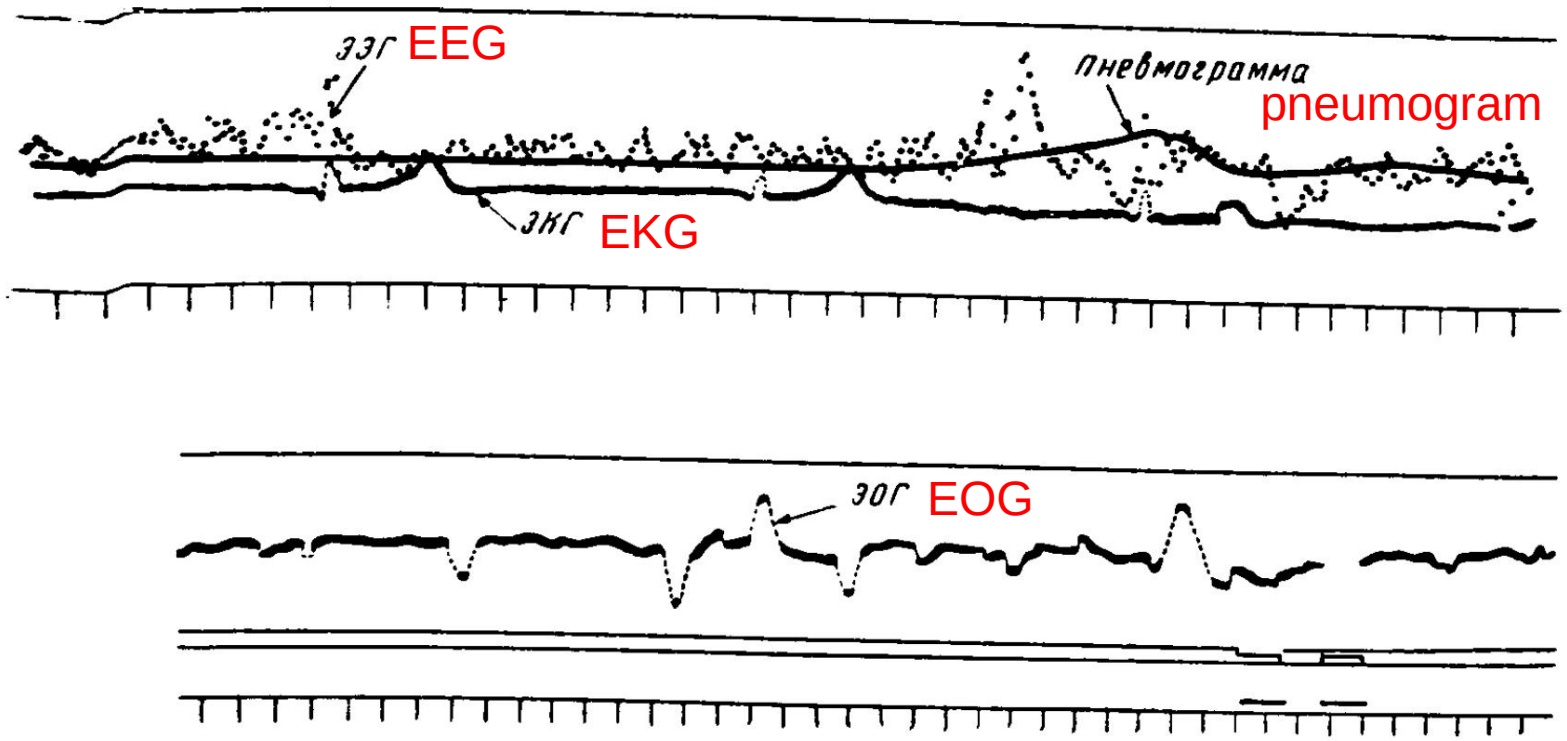


1965 — Gemini VII

1966 — Soyuz

1973 — Skylab

First EEG Recording in Spaceflight, August 1962



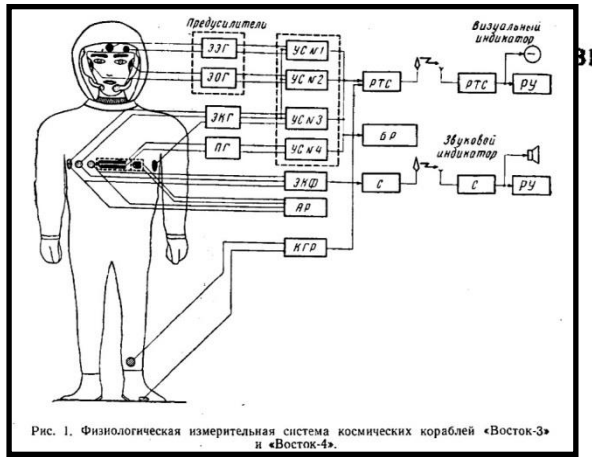


Рис. 1. Физиологическая измерительная система космических кораблей «Восток-3» и «Восток-4».

...иологических показателей, полученных во время полета А. Г. Николаева.

Akulinichev and Baevsky, 1964

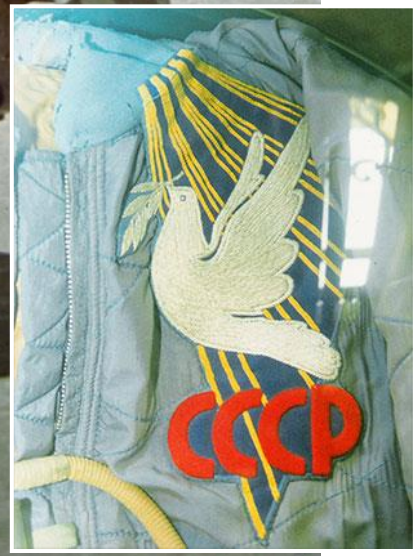
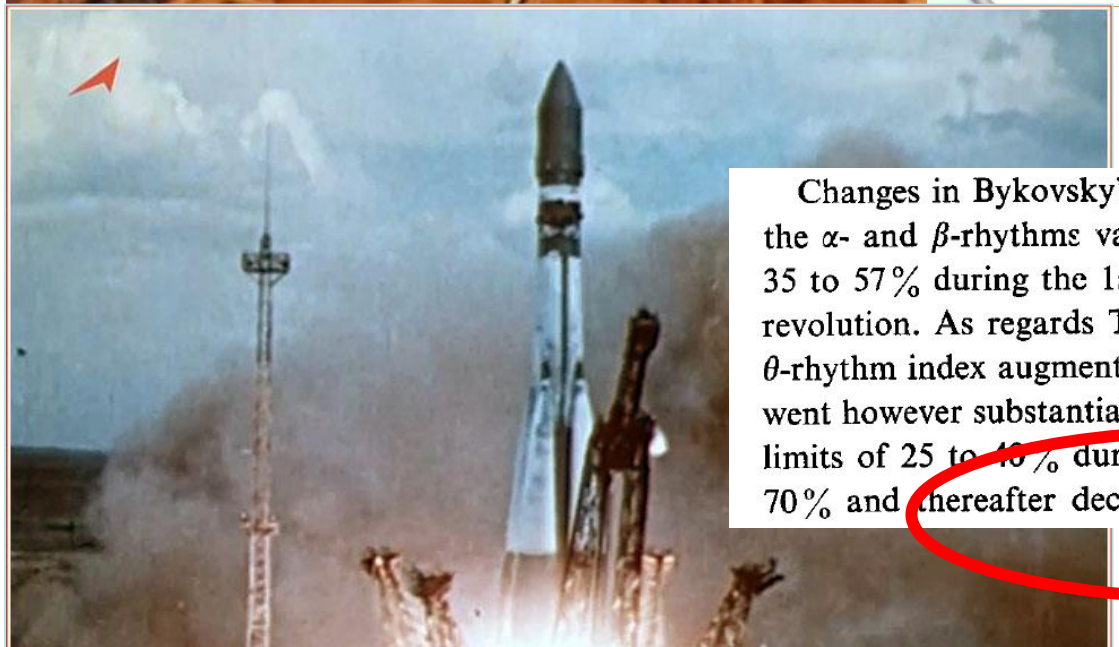


TABLE 2

Methods of recording of physiological parameters during flights of Soviet and American spaceships

Astronauts	Physiological parameters								
	ECG	Pneumogram	Kinetocardiogram	EEG	PGR	EOG	SCG	Arterial blood pressure	Body temperature
Glenn	+	+	–	–	–	–	–	+	+
Carpenter	+	+	–	–	–	–	–	+	+
Schirra	+	+	–	–	–	–	–	+	+
Cooper	+	+	–	–	–	–	–	+	+
Gagarin	+	+	–	–	–	–	–	–	–
Titov	+	+	+	–	–	–	–	–	–
Nikolayev	+	+	–	+	+	+	–	–	–
Popovich	+	+	–	+	+	+	–	–	–
Bykovsky	+	+	–	+	+	+	+	–	–
Tereshkova	+	+	–	+	+	+	+	–	–

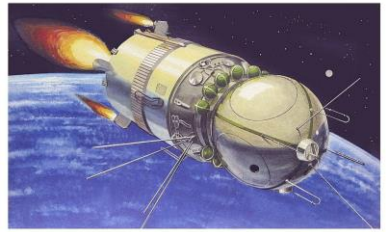
Parin et al., 1965



Changes in Bykovsky's encephalogram were rather equivocal. Indices of the α- and β-rhythms varied substantially, e.g. the α-rhythm index ranged 35 to 57% during the 1st to 4th revolutions and reached 85% at the 51st revolution. As regards Tereshkova, her β-rhythm index lowered while the θ-rhythm index augmented during the weightless state. Both indices underwent however substantial deviations. The α-rhythm index ranged within the limits of 25 to 40% during the first two days, then increased up to 50 to 70% and thereafter decreased up to 35 to 38% by the end of the flight

Parin et al., 1965

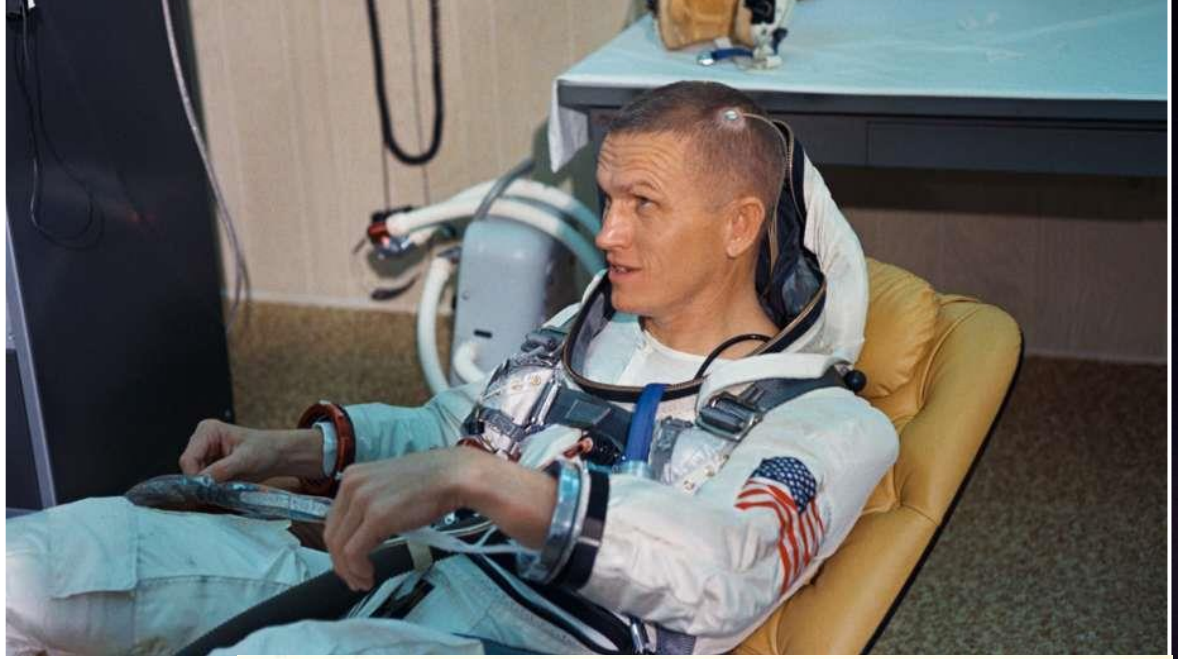
Vostok (1961-1963)

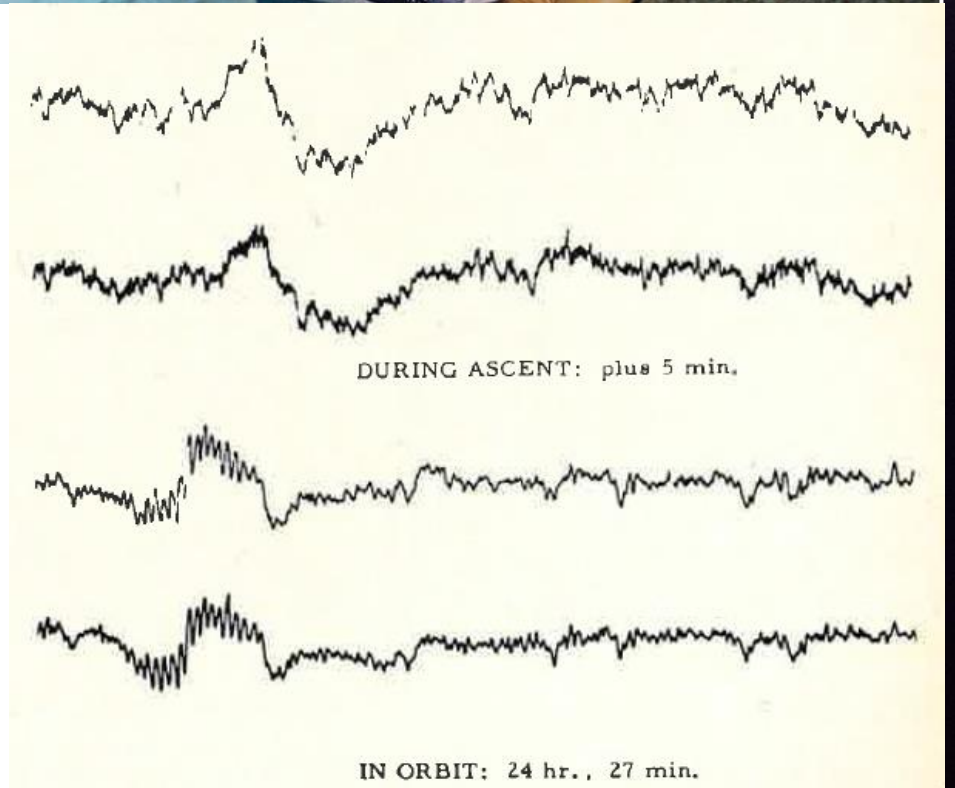


Vostok 1- Yuri Gagarin

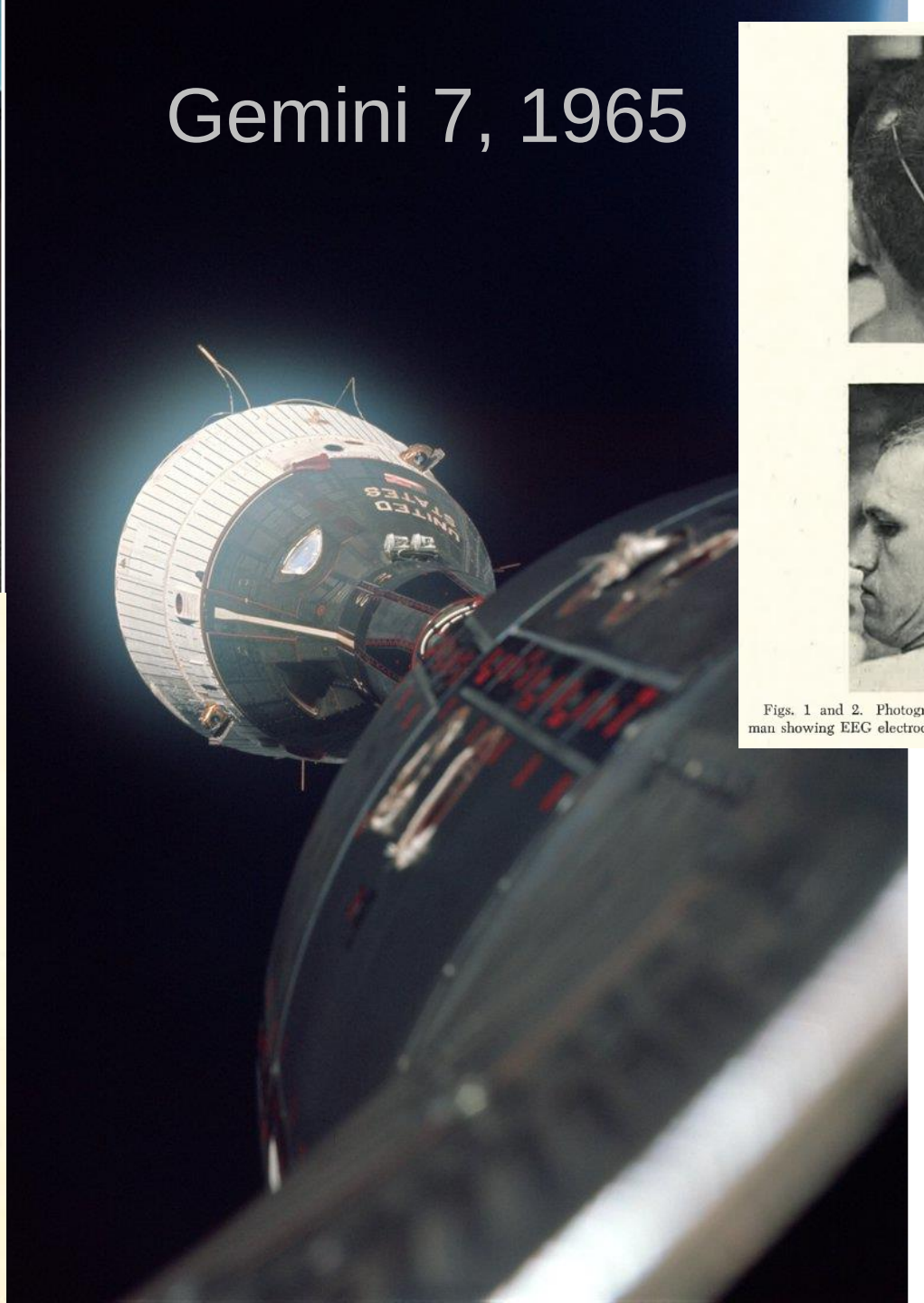
Vostok 2- Gherman Titov

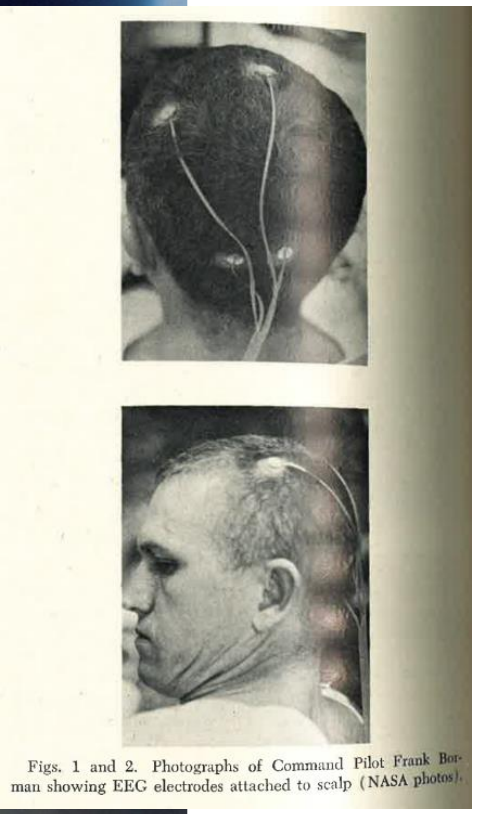
Vostok 6- Valentina Tereshkova





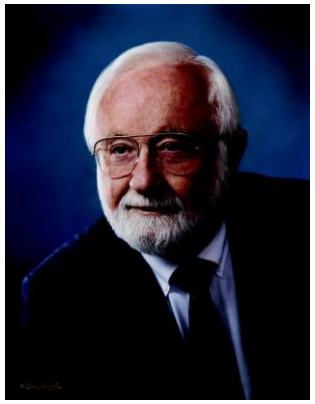
Gemini 7, 1965





Figs. 1 and 2. Photographs of Command Pilot Frank Borman showing EEG electrodes attached to scalp (NASA photos).

Gemini VII (1965)



Dr. Peter Kellaway

GEMINI PROGRAM MISSION REPORT

GEMINI VII

(U)

(NASA-TM-X-62892) GEMINI PROGRAM MISSION REPORT, GEMINI 7 (NASA) 395 p

N79-76319

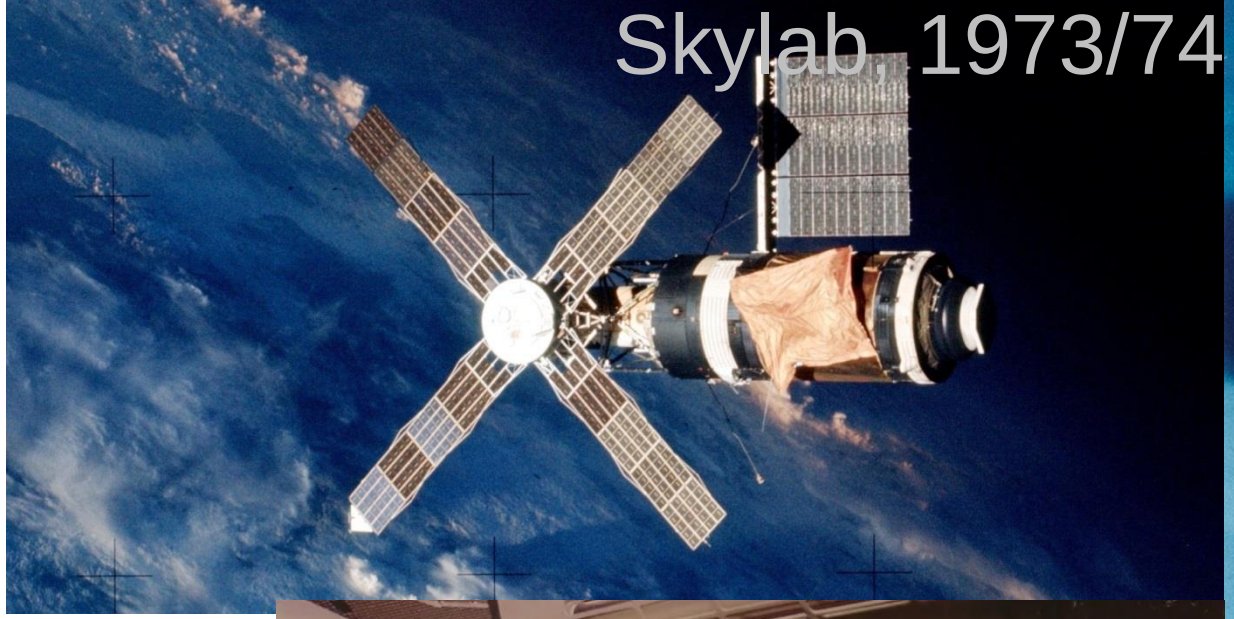
Unclas
00/18 11130
(CODE)

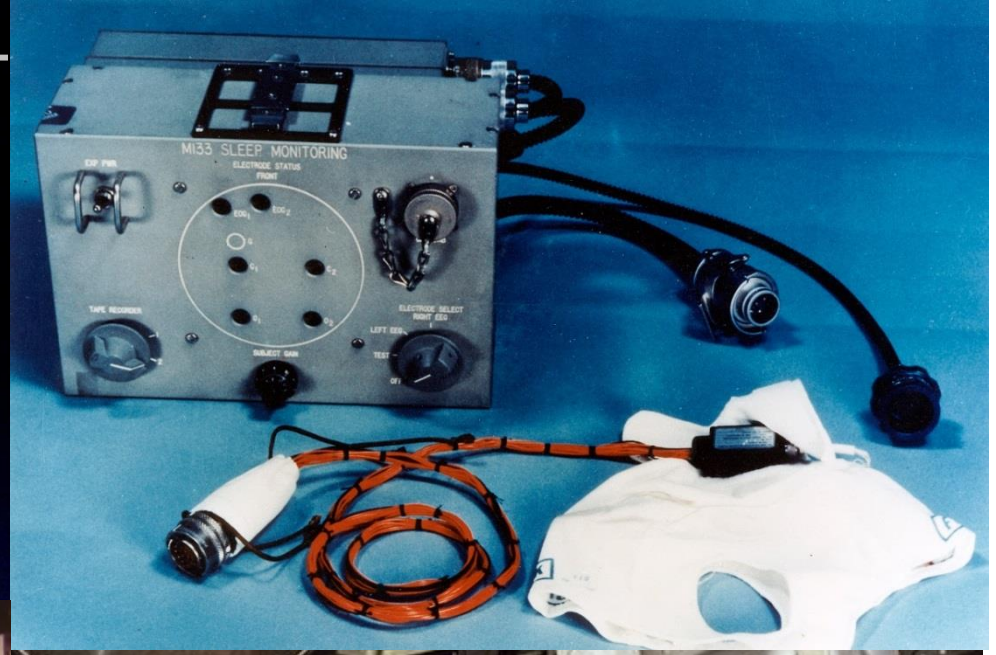
7.2.2.1.5 Other physiological data measurements: The EEG and phonocardiogram records were recorded on the inflight biomedical recorder only. The EEG was to be recorded continuously for 96 hours (4 days). During the first day of flight, one lead was detached inadvertently, despite the fact that the command pilot wore his helmet continuously to protect the sensor and leads. During the second day of flight, the remaining three leads became snagged on the ejection seat back and were detached. An attempt by the crew to replace the sensors was unsuccessful.

8.10.4 Results

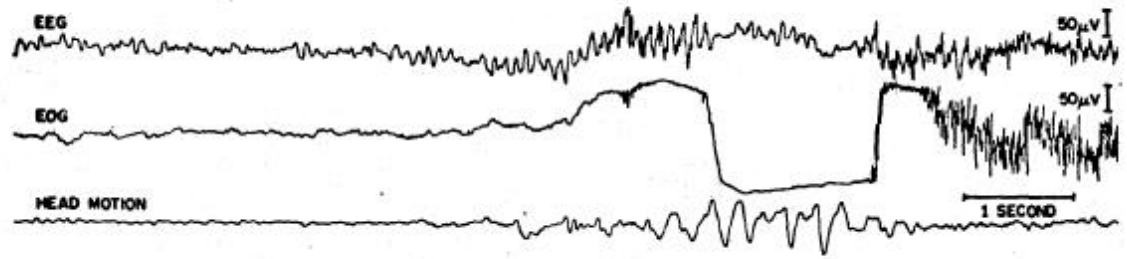
The experiment was terminated by the command pilot at 55:10 hours ground elapsed time after the accidental removal of all of the electrodes. A "quick-look" examination of the tapes has shown that usable EEG data were obtained during the 55-hour duration of the experiment. Analysis of the data is continuing.

Skylab, 1973/74

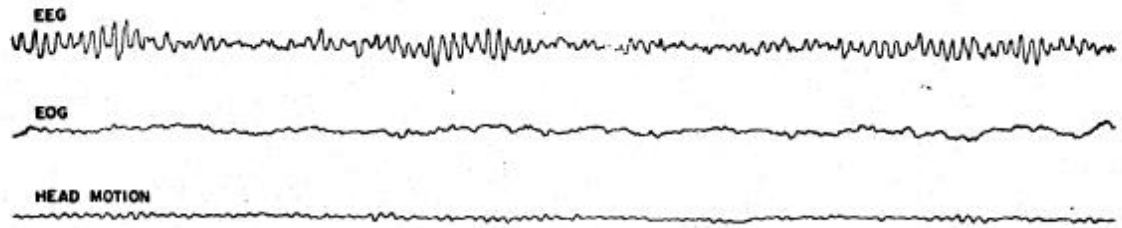




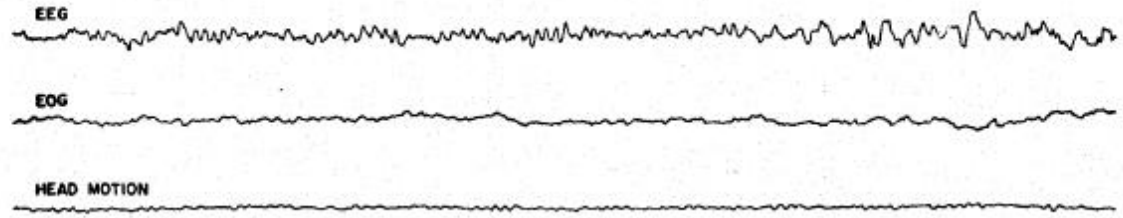
Q.G. SL/3 M.D. 29



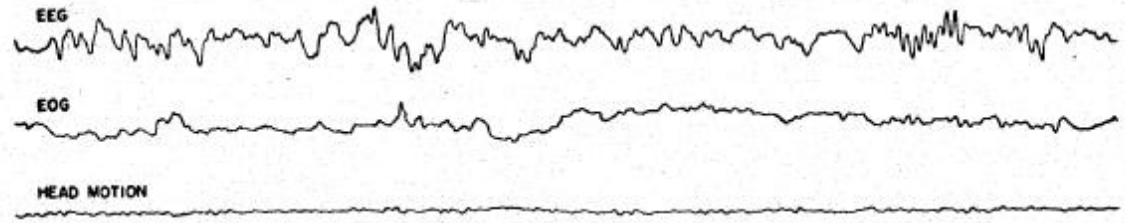
A. AWAKE, MOVING



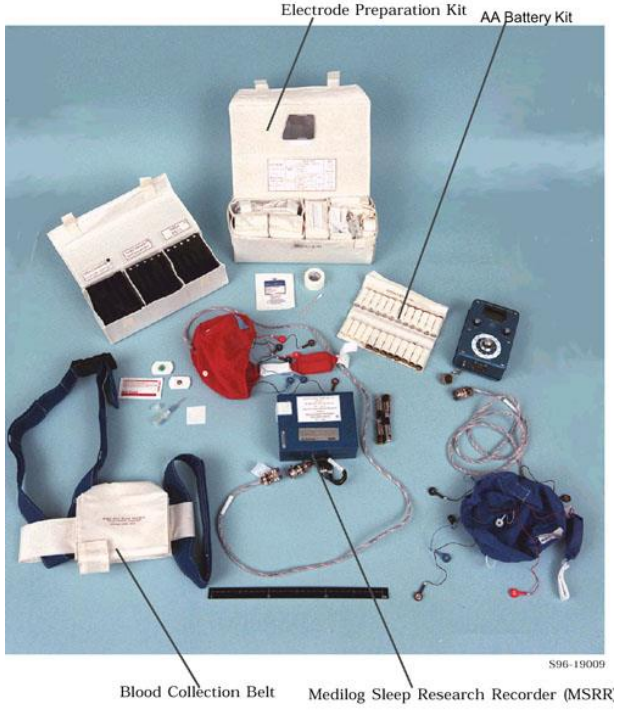
B. AWAKE, RELAXED

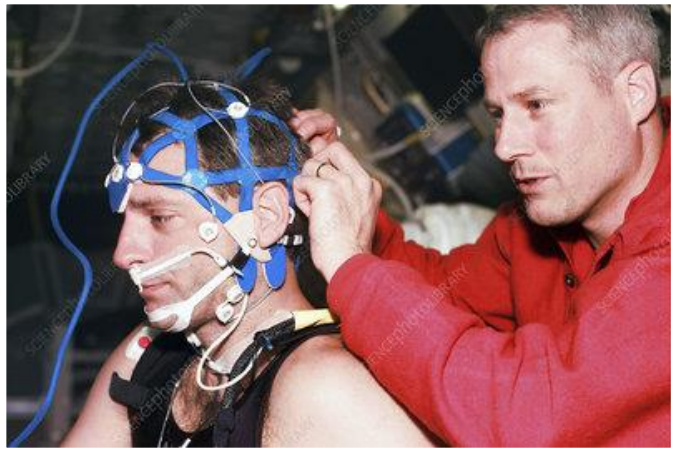


C. STAGE 1

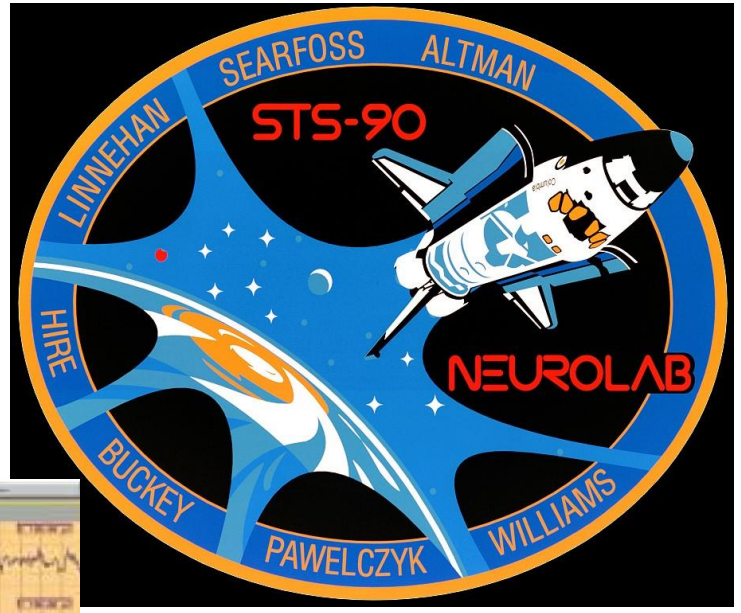


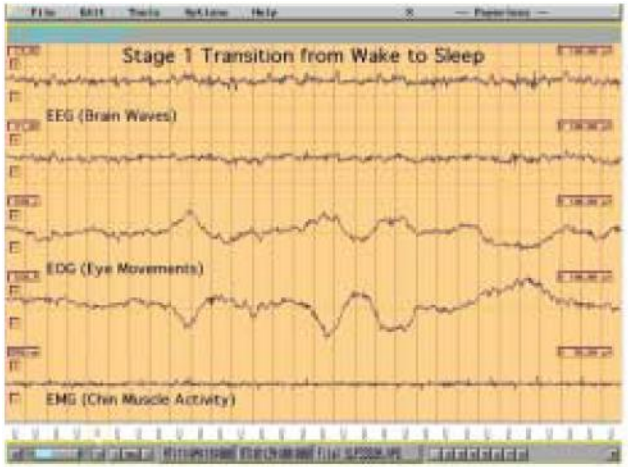

MIR

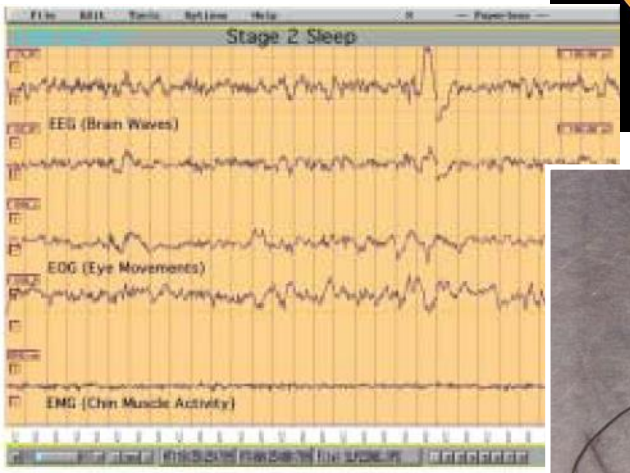

Electrode Preparation Kit
AA Battery Kit
S96-19009
Blood Collection Belt
Medilog Sleep Research Recorder (MSRR

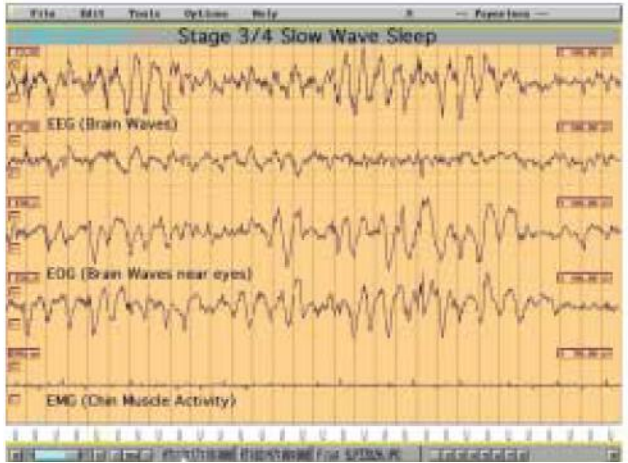


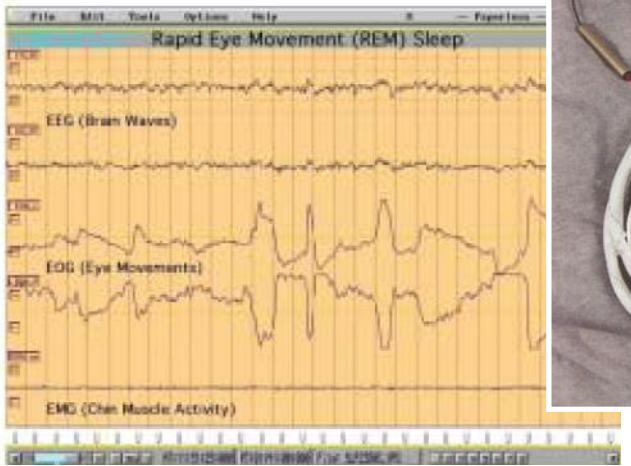
9301104
PI: Czeisler (USA)
1998





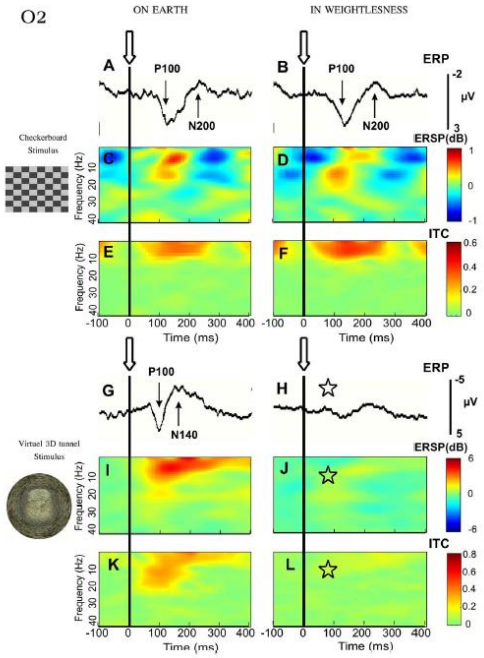






NEUROCOG/NEUROSPAT (ESA)

PI: Dr. Cheron (BE)



ALTEINA/ALTEA (IT/RU)

PI: Dr. Narici (IT)

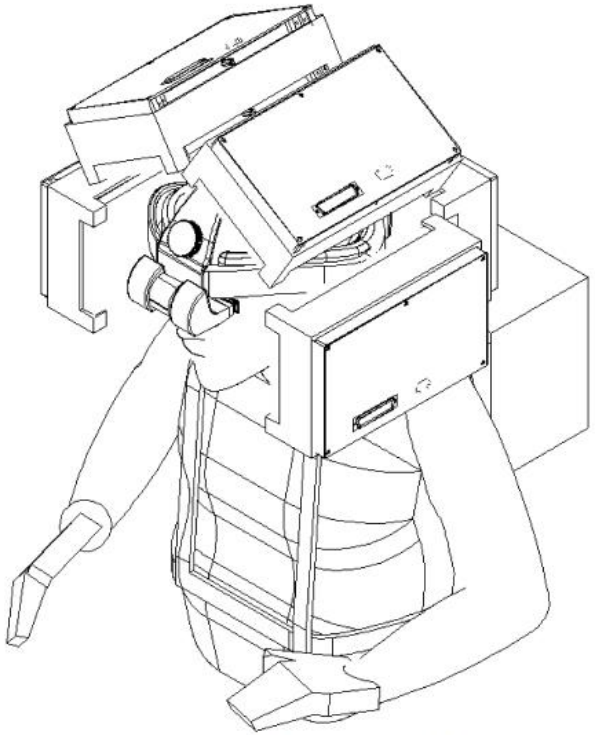
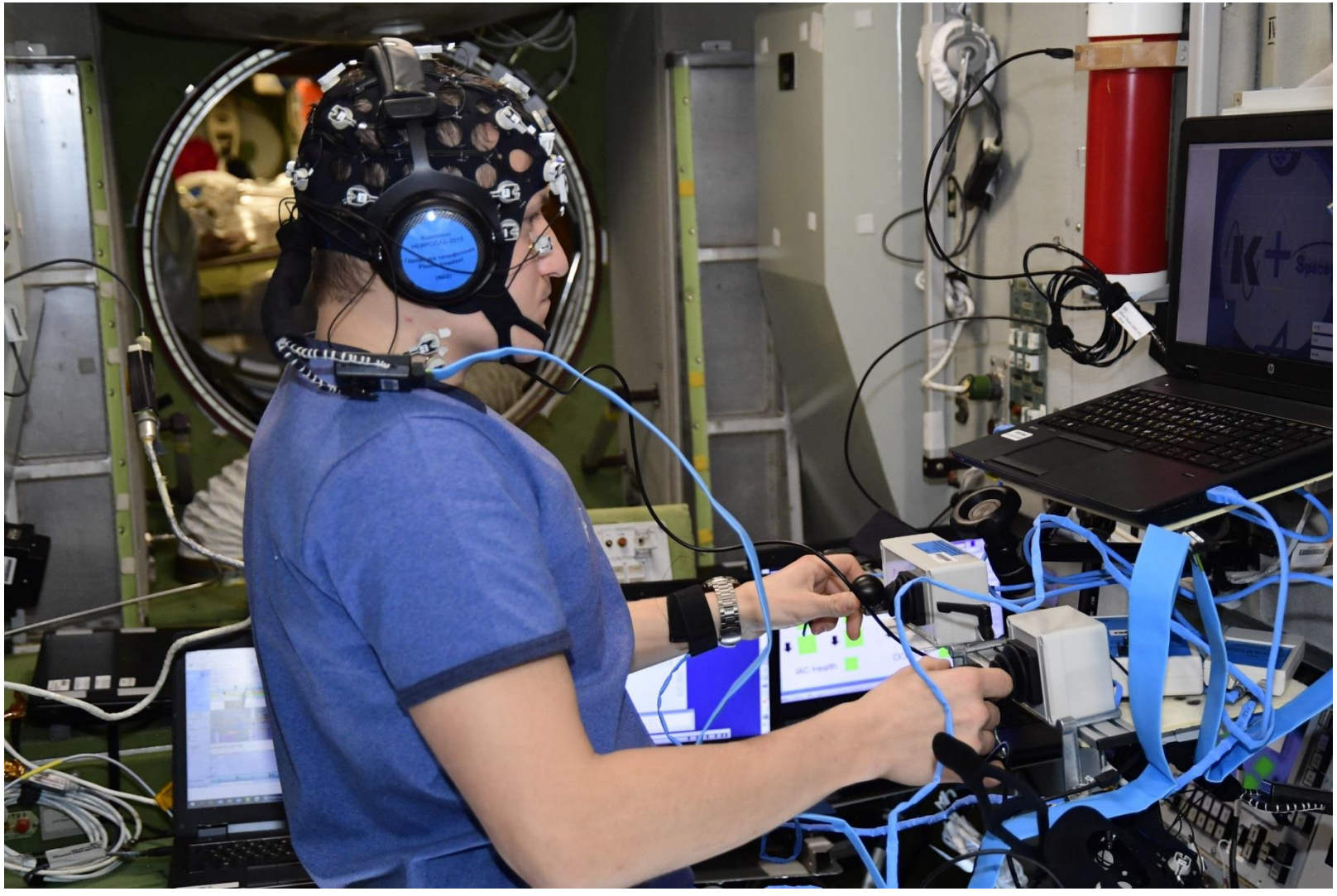


Fig. 1 – A schematic view of the astronaut with the ALTEA system (frontal Silicon Telescopes box not shown).

PILOT-T (ROSCOSMOS/DLR)

PIs: D. Schastlivtcheva (RU), B. Johannes (GE) 2015




F
E
G
A
D
B
A
NASION
Fp1
Fp2
F7
F3
Fz
F4
F8
A1
T3
C3
Cz
C4
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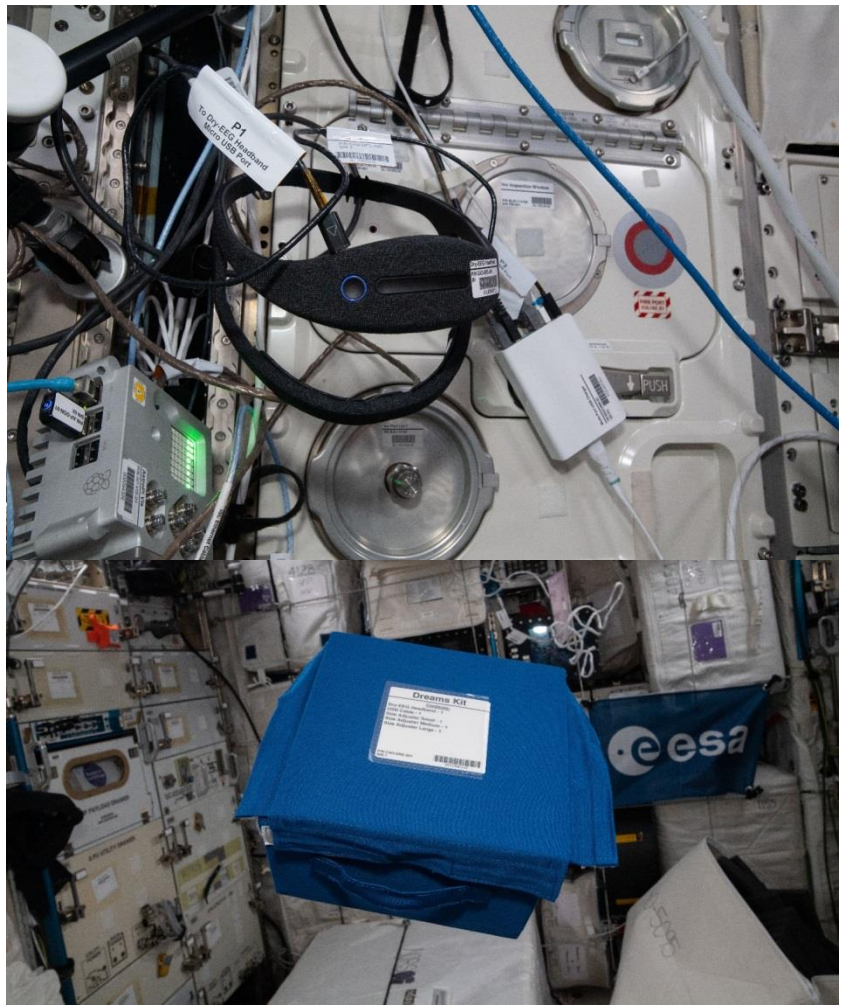
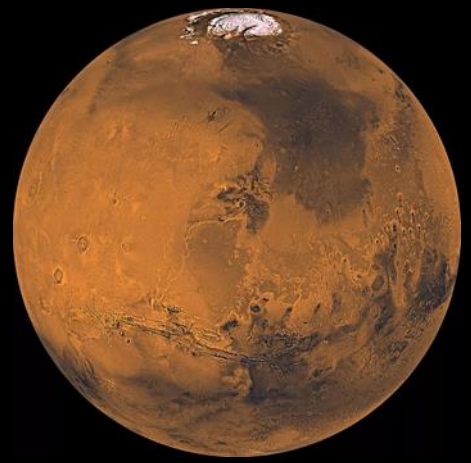
A2
T5
P3
Pz
P4
T6
01
02
INION
C
C


P1
To Cyt-EEG Headband
Main USB Port
PUSH
Dreams Kit
esa

TIANHE (CNSA)

AXIOM-1 (Commercial Mission)



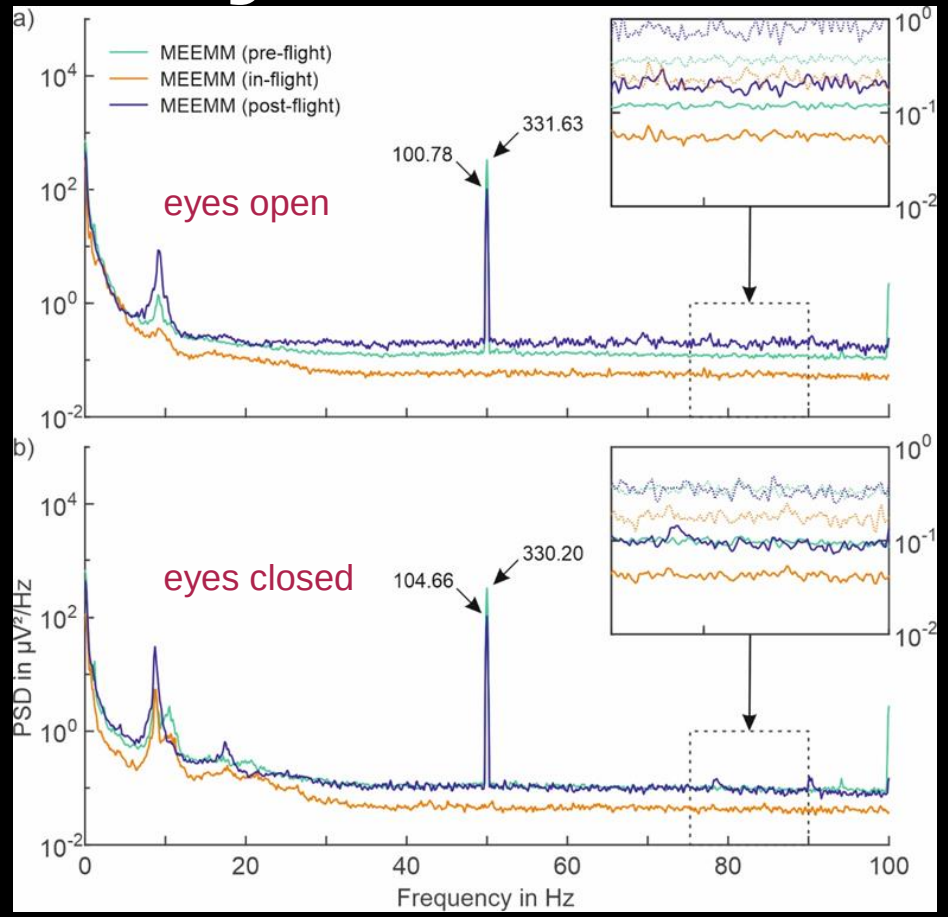
Data Quality

EEG in-flight recording (orange) of superior quality compared to ground recordings.

Average EEG power spectra of resting-state EEG data recorded with the MEEMM system during ground-level (pre- and post-flight) and in-flight conditions.

Solid lines represent mean; dotted lines represent mean + standard deviation

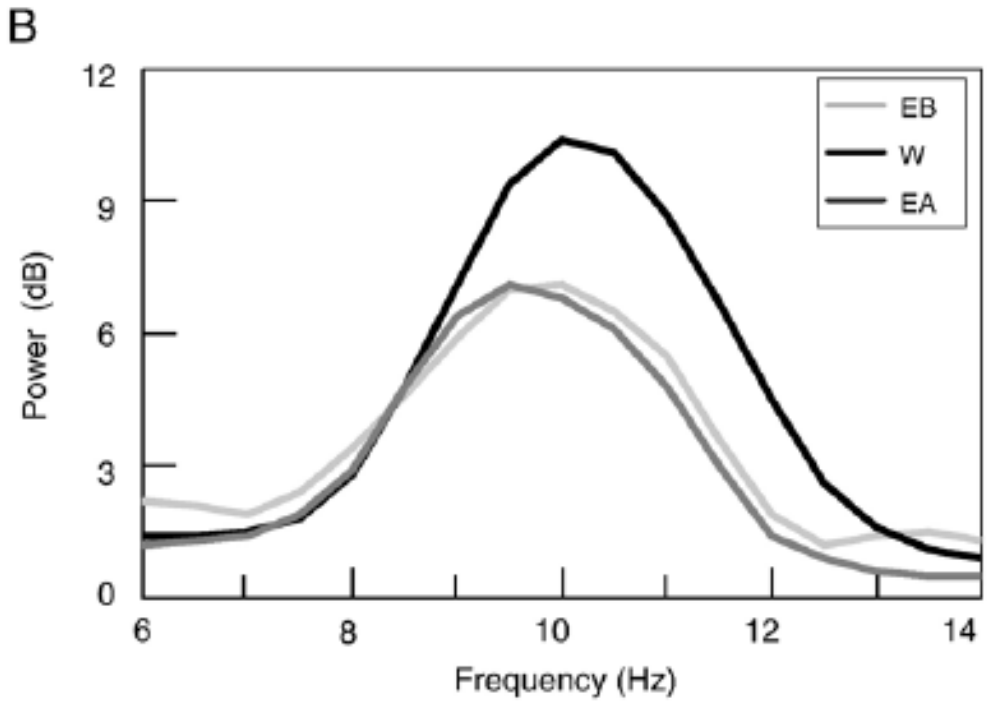
Fiedler et al., 2023, Plos One



Grand average power spectra of 120 s of EEG data from 5 astronauts pre-flight, inflight, and postflight.

Seminal EEG data

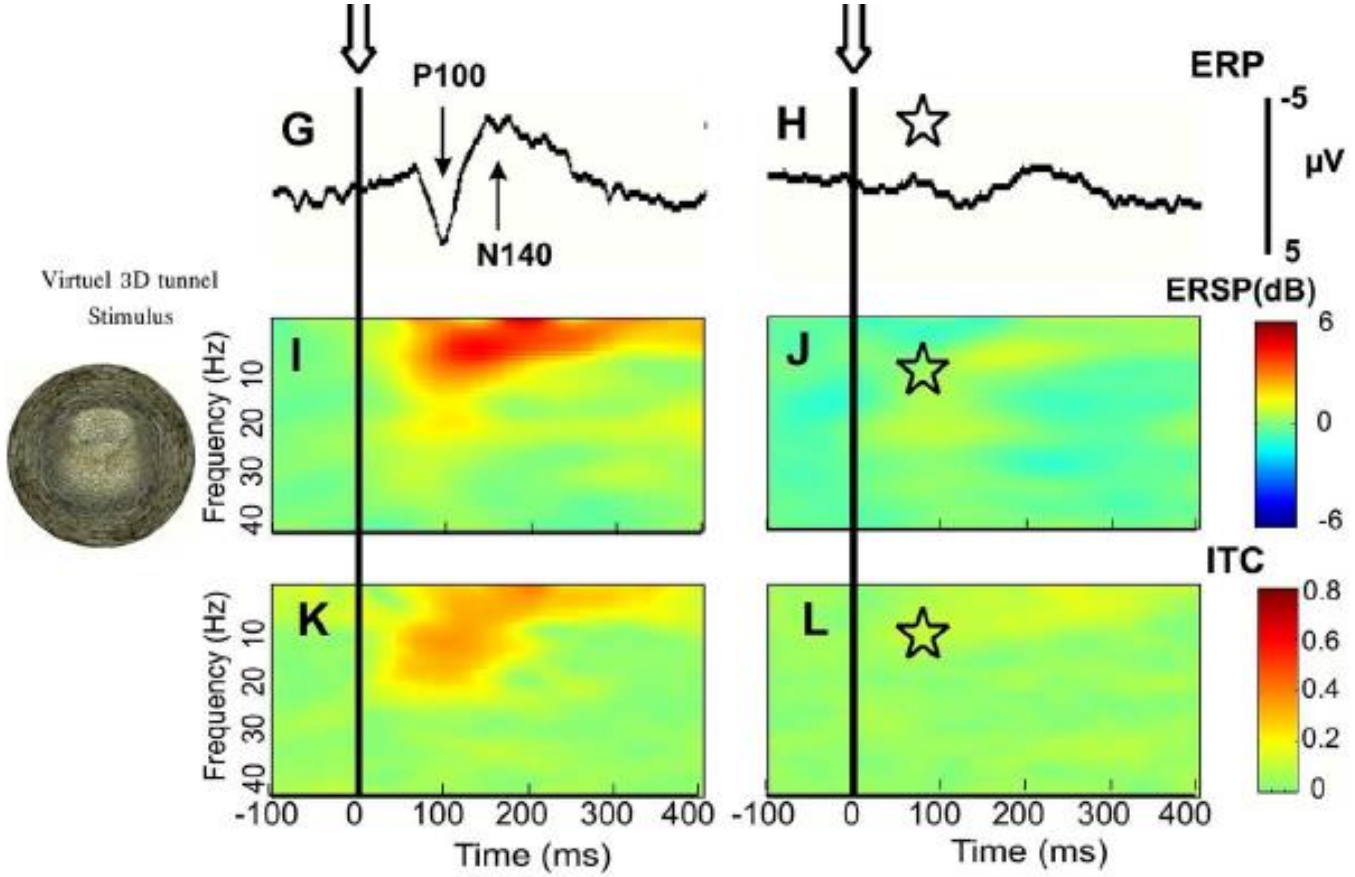
Differences between eyes close and open



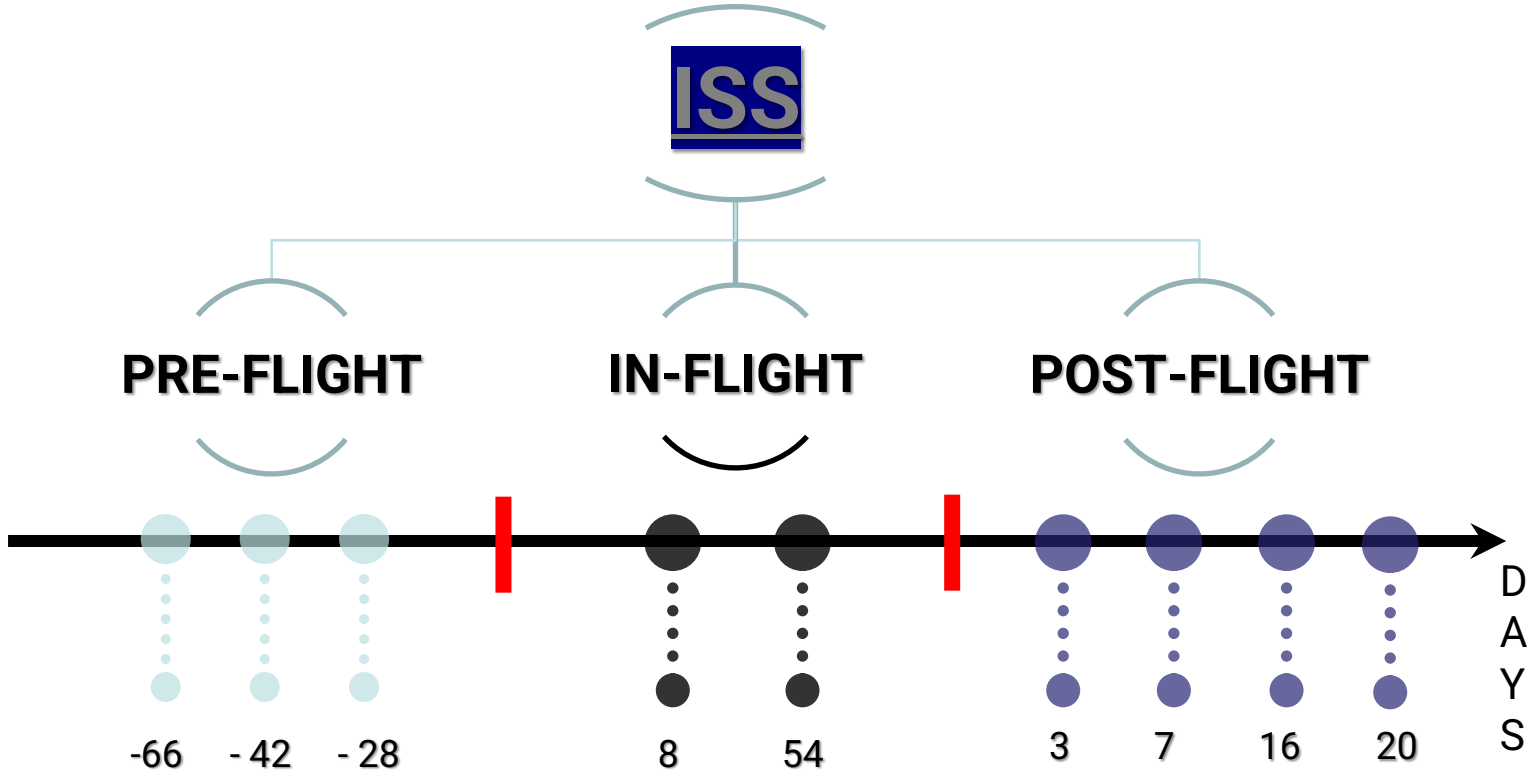
(Cheron et al, 2006)

Seminal EEG data

phase-locking of theta-alpha oscillations was suppressed in weightlessness



(Cheron et al, 2014)



5 Subjects
A, B, C, D & F

Eyes closed

Measures

Source space (eloreta)
Alpha peak
Power (AVG - DMN)
FC (PLV) – Strength (AVG - DMN)

Frequency Bands:
Delta: 2-4Hz
Theta: 4-8Hz
Alpha: 8-12Hz
Beta: 12-30 Hz
Gamma: 30 -45 Hz

(Cheron et al, 2014)

(Pusil et al, 2023)

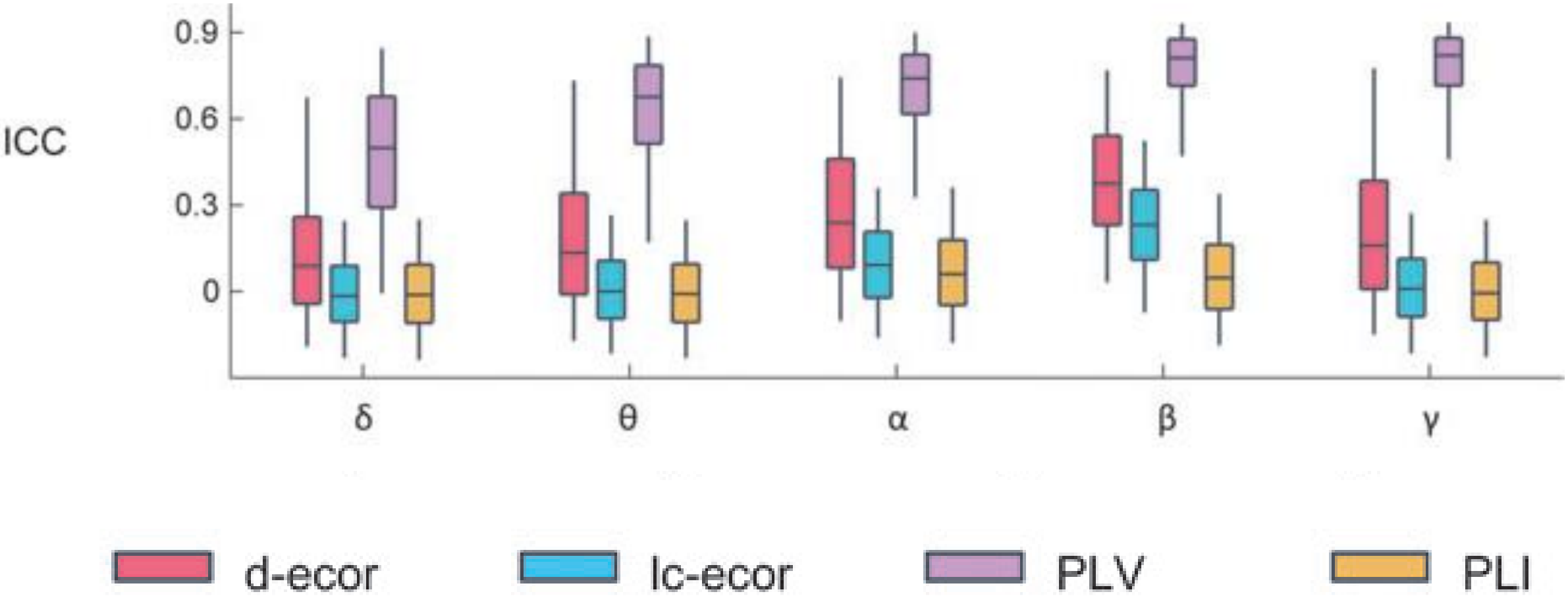
16 subjects (8 in the morning 8 in the afternoon)

One week

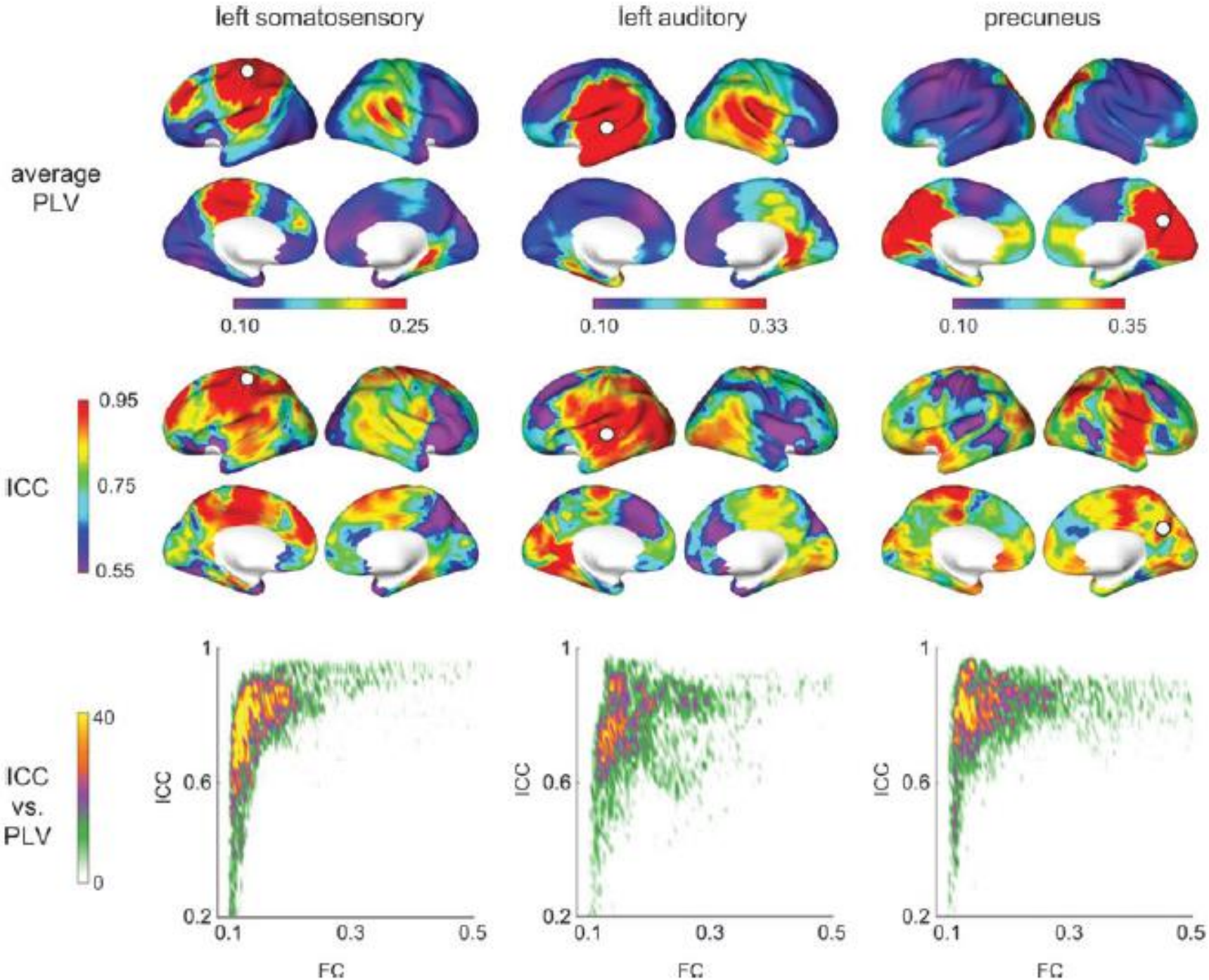
One week

Time

(Garces et al, 2016)



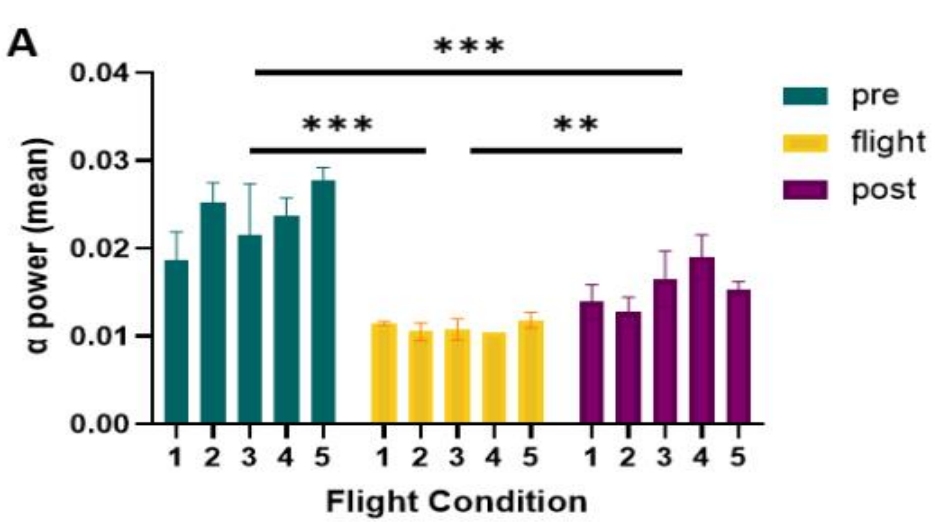
(Garces et al, 2016)

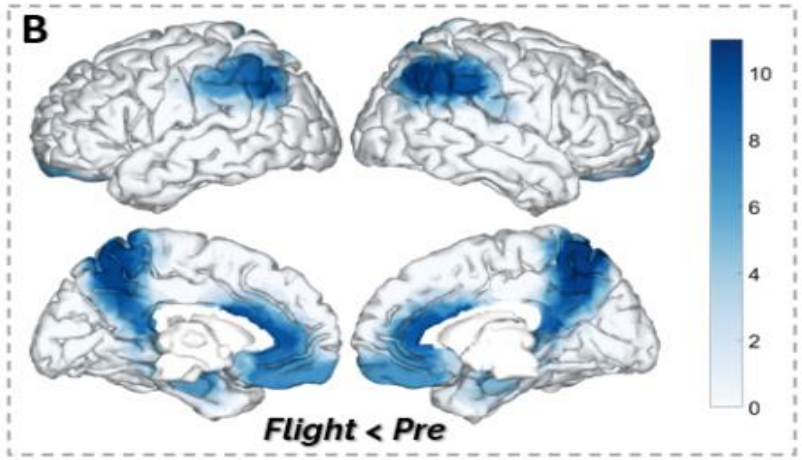


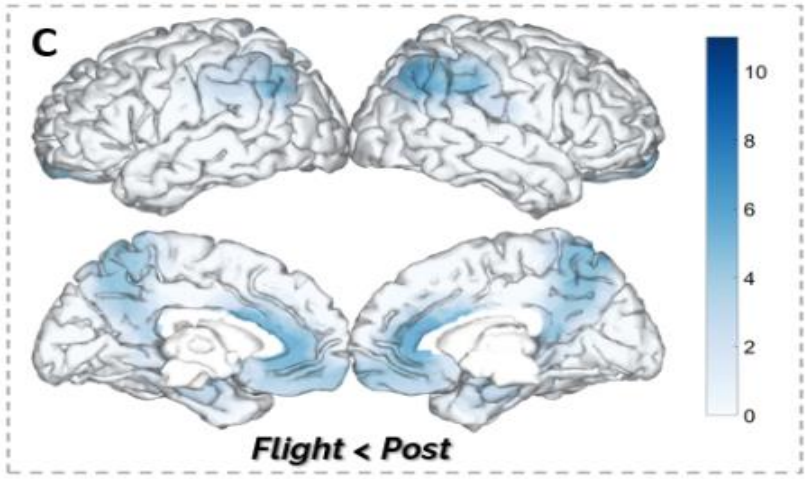
(Garces et al, 2016)

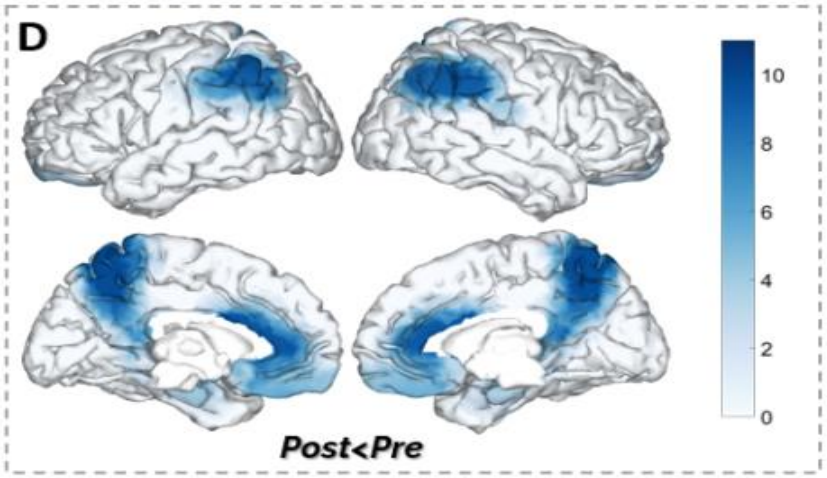
EEG results during Spaceflights

Changes in DMN Alpha band power (eyes closed) between flight conditions





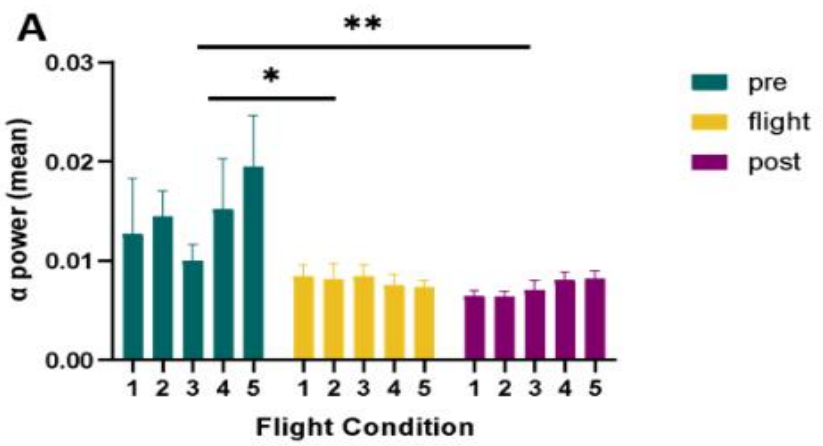


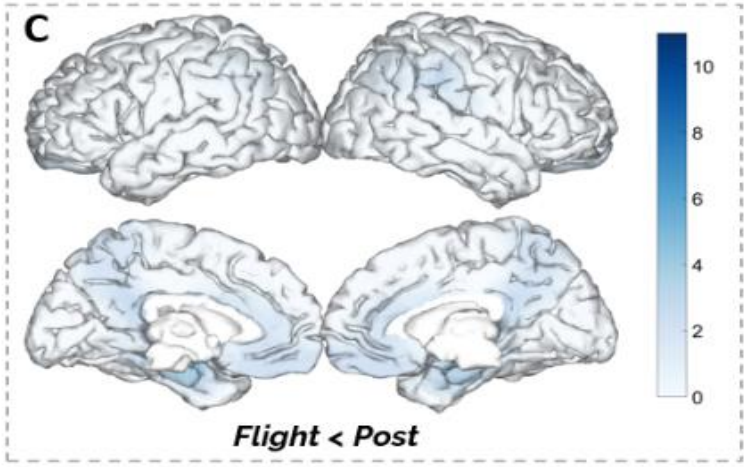


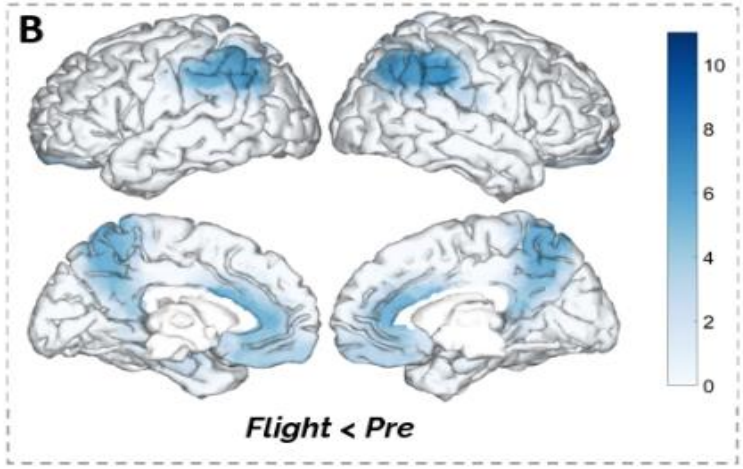
(Pusil et al, 2023)

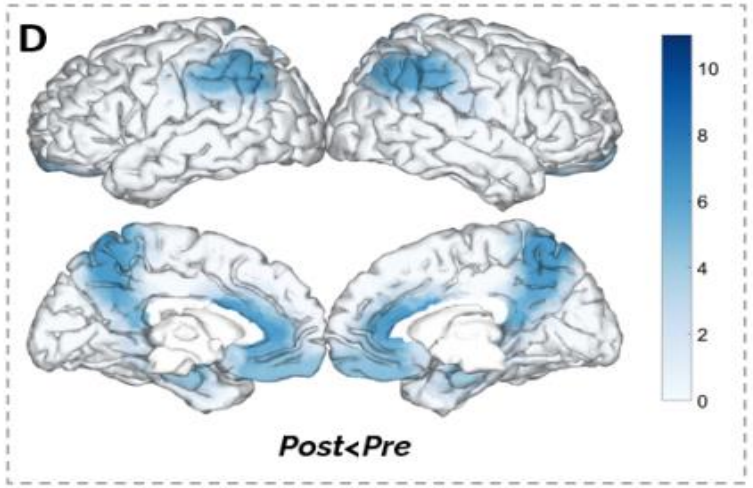
EEG results during Spaceflights

Changes in DMN Alpha band power (eyes open) between flight conditions



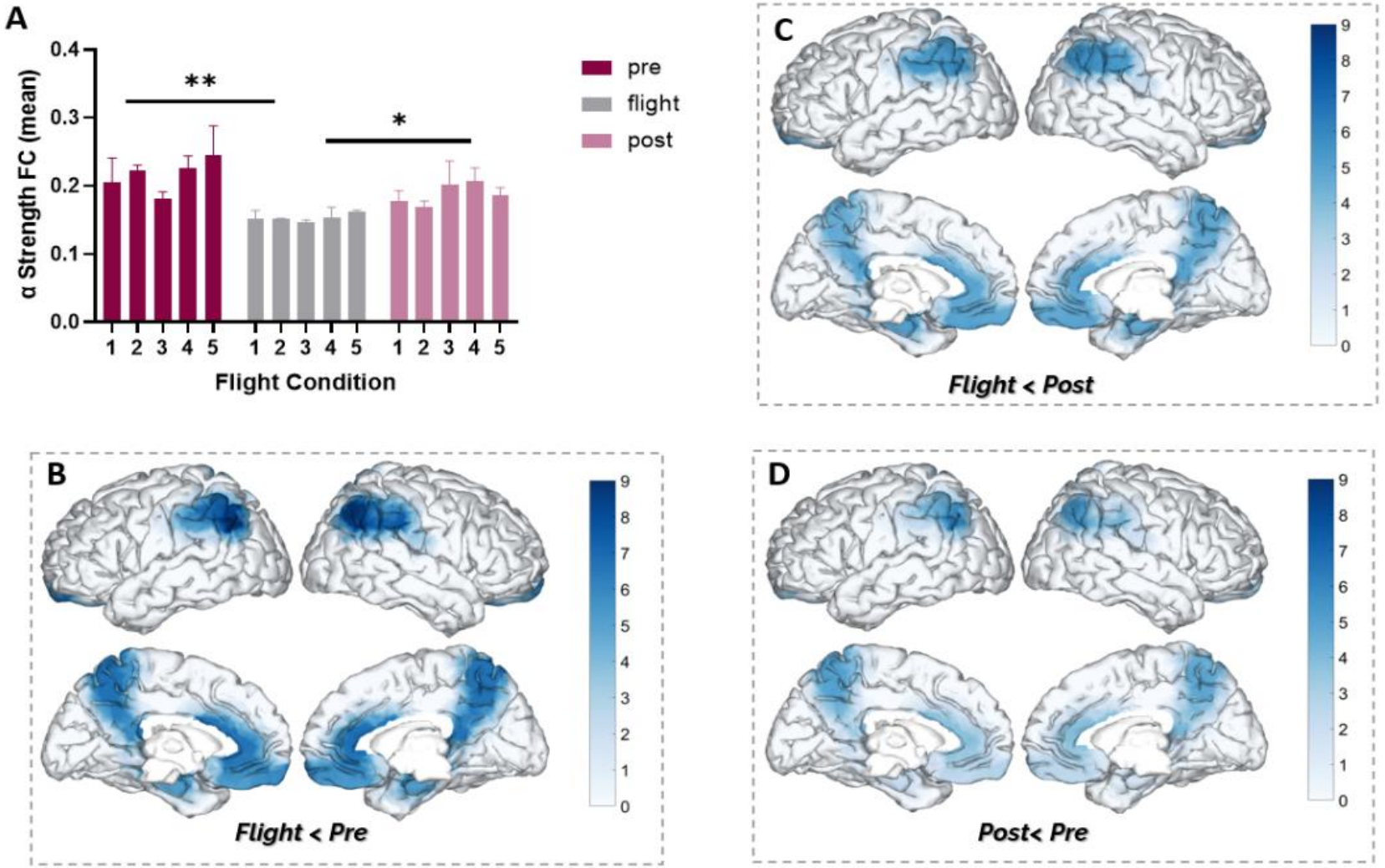






(Pusil et al, 2023)

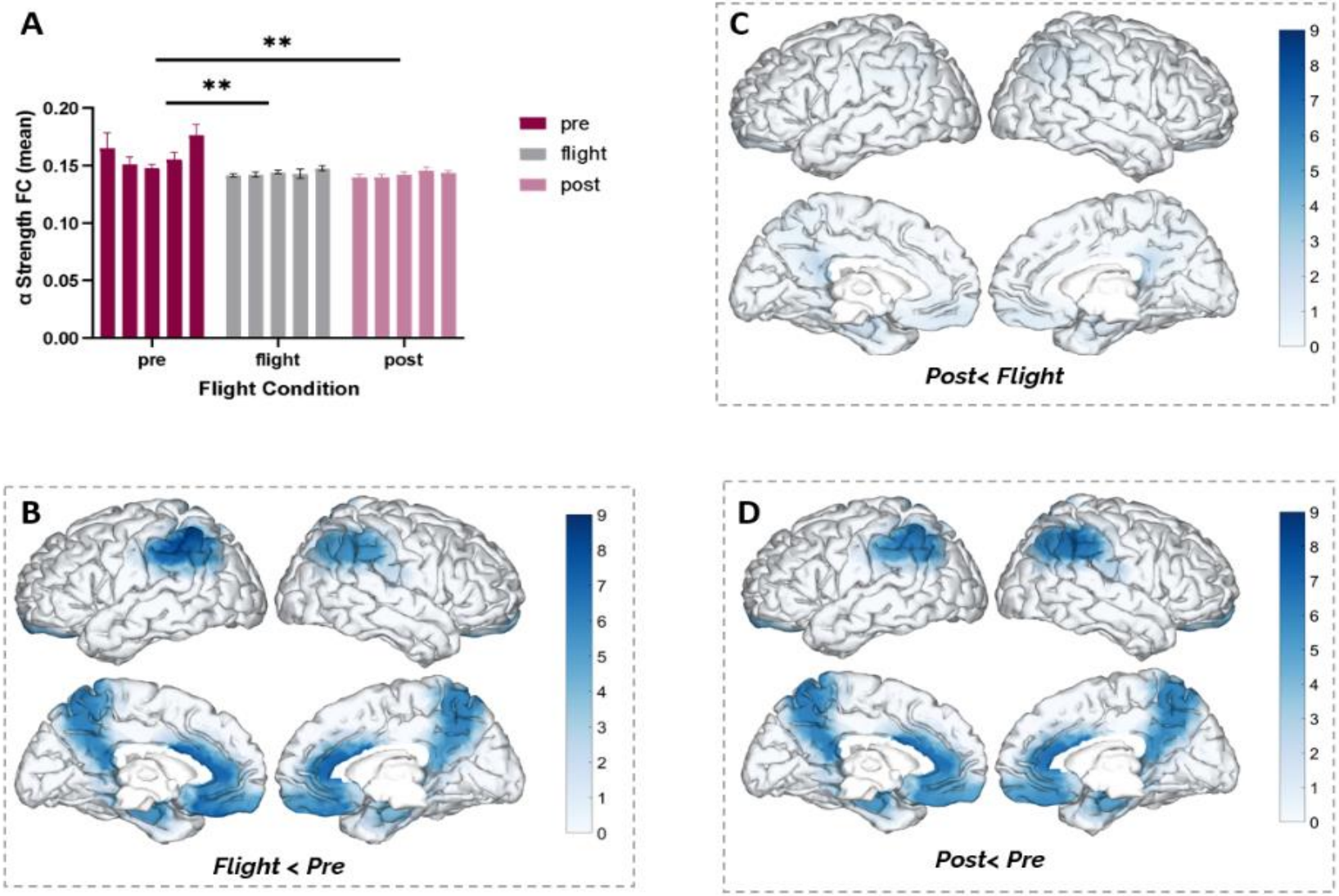
Changes in DMN Alpha Strength (FC – eyes closed) between flight conditions



(Pusil et al, 2023)

EEG results during Spaceflights

Changes in DMN Alpha Strength (FC – eyes open) between flight conditions

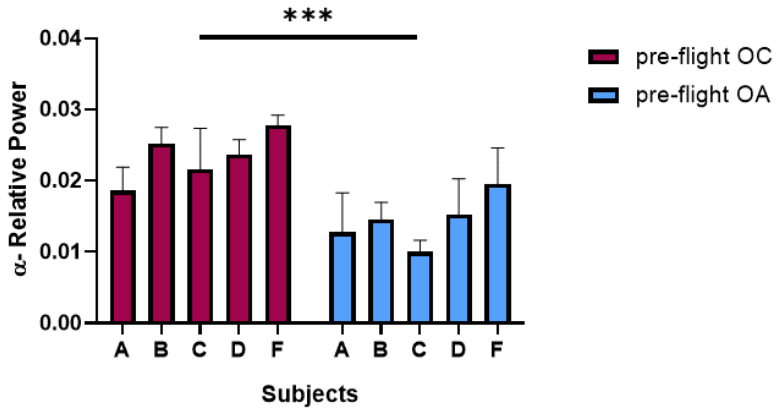


(Pusil et al, 2023)

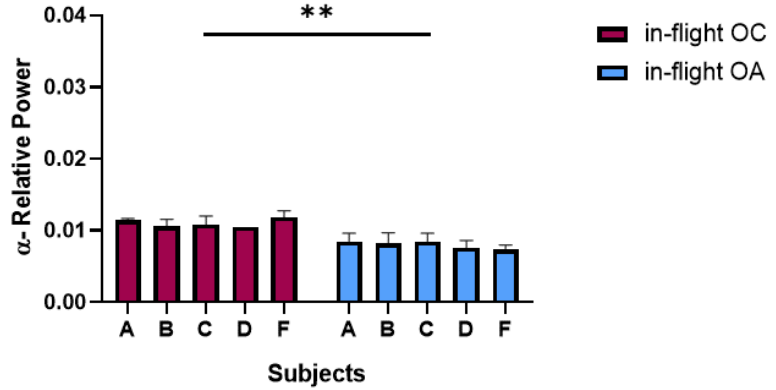
EEG results during Spaceflights

Differences between eyes closed and open in DMN Alpha band relative power between flight conditions

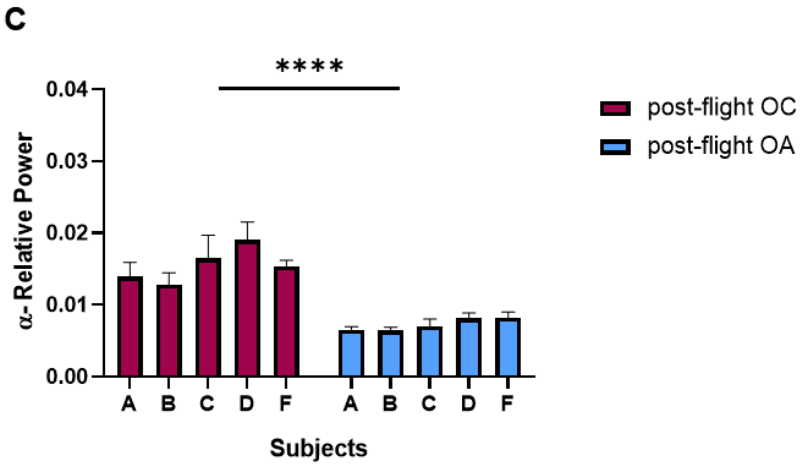
A



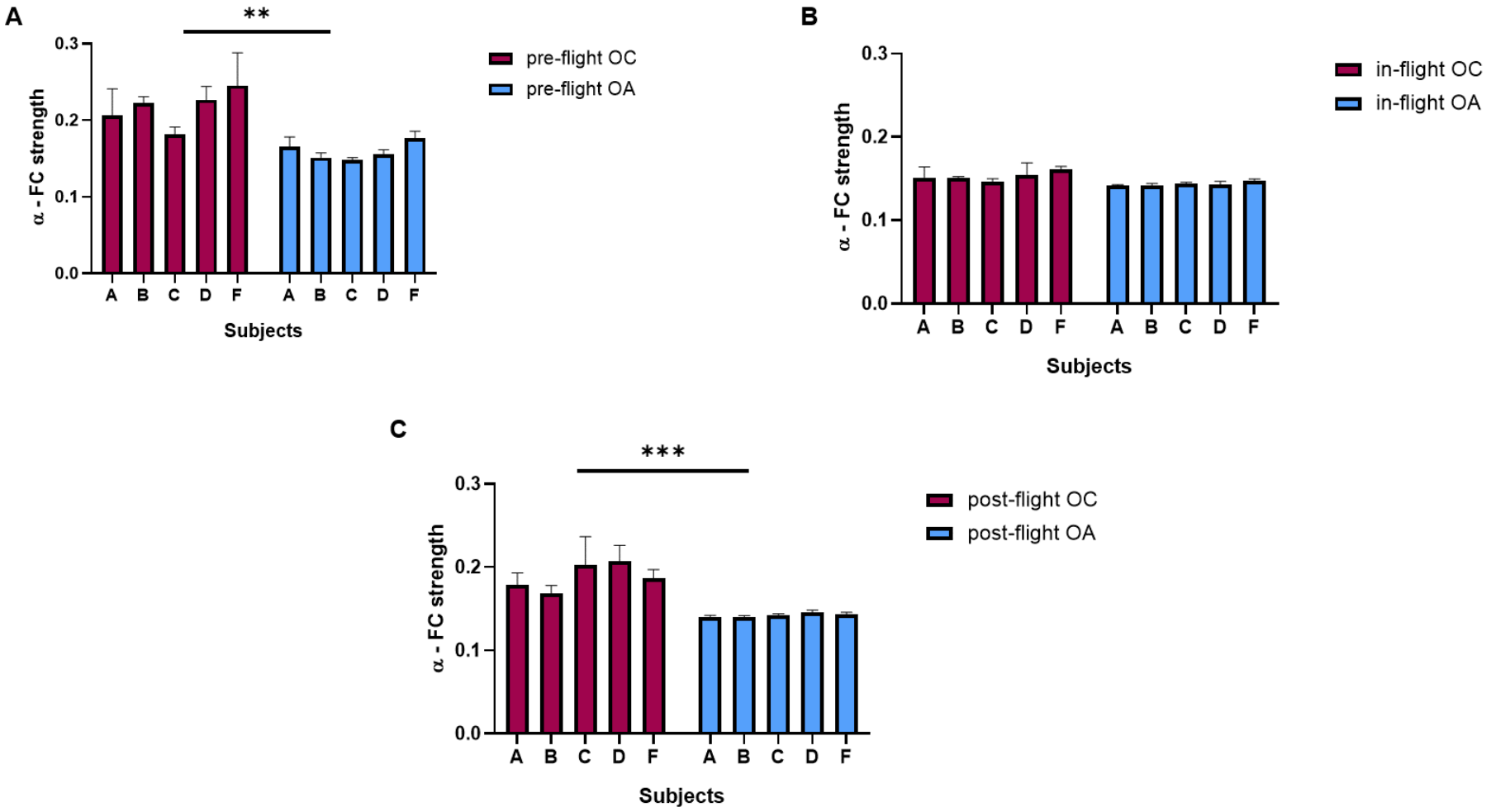
B



C

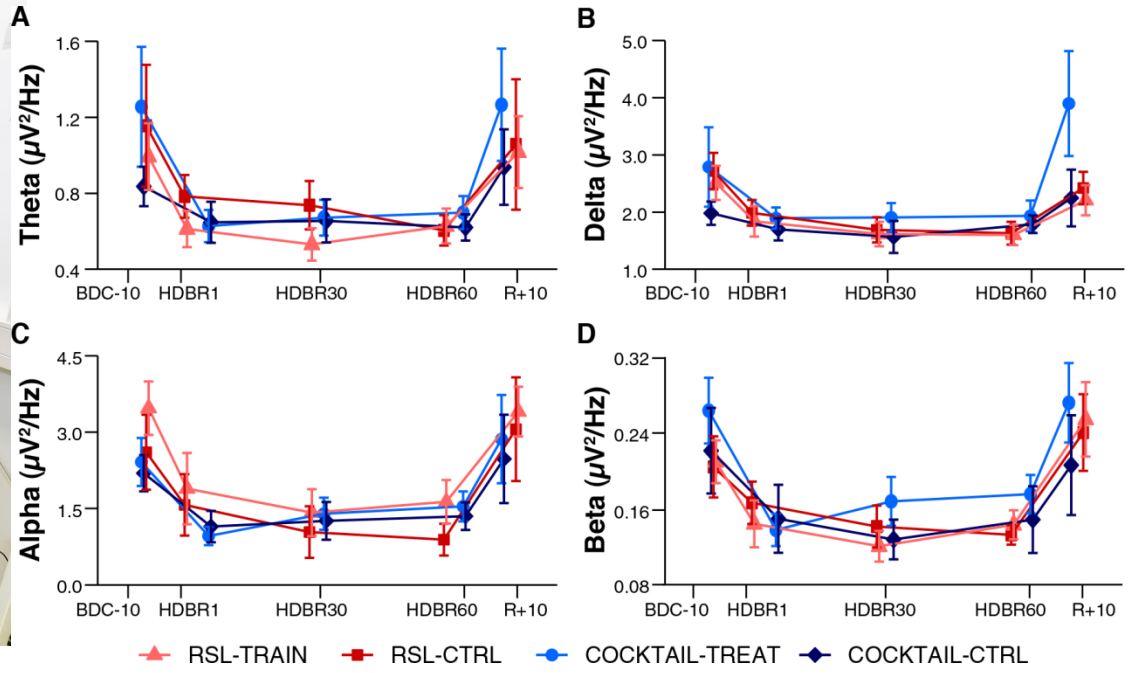


Differences between eyes closed and open in DMN Alpha band FC strength between flight conditions



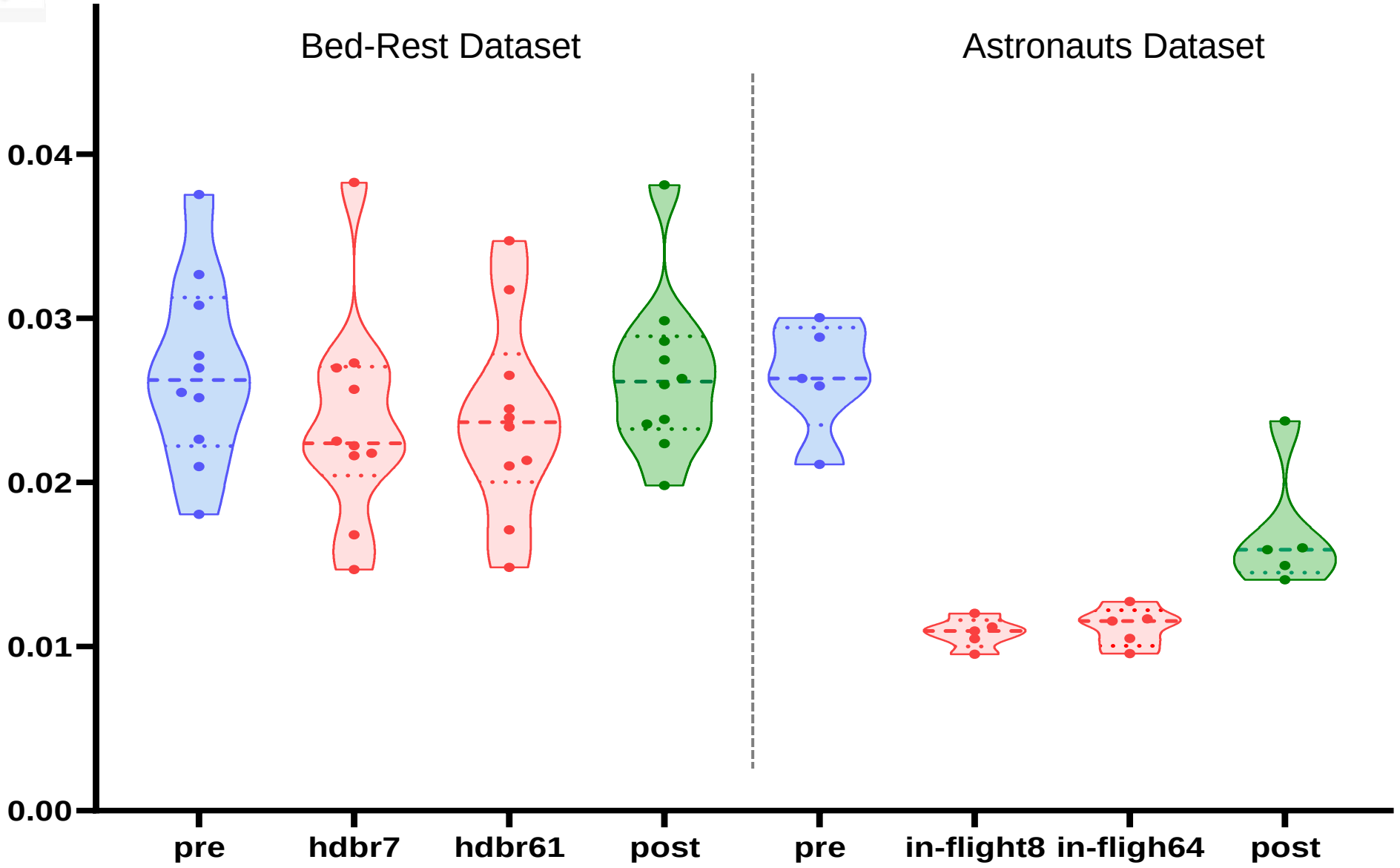
Microgravity Bed-rest and in-flights EEG recording

Bed-Rest Dataset



(Brauns et al, 2021)

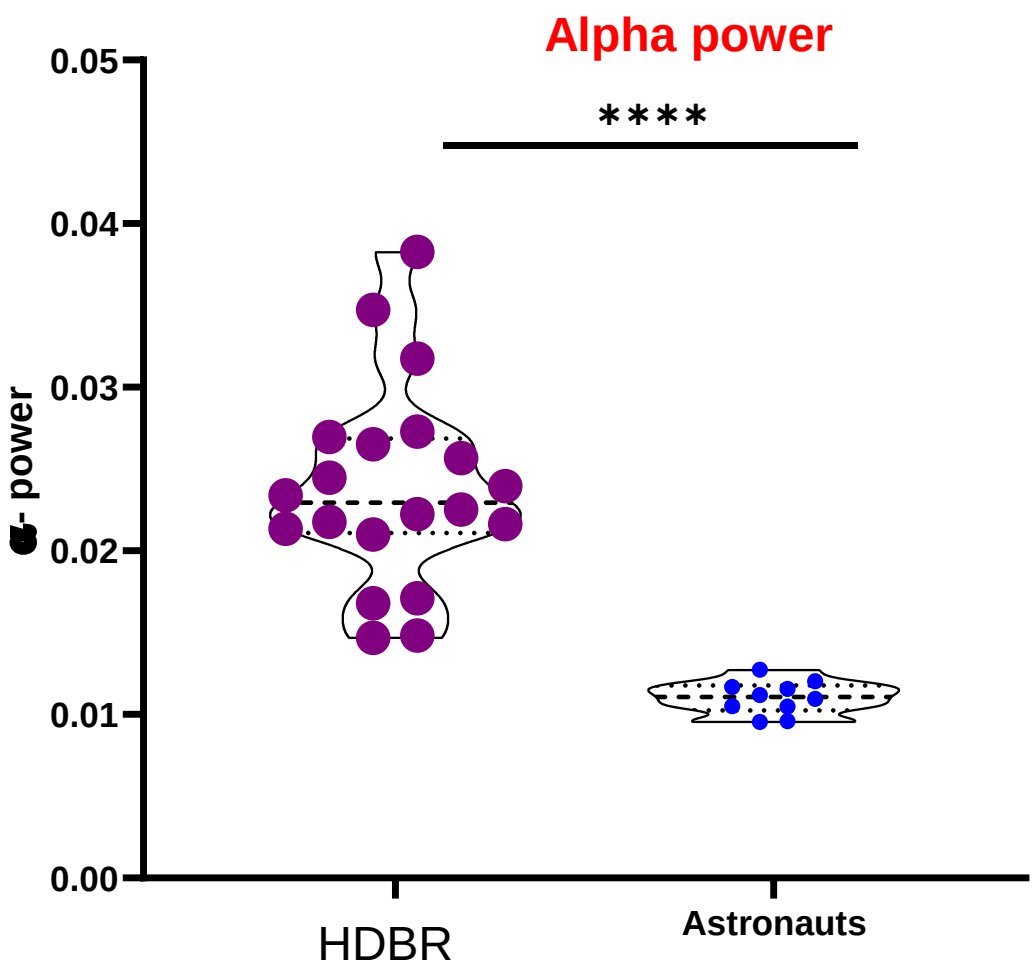
MicrogravityBed-rest and in-flights EEG recording

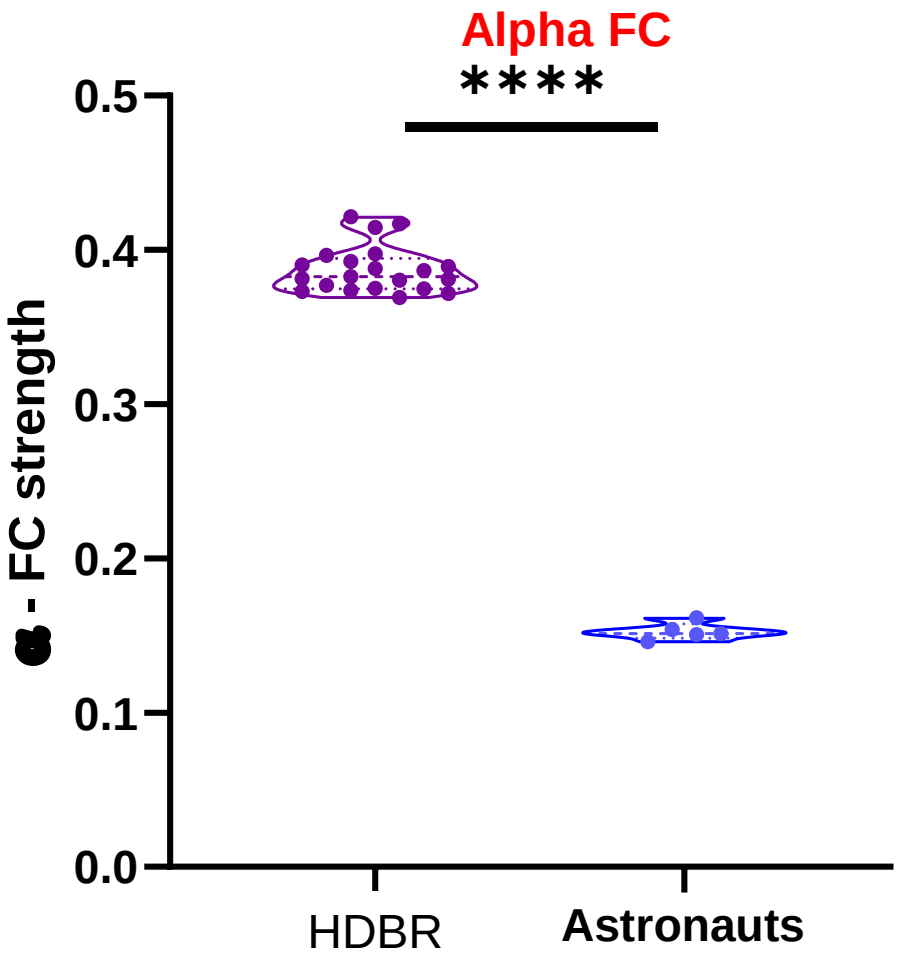


(Sevilla, Quivira et al, unpublished)

EEG results during Spaceflights

HBDR vs Astronauts Dataset (in-flight)

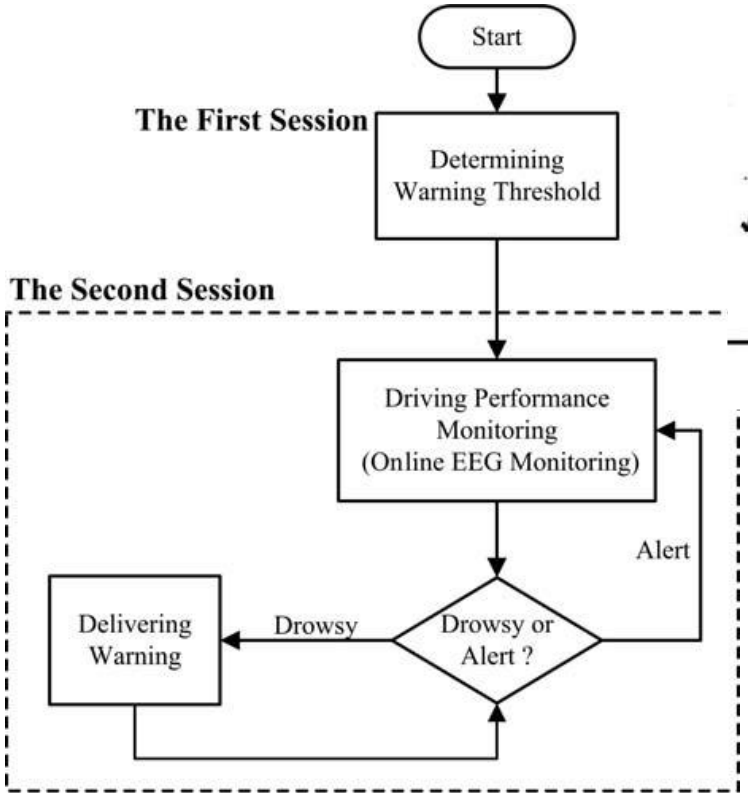


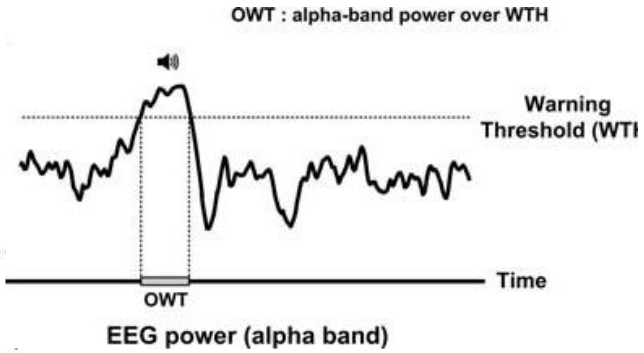


Between groups differences p<0.0001

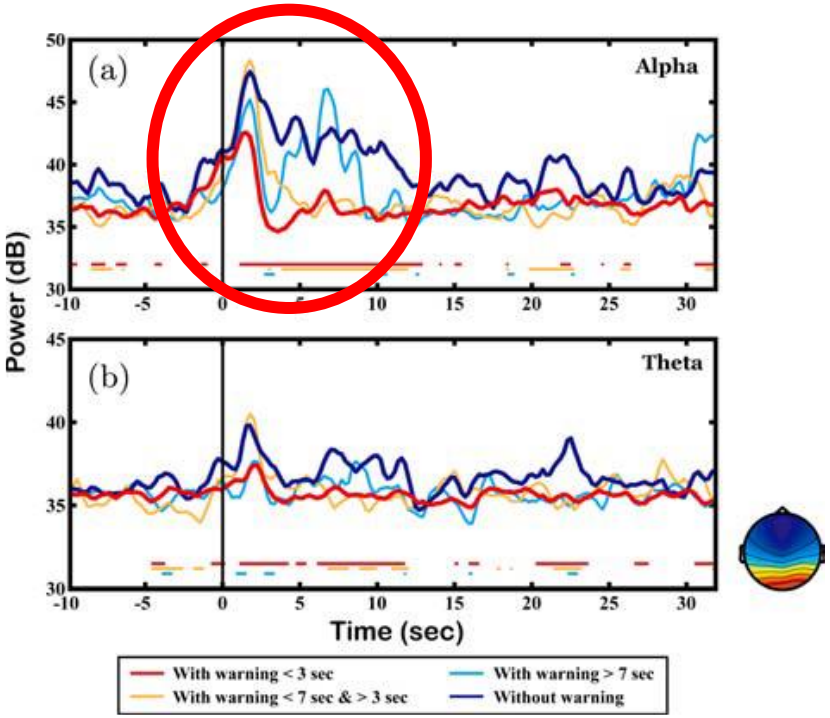
(Sevilla, Quivira et al, unpublished)

Fatigue





Alpha threshold



(Huang et al, 2016)

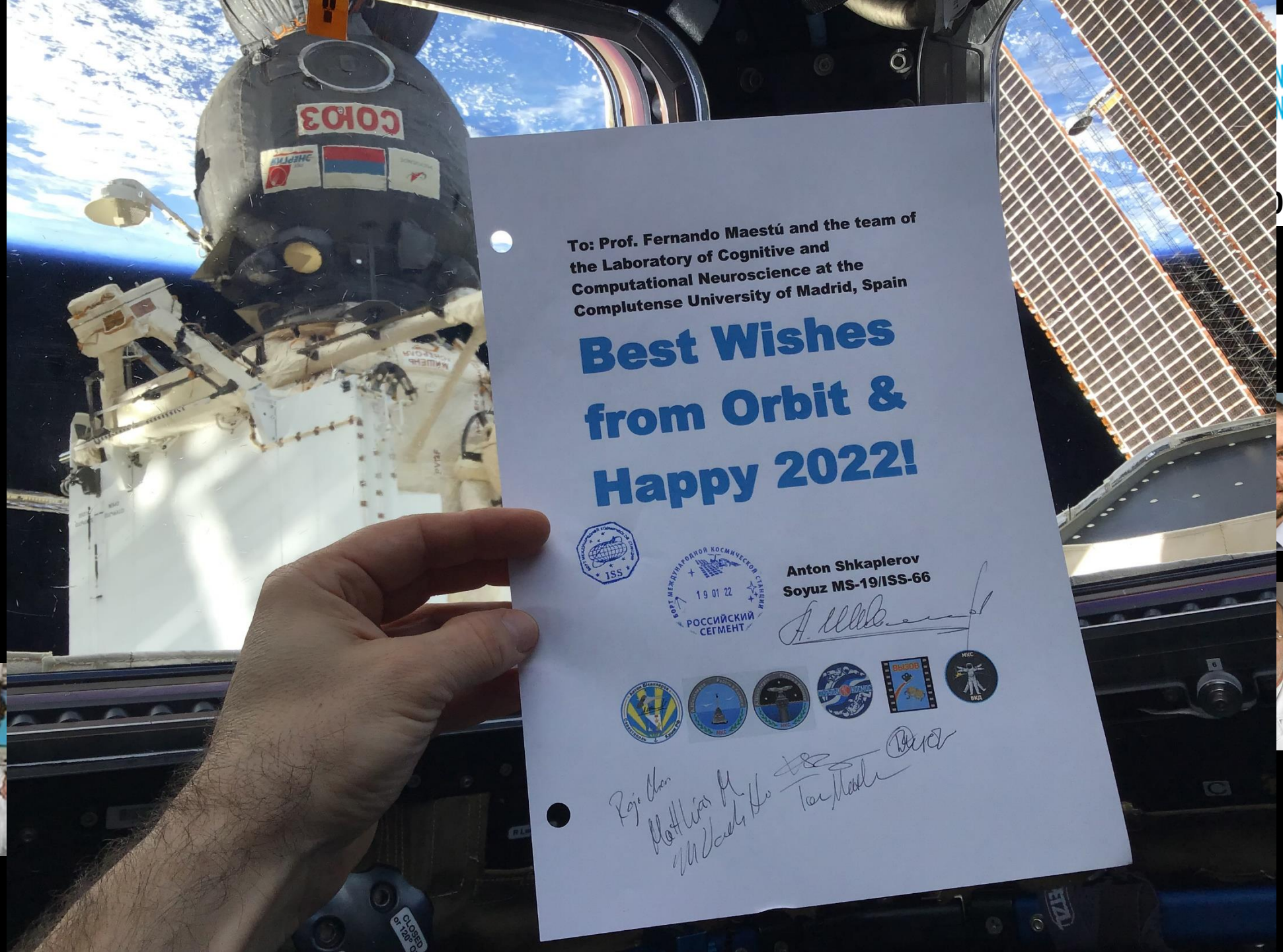
CONCLUSIONS

1. Functional and anatomical changes after spaceflights

2. Cognitive and motor performance could have a physiological EEG equivalent

3. Reduced alpha power and connectivity during flight conditions

4. More data and research needed



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