UNOOSA Webinar Series on Hypergravity/Microgravity

Life Science: Human Physiology

Wednesday 5th May 2021

BRAIN and BEHAVIOUR IN MICROGRAVITY

DR ELISA R FERRE

ROYAL HOLLOWAY UNIVERSITY OF LONDON

elgra European Low Gravity Research Association

TODAY'S TALK

Outline

Intro on **GRAVITY RELATED RESEARCH**

Effects of Microgravity on human **BODILY PHYSIOLOGY**

Effects of Microgravity on **BRAIN & BEHAVIOUR**

Microgravity induced changes in **BRAIN STRUCTURES**

Microgravity induced changes in **BRAIN FUNCTIONS**

LAB STUDIES to understand gravity contribution to behaviour

WHO AM I?

A Short Introduction

SENIOR LECTURER

Behavioural Neuroscience
Department of Psychology
Royal Holloway University of London

DIRECTOR

Vestibular Multisensory Embodiment Lab
Department of Psychology
Royal Holloway University of London

Research

VESTIBULAR MULTISENSORY EMBODIMENT

VeME Lab @ Royal Holloway University of London

Dr A Torok Postdoc
M Gallagher Postdoc
R Choi RA
G De Maio PhD Student
I Arshad PhD Student

And many other (great) RHUL Research Students

Cognitive Neuroscience

Vestibular Physiology

Teaching

Behavioural Neuroscience
Year 1 BSc Psychology (>350 students)

Committee Member

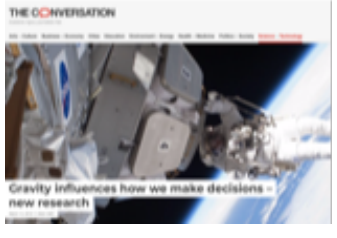
EPS Experimental Psychology Society

The British Psychological Society

elgra

UK Space L.A.B.S

Public Engagement



WHO AM I?

My Journey

BSc
MSc
Psychology/
Experimental
Psychology
UNIVERSITY OF PAVIA

PhD (1y)
Psychology/
Cognitive Neuroscience
UNIVERSITY OF PAVIA

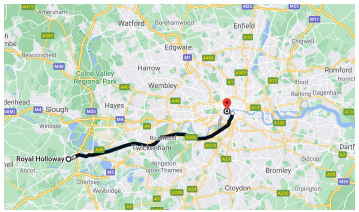
PhD/RA (3y)
Psychology/
Cognitive Neuroscience
UNIVERSITY COLLEGE LONDON
INSTITUTE COGNITIVE NEURO

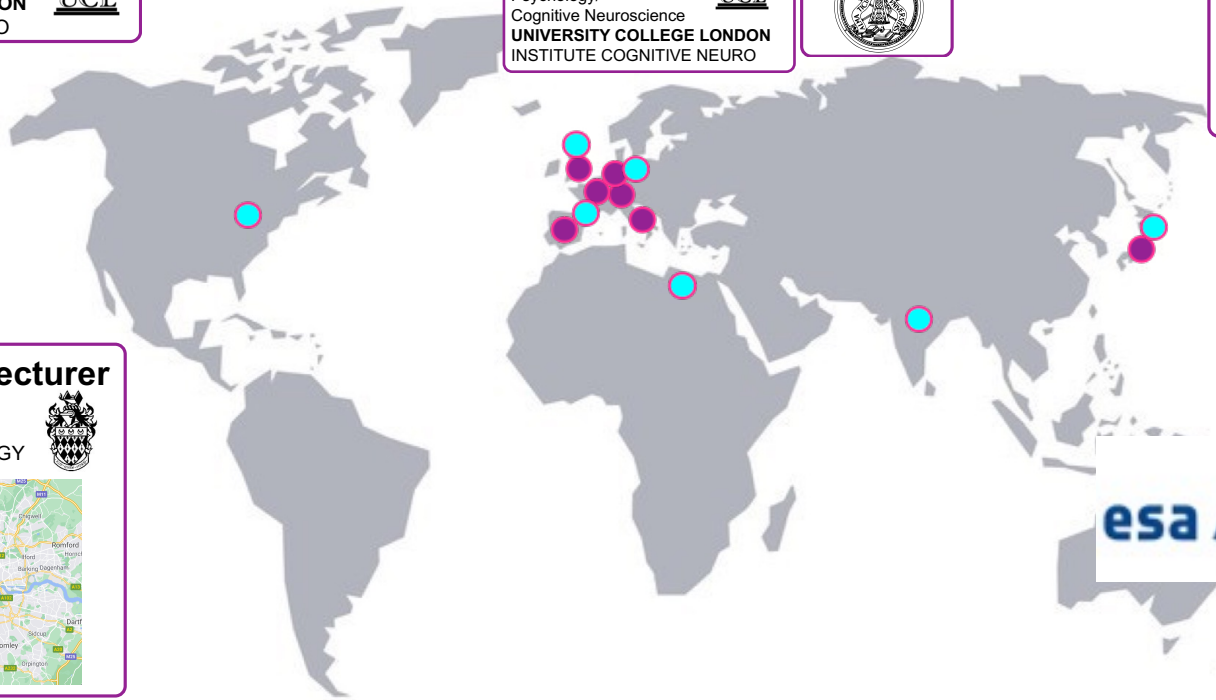
Post-Doc Fellow (4y)
Psychology/Cognitive Neuroscience
UNIVERSITY COLLEGE LONDON
INSTITUTE COGNITIVE NEURO

Visiting Academic Researcher
UNIVERSITY OF OSAKA (JP)
CiNET

Visiting Post-Doc
EPFL (CH)
Scuola Superiore Sant'Anna (IT)
Luebeck Univ (DE)
Barcelona Univ (SP)
Hamburg (DE)

Lecturer/Senior Lecturer
ROYAL HOLLOWAY
UNIVERSITY OF LONDON
DEPARTMENT OF PSYCHOLOGY





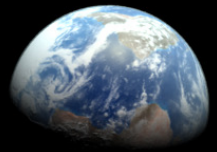
esa academy

SPACE GENERATION ADVISORY COUNCIL

ROYAL HOLLOWAY UNIVERSITY OF LONDON

WHY

Space?



“I think we’re going to the Moon because it’s in the nature of the human being to face challenges. It’s by the nature of his deep inner soul. We’re required to do these things just as salmon swim upstream.” — *Neil Armstrong*

WHAT IS

Gravity?

"GRAVITY IS THE FIRST THING WHICH YOU DON'T THINK"

A. EINSTAIN

$1g = 9.8\ m/s^2$

Gravity is the constant **ATTRACTION**
that the Earth exerts on all objects

JUST A COUPLE OF

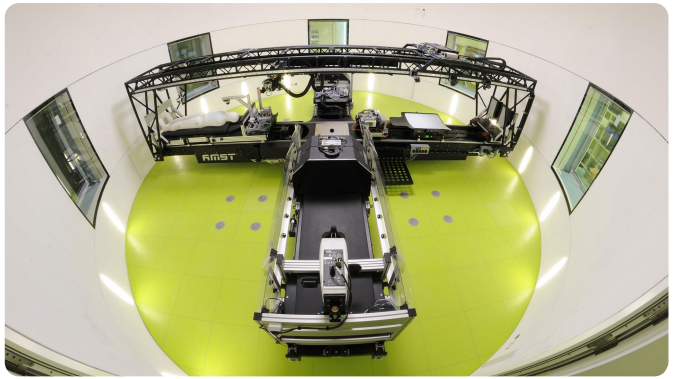
DEFINITIONS

MICROGRAVITY (μg)

a "*state of very little gravity*"
Weightlessness and **Zero-g**

The prefix "micro":
Greek word *mikros*, meaning "*small*"

HYPERGRAVITY



indicates a condition
where the force of gravity
exceeds that on the surface of the Earth

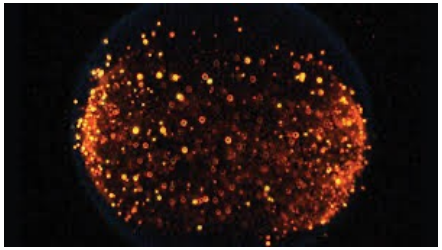
(>1g)

GRAVITY-RELATED

Research

Aims to increase the understanding of the **EFFECTS OF GRAVITY** on **biological**, **physical** and **chemical** systems






Multi-Disciplinary
LIFE SCIENCES, PHYSICAL SCIENCES, ENGINEERING

Multi-Methods
LAB-BASED EXPT, GROUND-BASED EXPT, SPACEFLIGHT

Economic, Industrial and Societal **IMPACT**

GRAVITY-RELATED RESEARCH

Methods

Spaceflight

ISS

Satellites

Payload

Ground–Based Facilities

Clinostat

Bed Rest

Drop Tower

Parabolic

Centrifuge

HUMAN PHYSIOLOGY IN

Microgravity

Humans
continuously and successfully
adapt
to new situations and demands
from the environment

Tuareg, Africa

Inuit, Subarctic

Outer Space

ULTIMATE FRONTIER
a REAL challenge
to human adaptive capabilities

- RADIATION
- **MICROGRAVITY**
- ACCELERATION
- ISOLATION
- STRESS

Body's response to microgravity

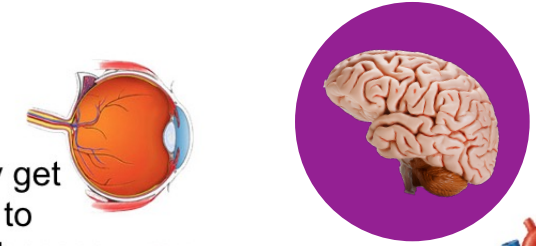
Successful and safe
outcome of
human space missions

WHAT HAPPENS TO THE BODY IN

Space?

Microgravity causes dramatic alterations in **bodily physiology**

“PUFFY FACE”



Vision may get worse due to pressure changes in the brain

Fluid shifting from the legs to the head might fill a 2L battle

Muscles shrink and absorb the extra tissue from their lack of use

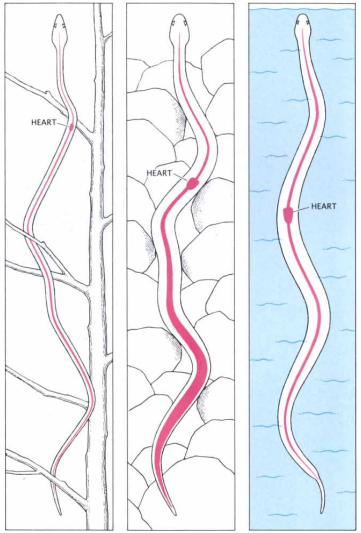
-12% of bone density

HUMANS AND

Gravity

Life on Earth has developed in a 1g environment and our **bodily physiology relies on gravity**

e.g. Evolution of Cardiovascular Anatomy



Gravity places special demands on the cardiovascular system of animals (and **humans**)

Gravity's effects can be particularly pronounced in species that adopt vertical orientations – for example, *snakes*

When a snake climbs or rears up, its cardiovascular system must resist strong pressure gradients.
These effects of gravity explain why
the circulatory system of a tree snake differs from that of a sea snake.

Lillywhite 1988

WHAT ABOUT HUMANS?

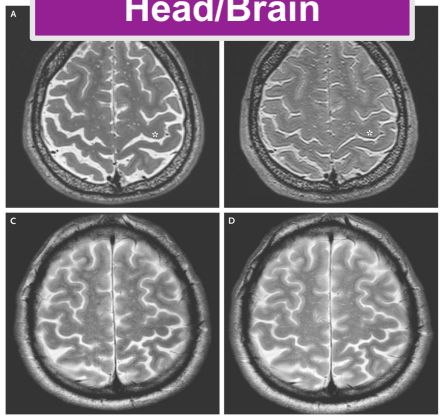
Hydrostatic Pressure

Upon entry into microgravity, the **hydrostatic pressure** is abruptly removed from the bodily tissues

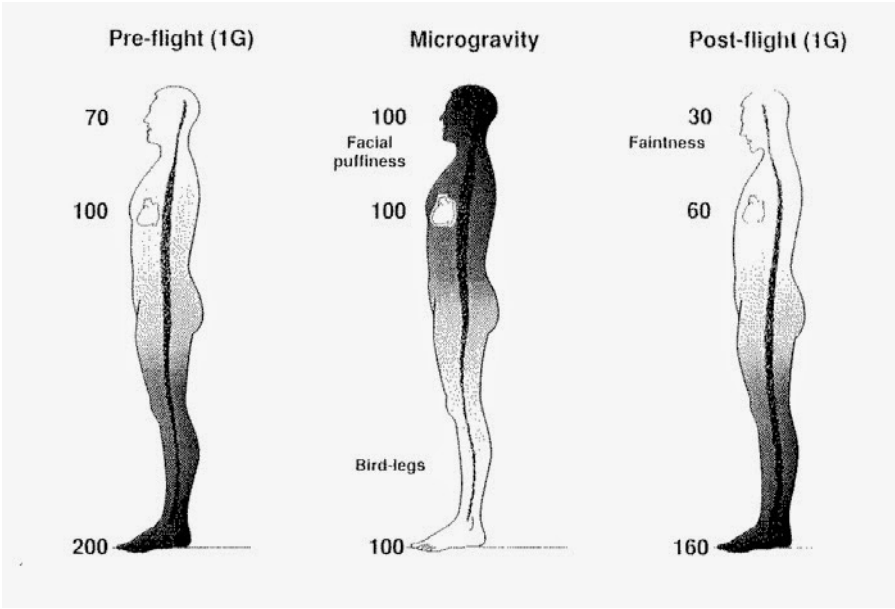
→ **migration of fluid from the legs toward the upper body and head**

“Puffy Face”

Head/Brain



Chicken Legs



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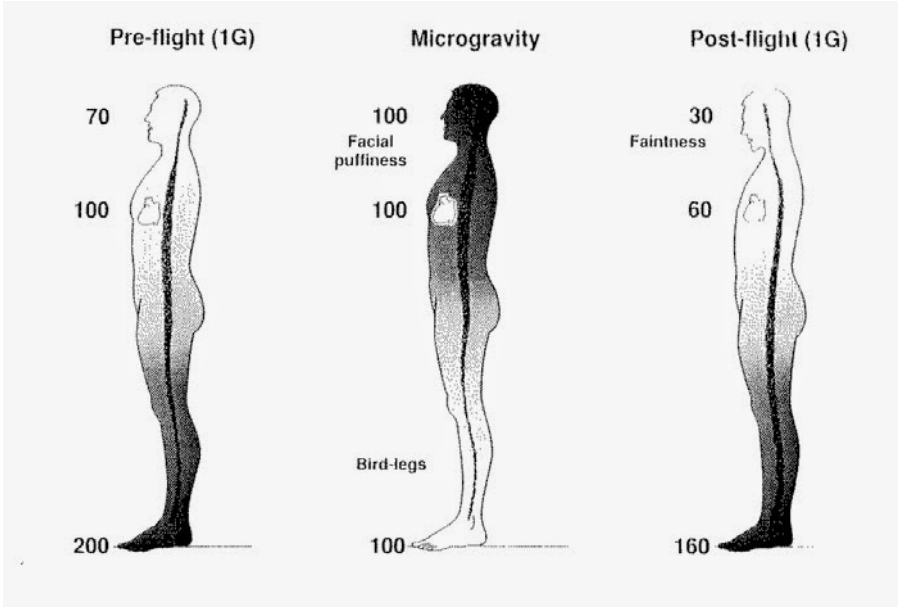
Heidemarie Stefanyshyn-Piper on 22 Sept. at Houston, Texas after STS-115 - Atlantis (September 9–21, 2006) landing

Post-flight Orthostatic Intolerance

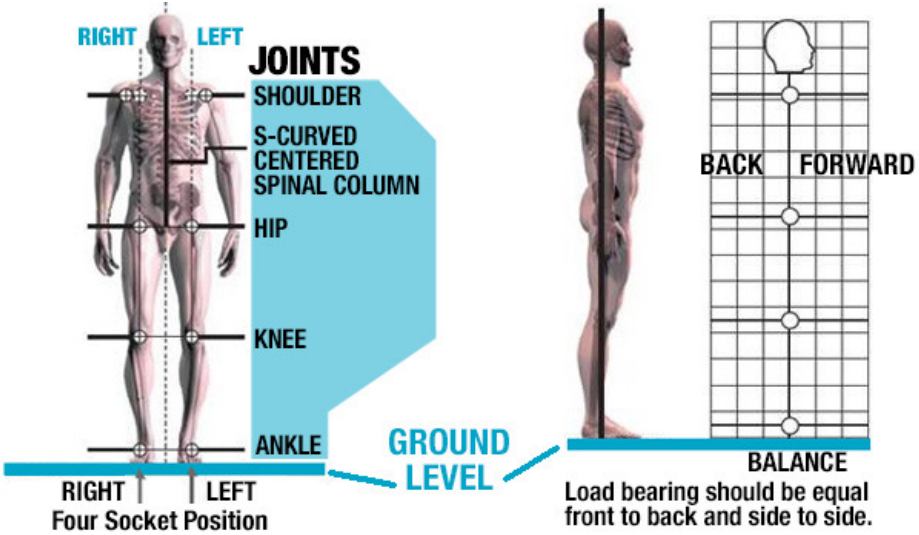


HUMANS AND

Gravity

Life on Earth has developed in a 1g environment and our **bodily physiology relies on gravity**

e.g. Evolution of Load-Bearing Structures



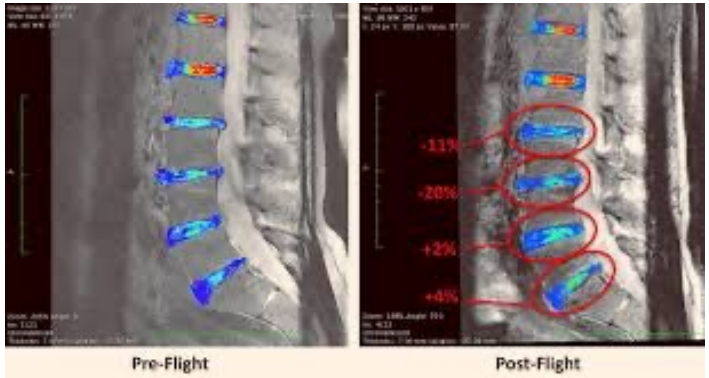
the % of body mass involved in **structural support** is proportional to the size of a land animal (20g mouse=~5%, 70kg human=~14%, and 7000kg elephant=~27%)

Load-bearing limbs, so important on Earth, are **less necessary in space!**

MICROGRAVITY-INDUCED

Spine Lengthening

A side effects of zero gravity is that it tends to lengthen astronauts spines



BACK PAIN

SkinSuit

Skinsuit **simulates gravity's spinal compression** to make sure future astronauts won't be suffering from back pain

HOW DO HUMANS KNOW ABOUT

Gravity?

HUMAN BRAIN

ROYAL HOLLOWAY UNIVERSITY OF LONDON

HOW DO HUMANS KNOW ABOUT

Gravity?

HUMAN BRAIN

HOW DO HUMANS KNOW ABOUT

Gravity?

HUMAN BRAIN → BRAIN PLASTICITY

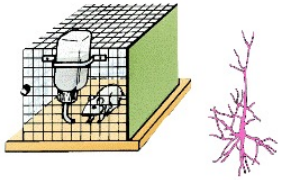
The ability of the brain to reorganize neural pathways based on new experiences

the brain ability to change with **learning**

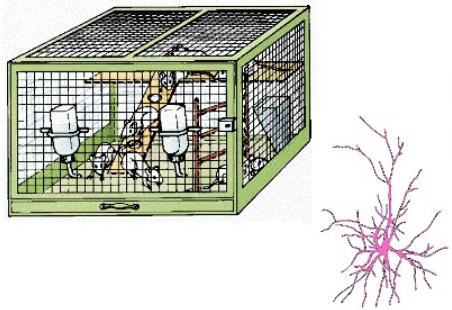
Persistent functional changes in the brain represent new knowledge

Environment Influences

NEUROPLASTICITY



Impoverished Environment



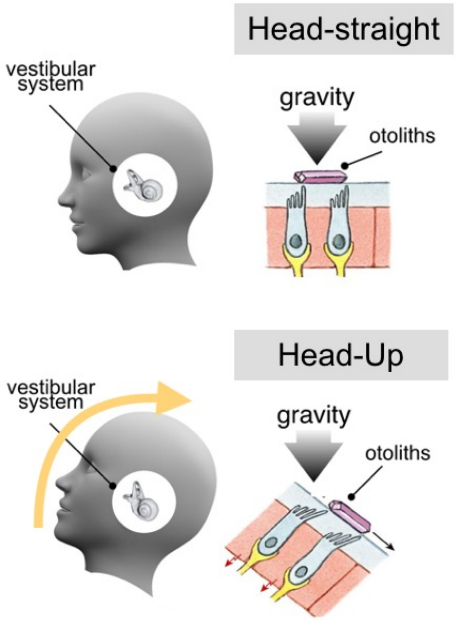
Enriched Environment

Gravity

Vestibular System

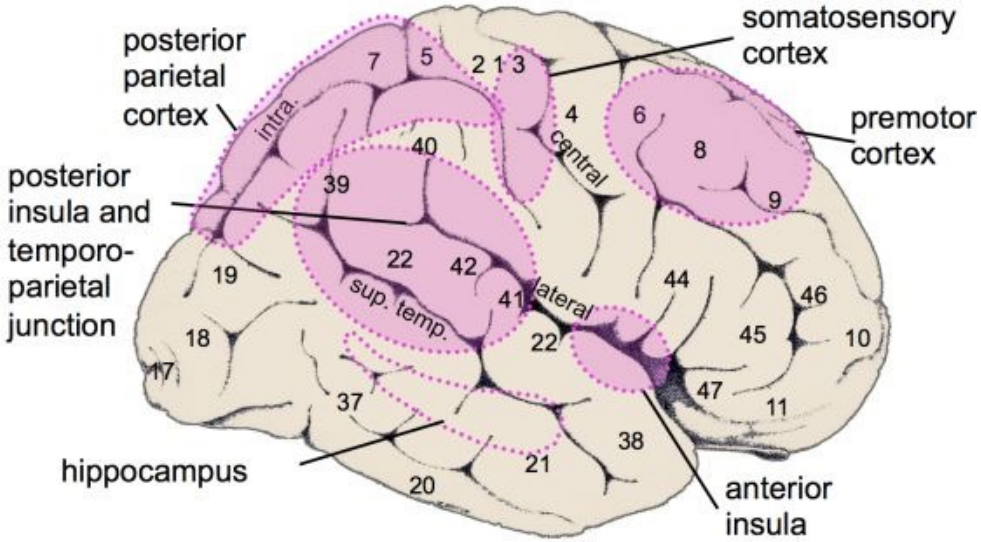
- Motion
- Balance
- Orientation

How does it work?



UNIQUE BRAIN ARCHITECTURE

NO UNIMODAL CORTEX



Gravity

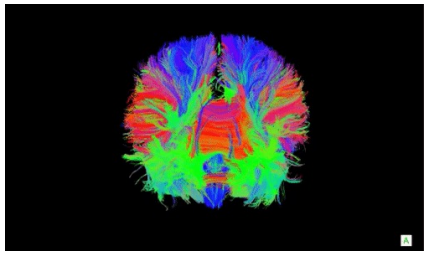
Vestibular System

- Motion
- Balance
- Orientation

Microgravity effects on Brain Structures

MRI

brain structure, structural connectivity, and functional connectivity

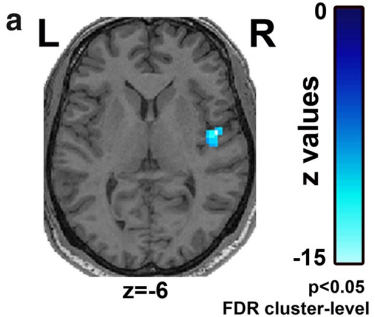


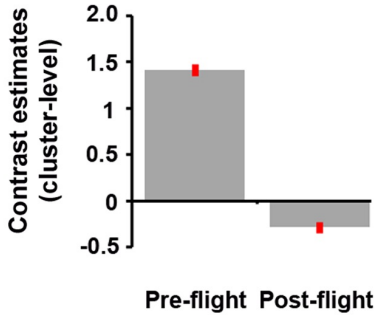
- A 44-year-old male cosmonaut
- First long-duration mission (**169 days**) to ISS in 2014

decreased connectivity in right insula

Vestibular-related cortical area

(Demertzi et al. 2016)





Gravity

Vestibular System

- Motion
- Balance
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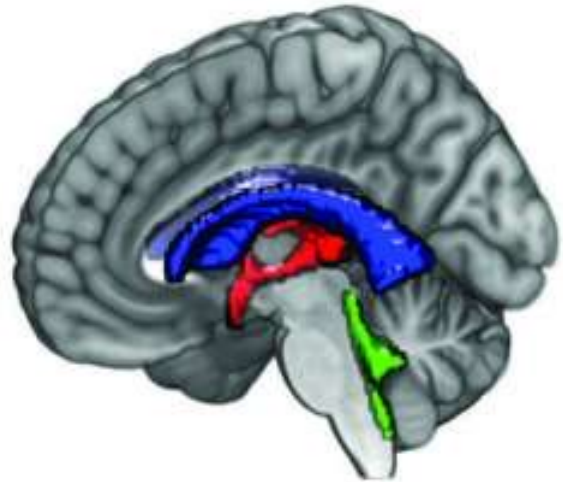
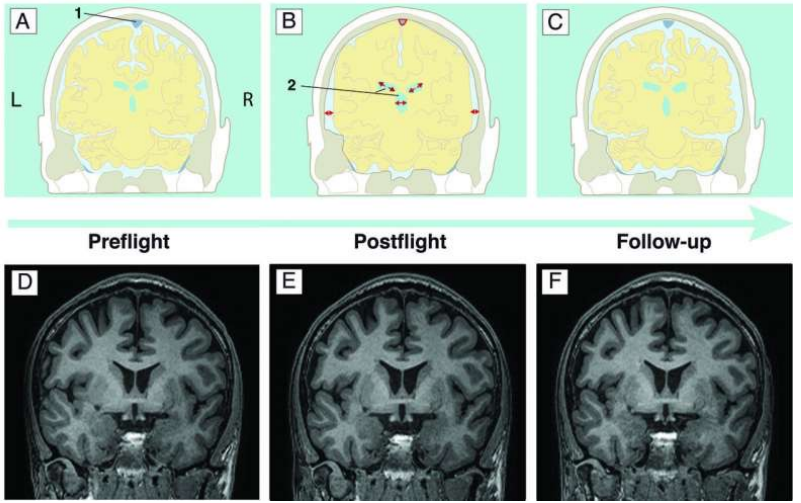
Microgravity effects on Brain Structures



Spaceflight leads to increase in brain ventricle size



Van Ombergen et al. 2019

HOW THE BRAIN DETECTS

Gravity

Vestibular System

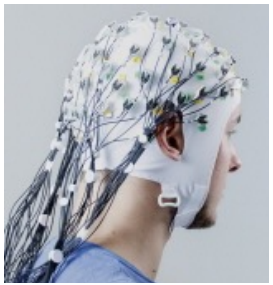
- Motion
- Balance
- Orientation

Microgravity effects on Brain Structures

Spaceflight changes electrocortical activity

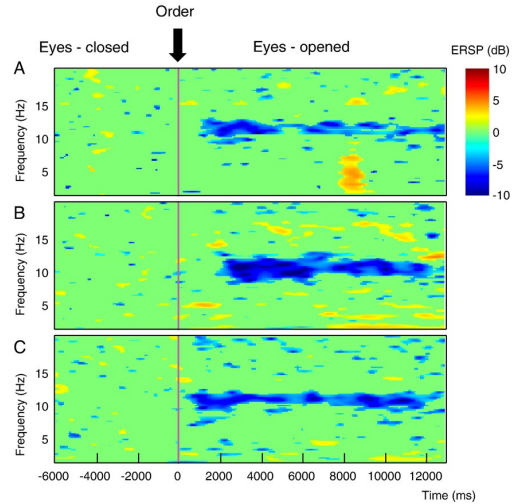
EEG data

Arrest Reaction in Microgravity (1 cosmonaut)



Cheron et al., 2006

INCREASE IN ALPHA POWER



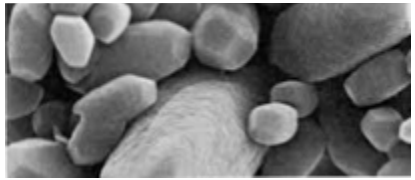
THE INTERNAL

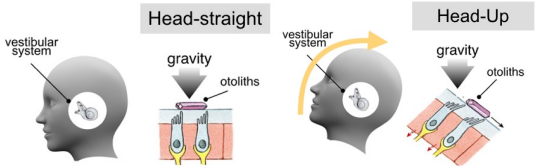
Gravity Model

Gallagher et al., 2019

“Graviception”

Vestibular

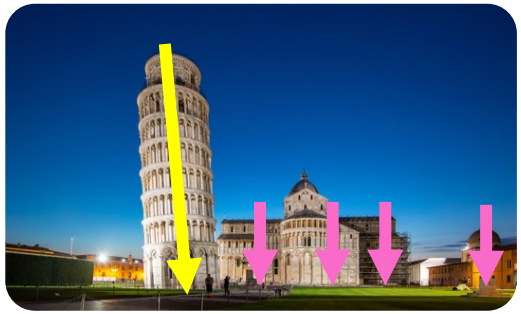




Vestibular cues, i.e. Otoliths

Merfeld et al., 1999

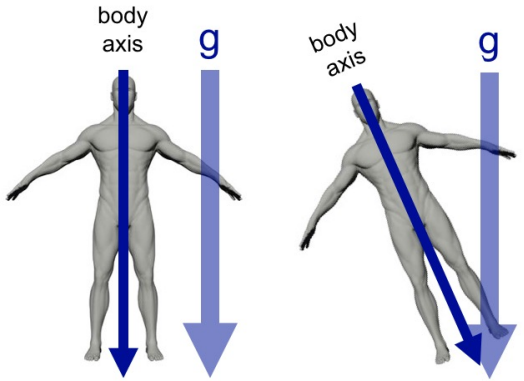
Visual



Environmental cues, i.e. Verticality

Harris et al., 2011

Proprioceptive



Bodily cues, i.e. Body Axis

Yardley, 1990

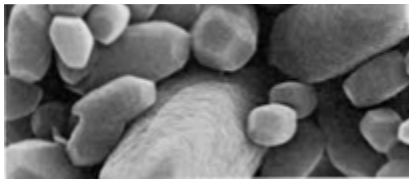
THE INTERNAL

Gravity Model

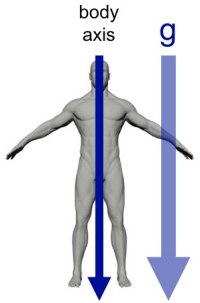
“Graviception”

Visual

Vestibular



Proprioceptive



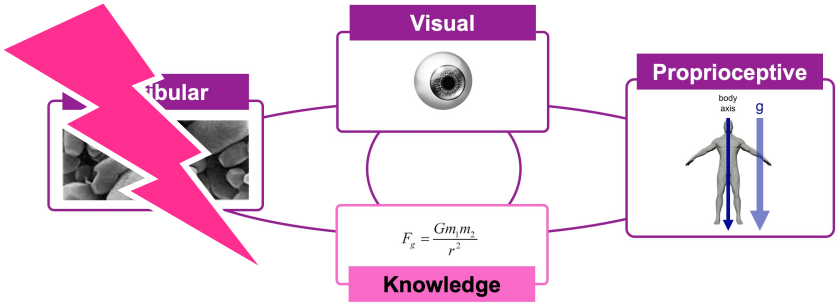
$$F_g = \frac{Gm_1m_2}{r^2}$$

Knowledge

WHAT IF THE GRAVITY MODEL

Does Not Work?

On Earth, the vestibular system
tells us how the head moves relative to gravity,
but in space,
the gravity reference is gone



SPACE ADAPTATION SYNDROME
(or Space Motion Sickness)

MOTION SICKNESS

(it mimics car motion sickness)
Experienced by *more than 50%* of all astronauts

Nausea and vomiting

Perceptual illusions
Difficulties in coordinating movements
Disorientation
Detrimental to crew performance

"The way to feel better is to lose up, to convince your **VISUAL SYSTEM** that up is wherever you point your head and down is where your feet are" (M. Ivins)

MICROGRAVITY ALTERS

Perception & Movement

"A Gemini Astronaut woke up in the dark during a mission and saw a disembodied glow-in-the-dark watch floating in front of him. Only after few moments later he realised that the watch was around his own wrist."

Proprioception

Vestibular

Vision

Sensory Integration

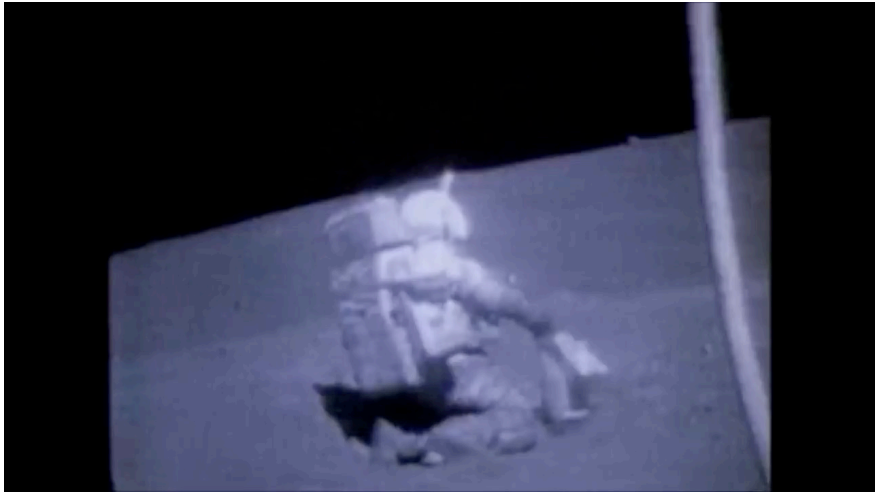
Balance & Motor Control

Goal-Dir Movement

Eye-Hand Coord.

Grip Force

Postural Control



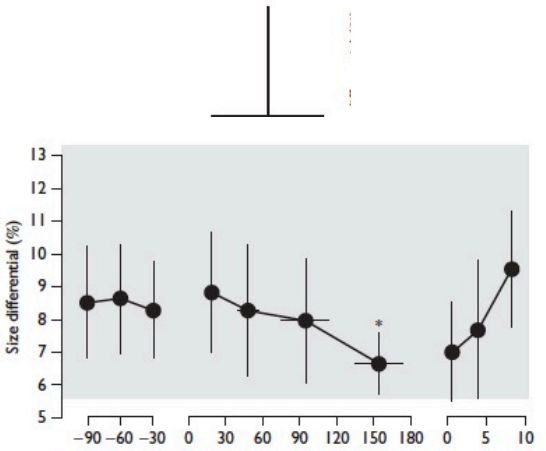
MICROGRAVITY ALTERS

Perception & Movement

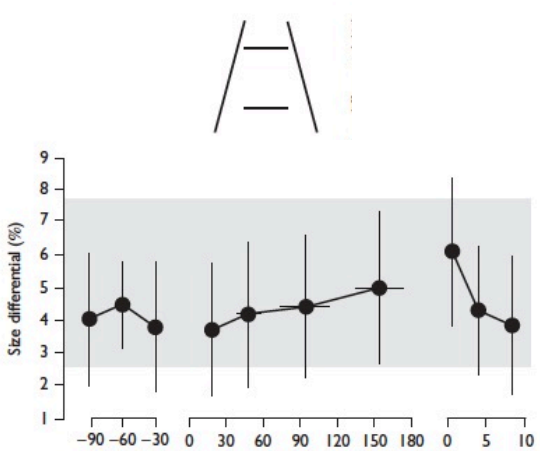
Clement G., 2012

GEOMETRIC ILLUSIONS

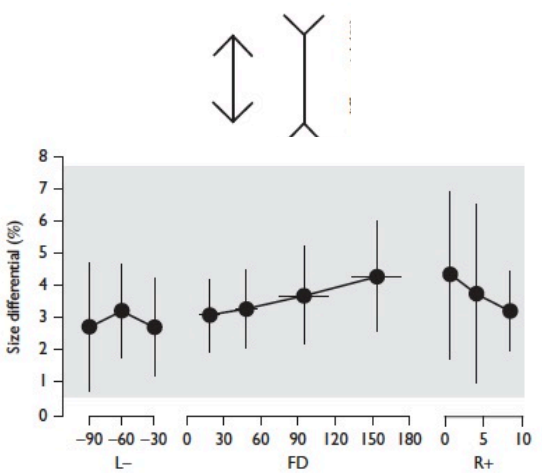
Inverted T



Ponzo



Muller-Lyer



Alterations in visuo-spatial processing → **VERTICAL DIMENSION**

LAB STUDIES – MICROGRAVITY EFFECTS ON

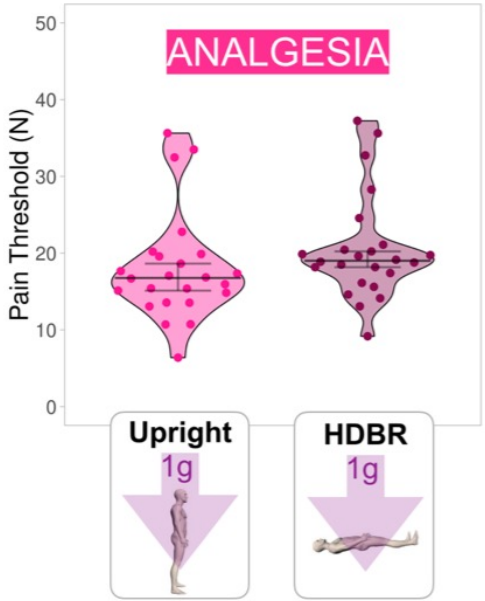
Perception

Ferre et al., In Prep

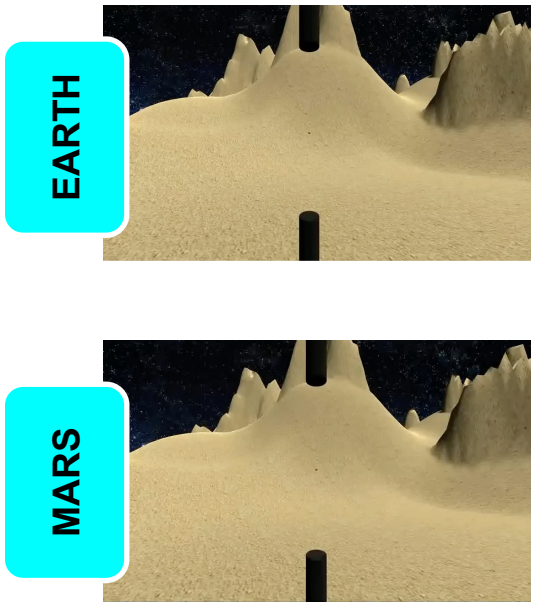
Pain Perception

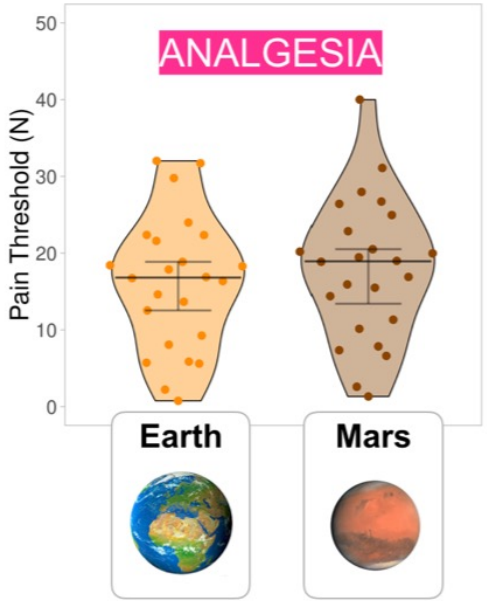
PAIN HAS AN ADAPTIVE FUNCTION

Bed Rest g-alteration



Virtual Reality (VR) g-alteration





LAB STUDIES – MICROGRAVITY EFFECTS ON

Motor Control

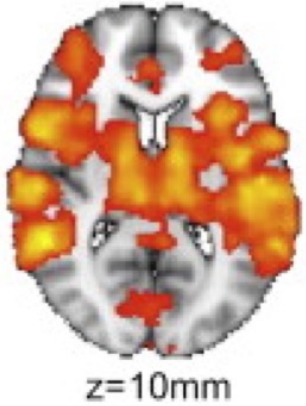
Motor Response to Stimuli

ABILITY TO RESPOND TO ENVIRONMENTAL STIMULI

ODDBALL TASK

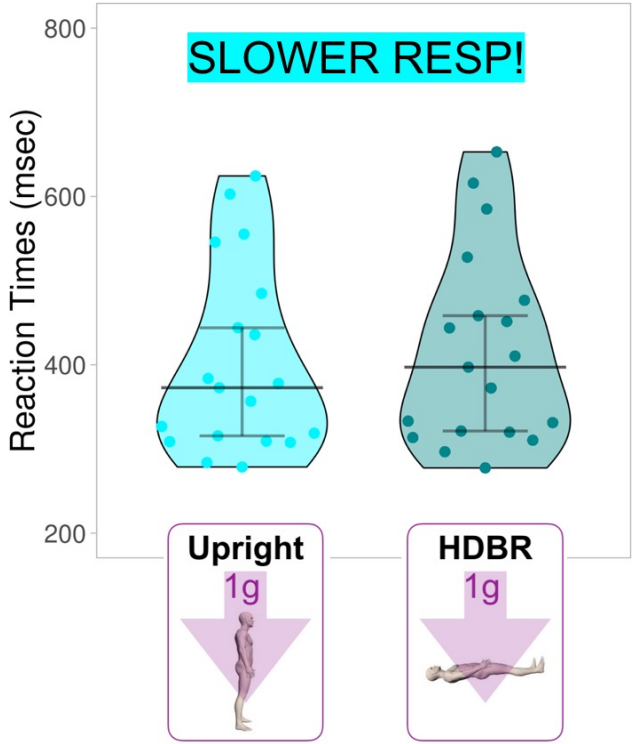
"Quickly Respond to Target Sound"

Widespread Brain Activation



Arshad et al., In Prep

Bed Rest g-alteration



LAB STUDIES – MICROGRAVITY EFFECTS ON

Decision Making

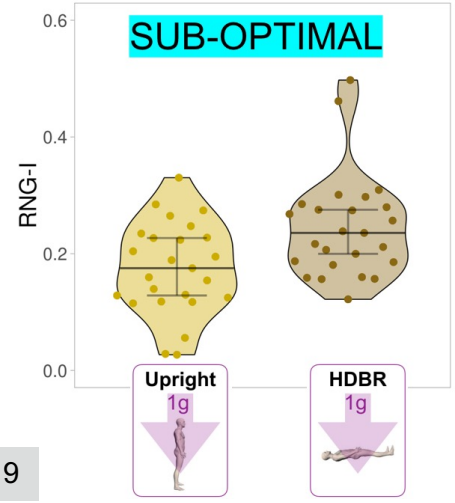
De Maio et al., In Prep

Decision-Making

ROUTINE vs. NOVEL BEHAVIOUR

Bed Rest g-alteration

A	B
3	3
3	9
6	6
6	4

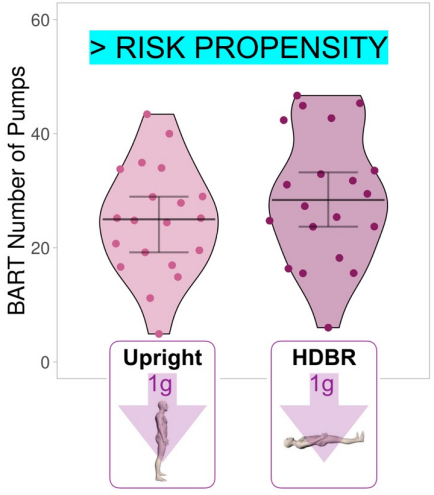


Gallagher et al., 2019

Risk-Taking Behaviour

ABILITY TO CONTROL HAZARDOUS TENDENCIES

Bed Rest g-alteration



Balloon Analogue Risk Task (BART)

an implicit behavioural measure of risk-taking propensity

EXPLOITING “ALTERED GRAVITY” TO UNDERSTAND

Life on Earth

Ferre et al., 2019

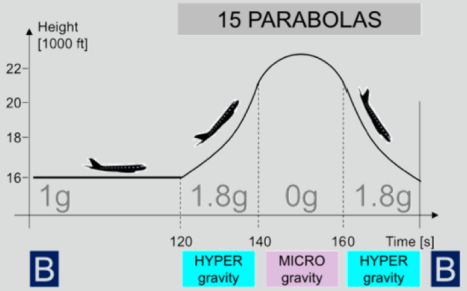
WEIGHT = m * g

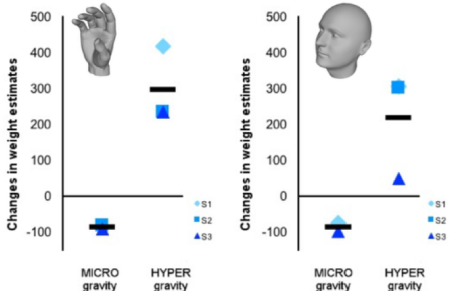
Different weight on Earth, Moon, ISS, etc

Parabolic Flight

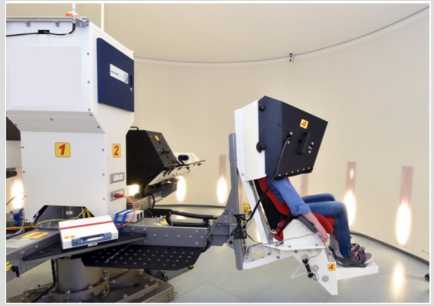
Body Weight Perception

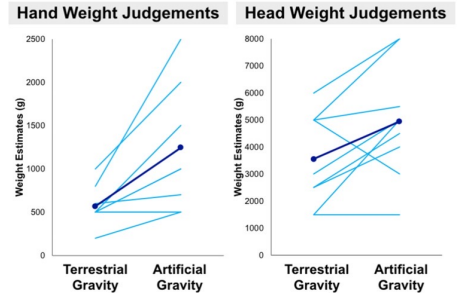
Parabolic Flight





Human Centrifuge





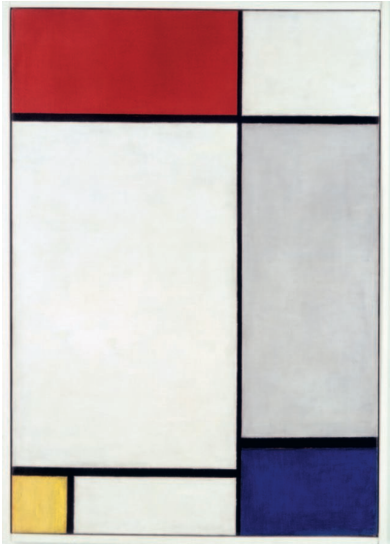
EXPLOITING “ALTERED GRAVITY” TO UNDERSTAND

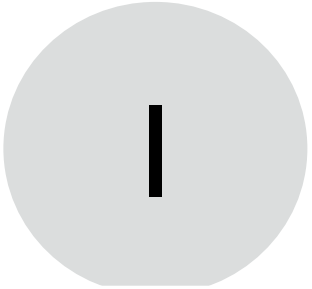
Art on Earth

VERTICALITY

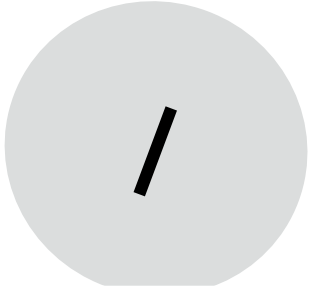
“What is UP”

It plays a role in the arts, portraying concepts such as power, grandeur, or morality





A



B

EXPLOITING “ALTERED GRAVITY” TO UNDERSTAND

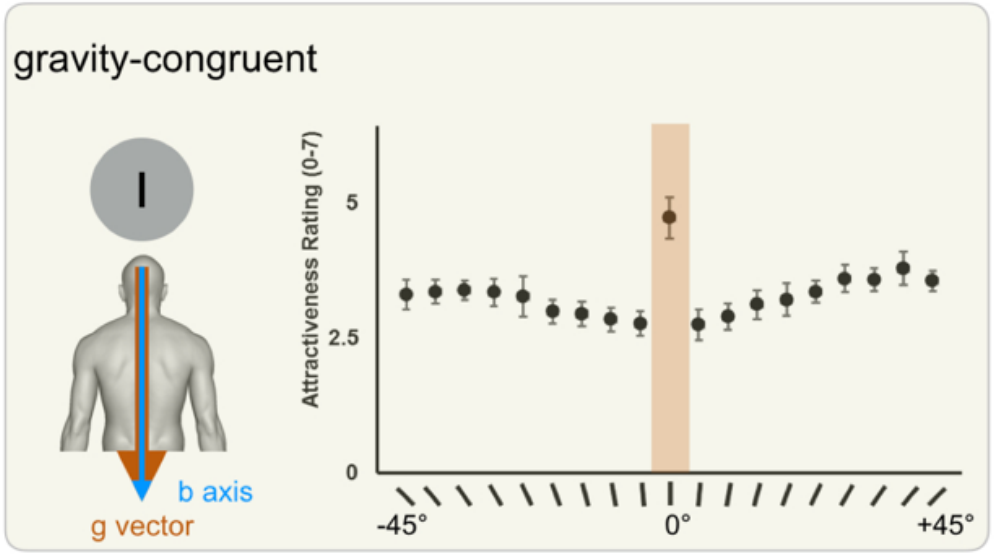
Art on Earth

VERTICALITY

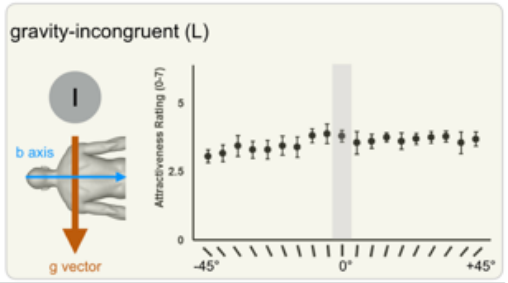
“What is UP”

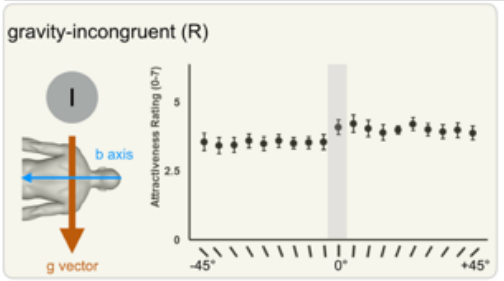
It plays a role in the arts, portraying concepts such as power, grandeur, or morality

Aesthetic Preference for Vertical



Gallagher et al., 2018





EXPLOITING “ALTERED GRAVITY” TO UNDERSTAND

Art on Earth

VERTICALITY

“What is UP”

It plays a role in the arts, portraying concepts such as power, grandeur, or morality

A B

SCIENCE/ART PROJECT

The Zero Gravity Band

What does it mean **ART** outside planet **EARTH**?

IT'S TIME TO

Sum Up

ALTERED-GRAVITY

SENSORY PROCESSING

Pain Perception

MOTOR CONTROL

Motor Response to Event

HIGH-LEVEL COGNITION

Decision-Making

Risk-Taking Behaviour

Fully myelinated at birth

The development of vestibular system and related functions in mammals: impact of gravity

Marc Jamon'

Fully functional before birth

Orbital Spaceflight During Pregnancy Shapes Function of Mammalian Vestibular System

April E. Ronca, Bernd Fritzsch, Laura L. Bruce, and Jeffrey R. Alberts

GRAVITY > SENSORY SIGNAL

No Phenomenology

Always ON

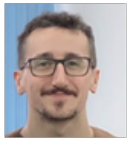
Not merely Background

Fundamental and Foundational

MANY THANKS FOR

Your Attention

M Gallagher
PhD Student



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