IL SISTEMA VESTIBOLARE IN MICROGRAVITA'

Luca Urbani
Azienda USL Rieti
Ospedale "S. Camillo de' Lellis"
U.O.C. ORL e Chirurgia Cervico-Facciale

L’alba dell’Uomo. (Da “2001: Odissea nello spazio”, di Stanley Kubrick, 1968).

L’uomo in movimento







Chinetosi (Motion Sickness)

"…**Motion sickness is the penalty for going beyond the design specifications intended for the human** and for doing something to which the evolutionary process has not specifically adapted mankind. …"

"…**Motion sickness is a normal response to an abnormal environment**. …"

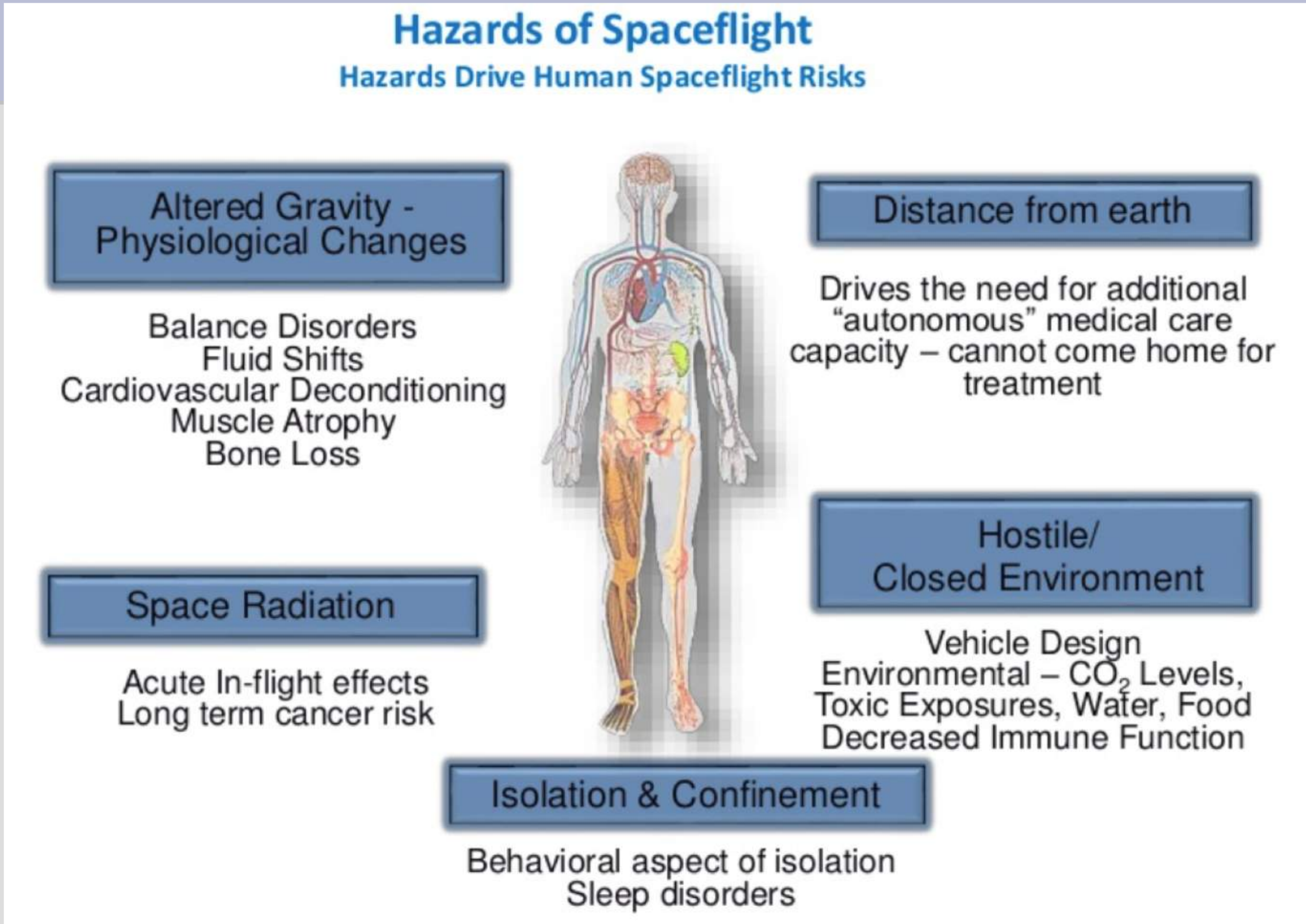
(*Oosterveld, 1995*)

Vostok-1
Y. Gagarin
12 aprile 1961

Più di 550 astronauti hanno volato nello spazio fino ad oggi, alcuni più volte

Soyuz MS-07
ISS – 54° Equipaggio
17 Dicembre 2017

Rischi del volo spaziale



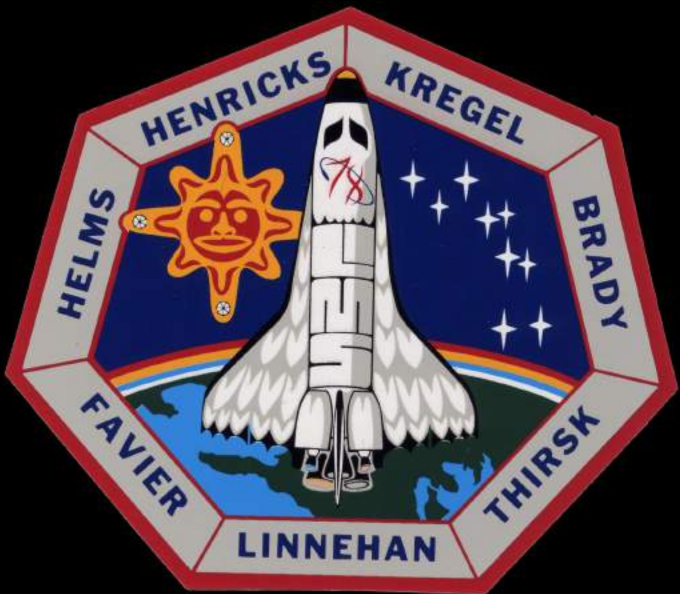
Valerij Poljakov
437 giorni
consecutivi
sulla Mir

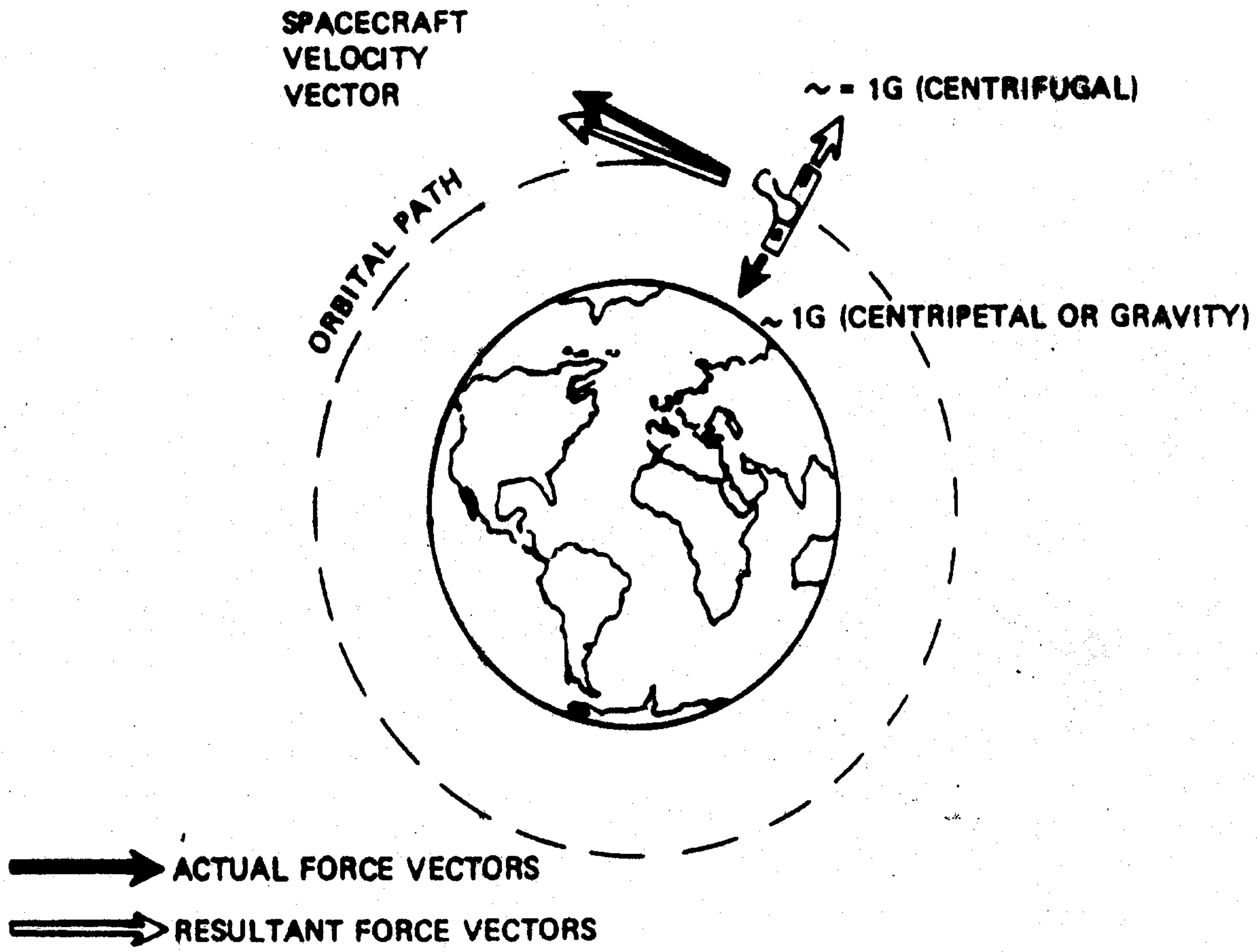
Gennady Padalka
878 giorni
su Mir e ISS

ISS

STS-78 LMS

20 giugno - 7 luglio 1996





Representation of the balance of forces that produces weightlessness (0 G) in earth orbit.

Space Motion Sickness (SMS)

SPACE MOTION SICKNESS (SMS)

SPACE SICKNESS

SPACE ADAPTATION SYNDROME (SAS)

- Sindrome clinicamente assimilabile alla MS
- Ne soffrono, con modalità variabili, il 50-70% degli astronauti.
- Insorge in genere poche ore dopo l'ingresso in orbita e si risolve in 2-3 giorni. Si può ripresentare al rientro sulla terra, specie dopo voli lunghi.
- Ruolo importante della mobilità degli astronauti (movimenti provocativi della testa - specie "pitch" - o di tutto il corpo).

Quadro clinico

SINTOMI

Malessere

Sudorazione

Fastidio epigastrico

Cefalea

Sonnolenza

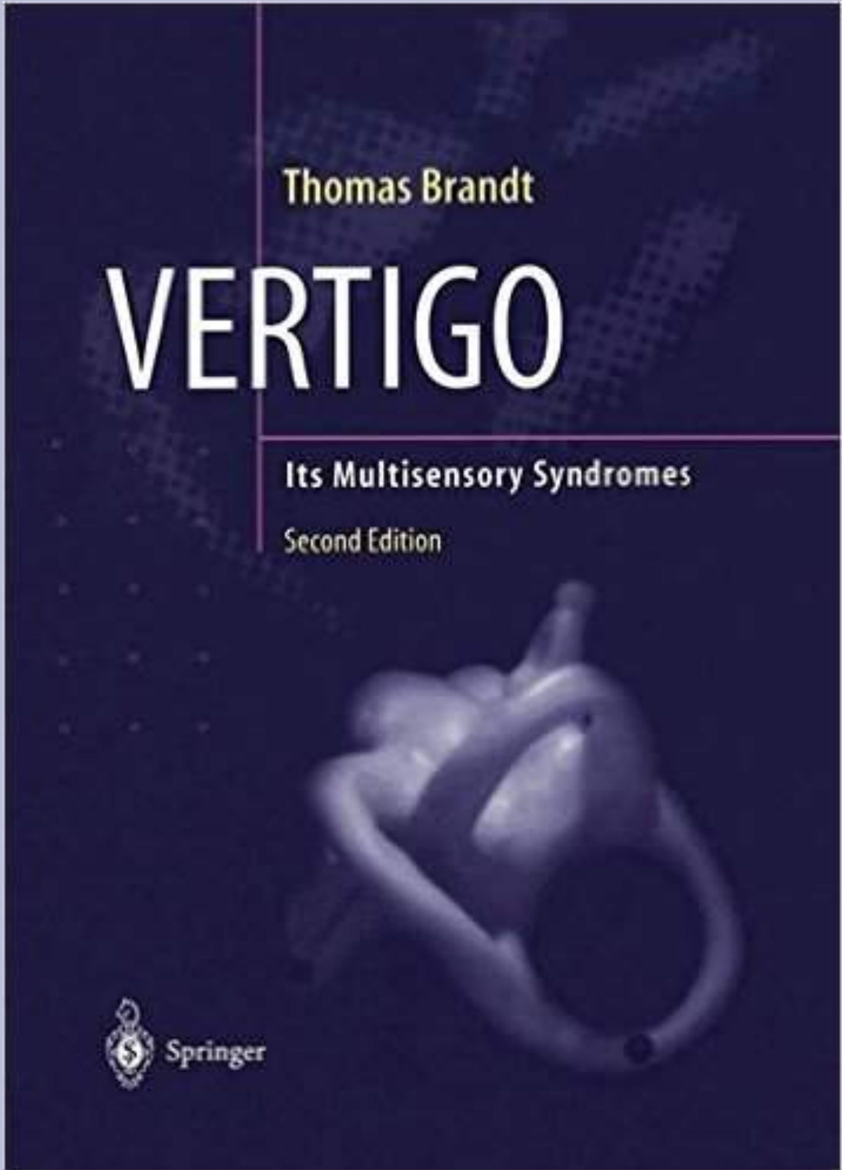
Nausea

Vomito

<u>Da lieve fastidio a grave malessere</u>

Effetti: da ridotta capacità operativa a incapacitazione totale

MS = VERTIGINE FISIOLOGICA



Vostok-2
G. Titov
6 agosto 1961

1° caso di SMS

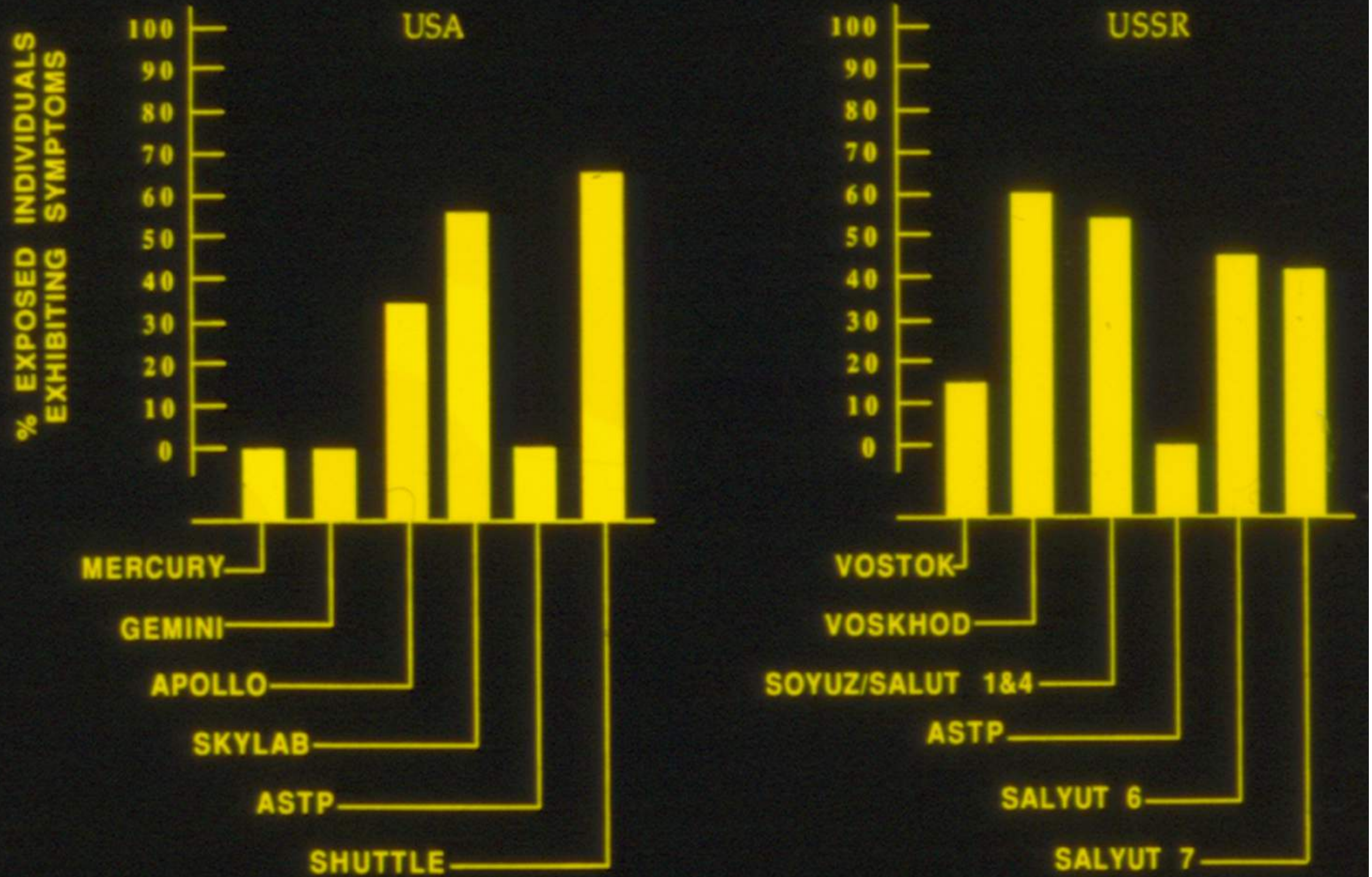


FIGURE 1. Incidence of space motion sickness in both the Soviet and U.S. manned flight programs.

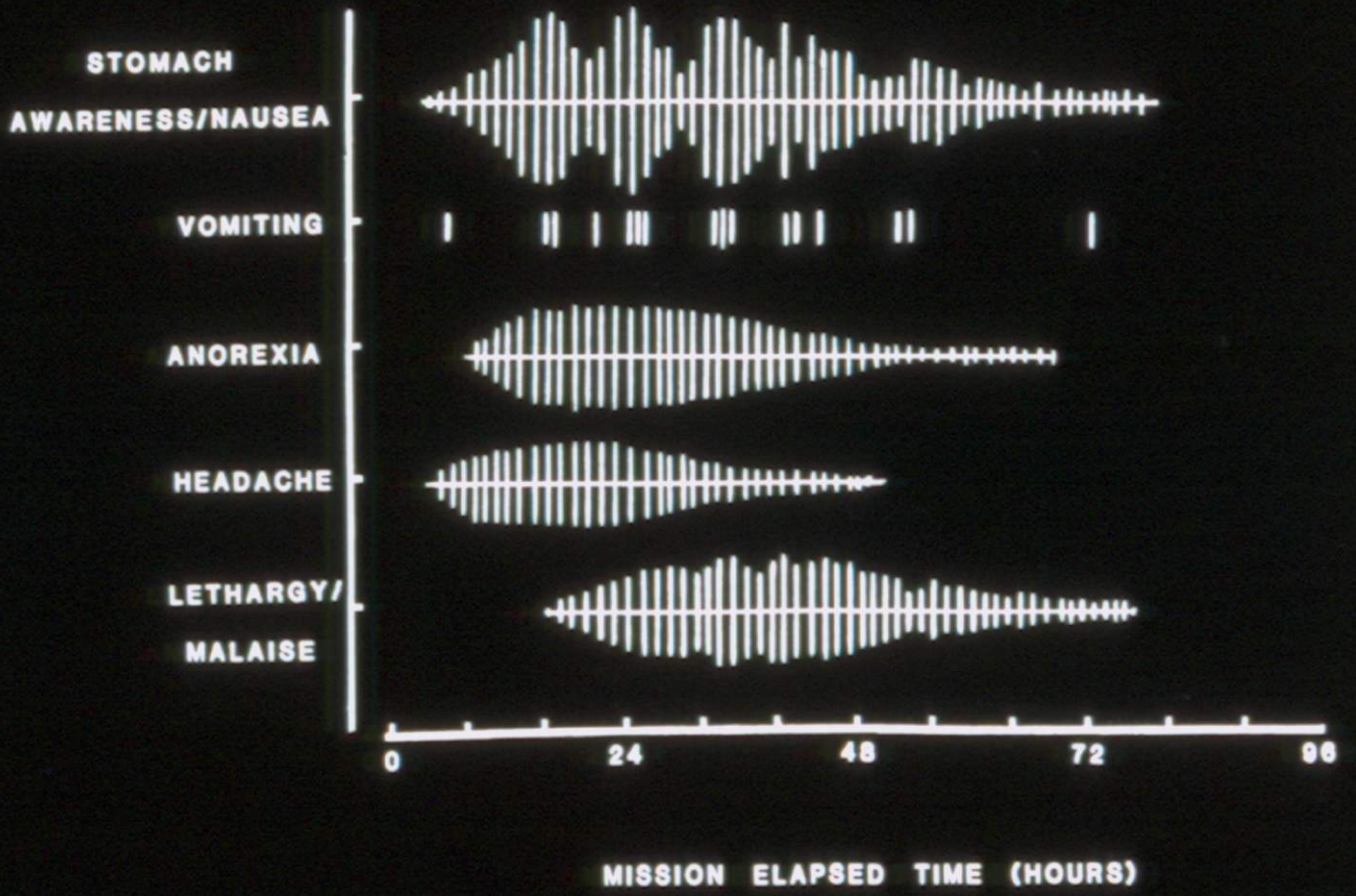


FIGURE 3. Illustration of the approximate time-course of major symptoms typically occurring during space motion sickness.

Grading della MS

DIAGNOSTIC CATEGORIZATION OF DIFFERENT LEVELS OF SEVERITY OF ACUTE MOTION SICKNESS

Category	Pathognomonic 16 points	Major 8 points	Minor 4 points	Minimal 2 points	AQS* 1 point
Nausea syndrome	Vomiting or retching	Nausea⁺ II, III	Nausea I	Epigastric discomfort	Epigastric awareness
Skin color		Pallor III	Pallor II	Pallor I	Flushing
Cold sweating		III	II	I	
Increased salivation		III	II	I	
Drowsiness		III	II	I	
Pain					Headache
Central nervous system					Dizziness: Eyes closed ≥ II; Eyes Open III

*AQS = Additional qualifying symptoms. ⁺III = severe or marked, II = moderate, I = slight.

Levels of Severity Identified by Total Points Scored

Frank Sickness	Severe Malaise	Moderate Malaise A	Moderate Malaise B	Slight Malaise
(S)	(M III)	(M IIA)	(M IIB)	(M I)
≥ 16 points	8 - 15 points	5 - 7 points	3 - 4 points	1 - 2 points

(Da Graybiel et al, 1968)

Grading della SMS

None	*No signs or symptoms reported*
Mild	*One to several transient symptoms* *No operational impact* *All symptoms resolved in 36-48 hours*
Moderate	*Several symptoms of a persistent nature* *Minimal operational impact* *All symptoms resolved in 72 hours*
Severe	*Several symptoms of a persistent nature* *Significant performance decrement* *Symptoms may persist beyond 72 hours*

NASA categorization of Space Motion Sickness according to the severity of symptoms.

Teorie patogenetiche MS

- teoria evoluzionistica di Treisman
- teoria del conflitto sensoriale
- teoria dell’instabilita’ posturale
- teoria del conflitto della verticale soggettiva

Teorie patogenetiche SMS

Teorie sulle chinetosi (MS) in generale

- Teoria di Treisman
- Teoria del conflitto sensoriale

Teorie specifiche sulla SMS

- *fluid shift*
- asimmetria otolitica
- *Otolith Tilt-Translation Reinterpretation* (OTTR)

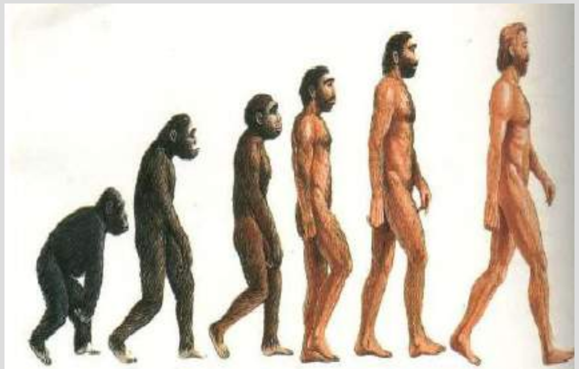
Teoria di Treisman

Science. 1977 Jul 29;197(4302):493-5.

Motion sickness: an evolutionary hypothesis.

Treisman M.

MS è il risultato dell'attivazione da parte di uno stimolo artificiale (movimento innaturale) di meccanismi che hanno la funzione di rimuovere tossine o veleni dallo stomaco



Nella MS il conflitto sensoriale simula l'avvelenamento nei meccanismi neurali

Evidenze sperimentali supportano la teoria:

la labirintectomia nel cane inibisce la risposta emetica ad alcune tossine

Teoria del conflitto sensoriale

Conflitto sensoriale
(Reason e Brand, 1975)
(mismatch sensoriale
mismatch neurale
riarrangiamento sensoriale)

Input conflittuali processati da un sistema sensoriale multimodale

Conflitto intrasensoriale (interazione canalare-otolitica) o intersensoriale (interazione visuo-vestibolare)

MS si sviluppa se gli input sensoriali sono in conflitto tra loro o con il pattern di input atteso/previsto da precedenti esperienze

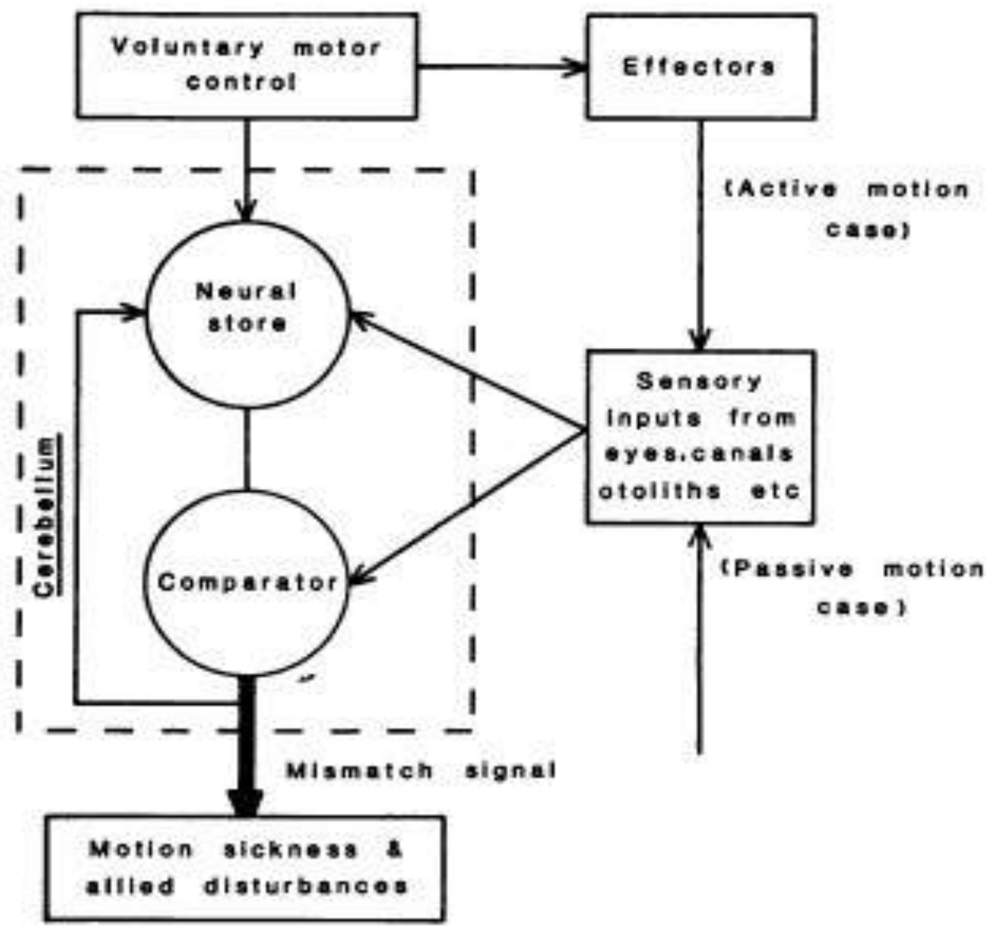


Figure 2. The basic structural components of the neural mismatch model

Da Reason, 1978

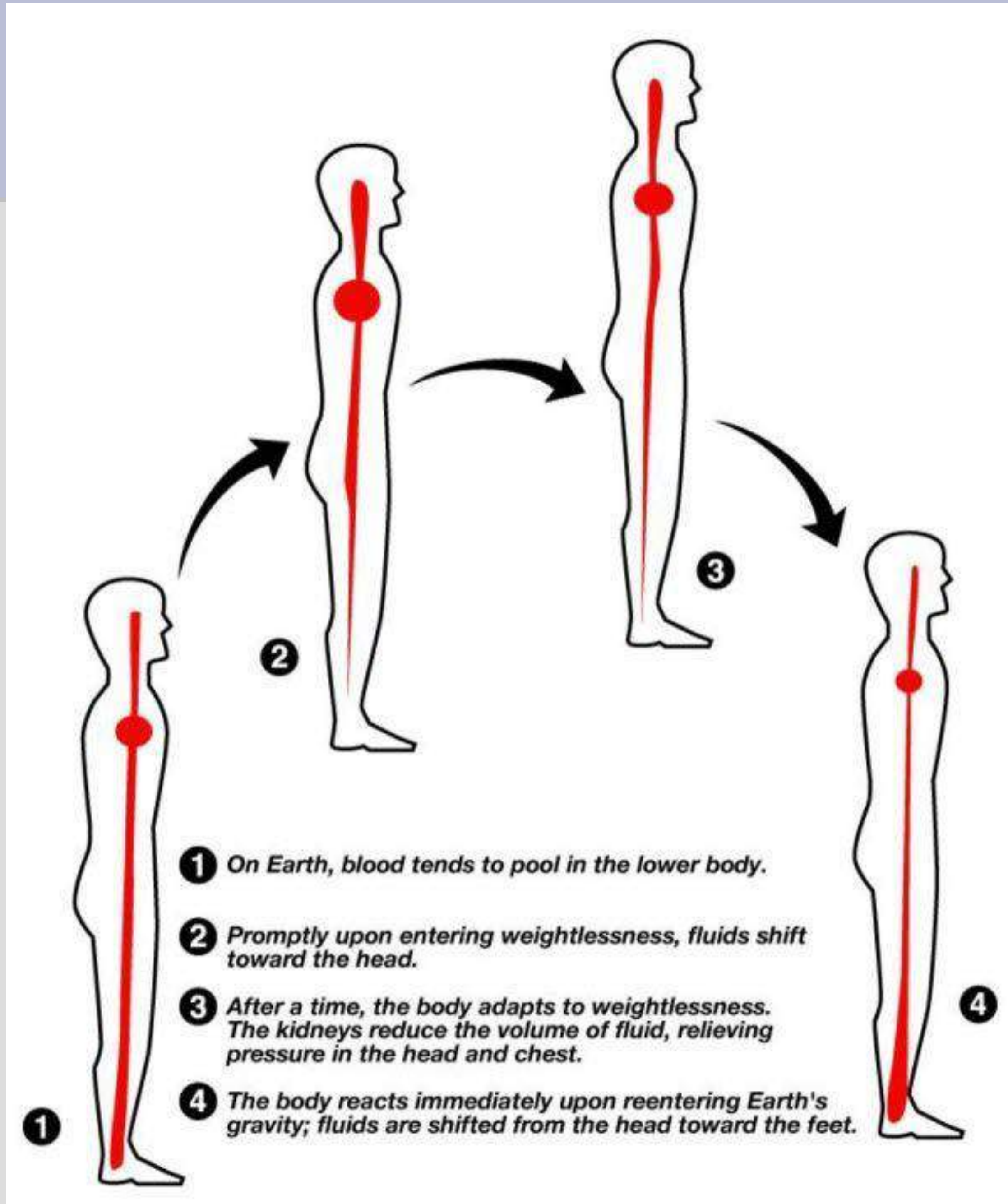
Teoria del *fluid shift*

Shift in direzione cefalica dei fluidi corporei

Espansione del volume centrale

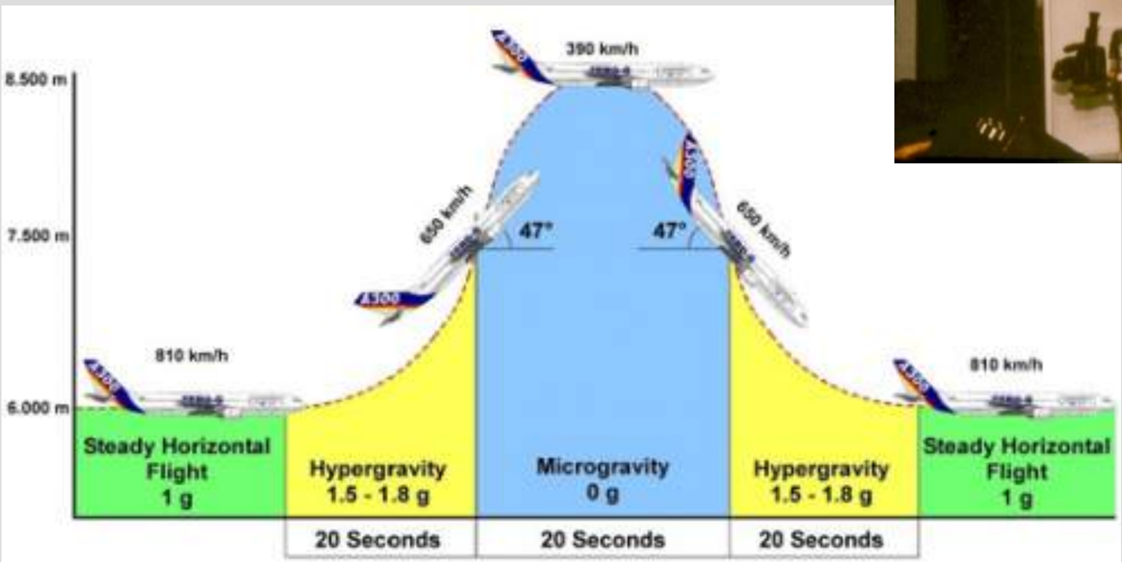
Aumento pressione intracranica

Alterata risposta recettori vestibolari



Teoria dell'asimmetria otolitica

Voli parabolici (0 g)



Teoria dell'asimmetria otolitica

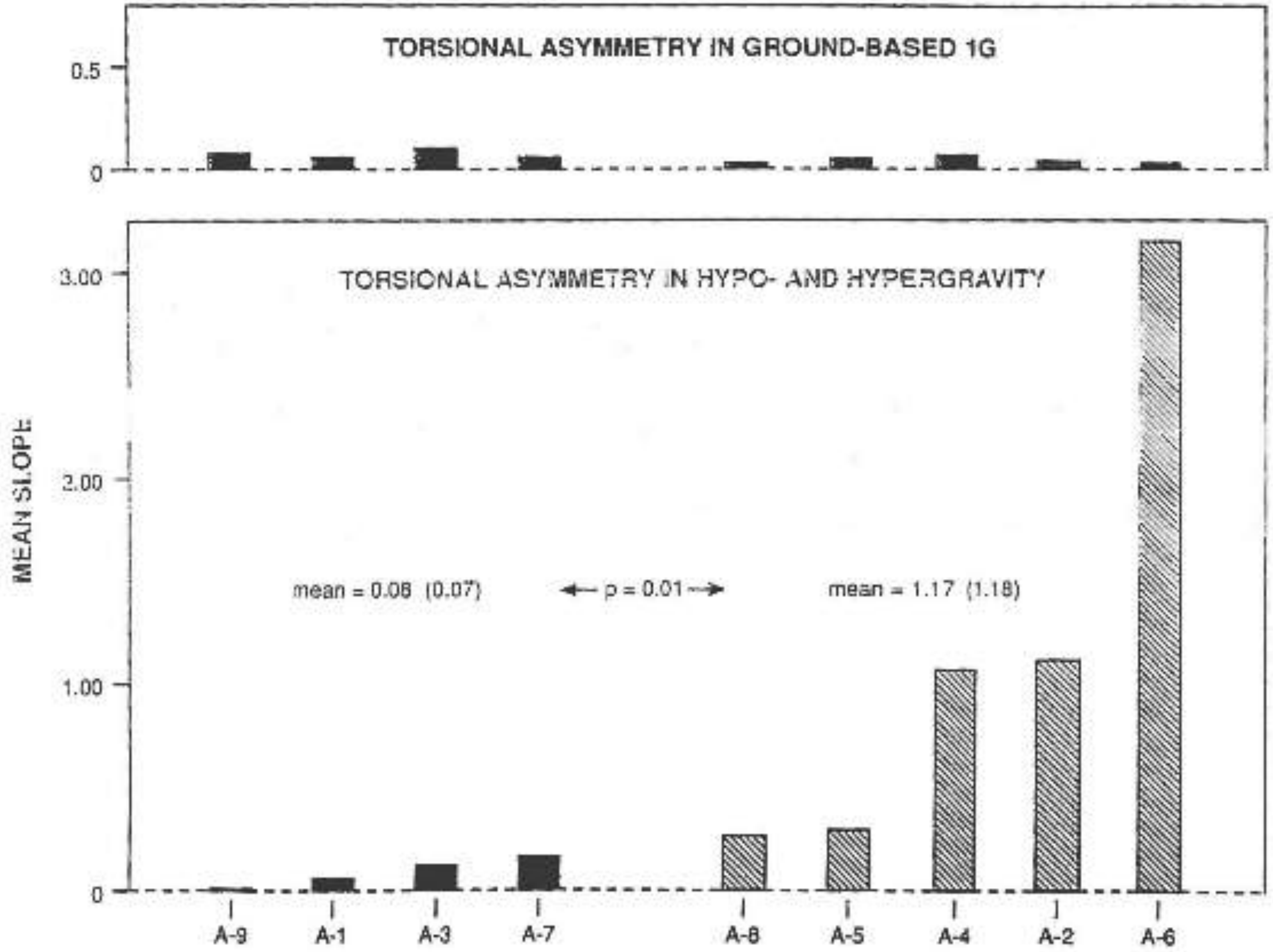


Figure 2. The top portion shows the 1 *G* disconjugate eye torsion scores of 9 astronauts. There were no differences between the subjects; all had low scores. The lower portion depicts the inflight scores. The 4 astronauts with the lowest scores of torsional asymmetry in the hypogravity and hypergravity on the KC-135 (shown with black bars) did not get sick in space. The 5 astronauts with the highest scores (gray bars) are those who had SMS during their space missions. Torsional asymmetry scores on the KC-135 differed significantly ($p = 0.01$) in the two groups. Severity of SMS was correlated with torsional asymmetry scores.

Da Diamond e Markham, 1992

Teoria dell’asimmetria otolitica

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Life Sci Space Res. 1979;17:161-70.

A model for vestibular function in altered gravitational states.

von Baumgarten RJ[1], Thumler R.

⊕ **Author information**

Abstract

During evolution, the vestibular organ was made to serve mainly two purposes: 1) to guide eye movements during sharp turns, so that the point of fixation in the visual field can be kept steady, a function accomplished by the semicircular canal system and 2) to indicate the terrestrial vertical, so that upright posture and gait can be maintained even in the dark. The otolith system serves the latter purpose. Since the function of the semicircular canal system does not depend on gravity, it is not grossly disturbed by gravitational levels different from 1 g. The proper function of the otolith system depends entirely on the presence of a gravitational force vector of 9.8/m/sec2 directed towards the center of the earth. This system therefore malfunctions when the amplitude of the combined gravito-inertial load is different from 1 g and also when the direction of the sensed gravitational pull is "contaminated" by additional inertial reactive forces as during horizontal acceleration. The effect of such inertial stimulations is probably even stronger in a weightless environment, in which case the background stimulation of terrestrial gravity is absent. Moreover, minor mass differences between the otolithic membranes of the left and right inner ear, even if well compensated on the ground, might lead to malcompensation in weightlessness as well as in hypergravity. A hypothetical model is developed to describe in the central nervous system compensating mechanisms in hypo- and hypergravitational states. The "space-sled" is introduced as a new research tool and recommendations are made for a prophylactic training regimen to reduce or prevent space sickness.

PMID: 12008702

[Indexed for MEDLINE]

Teoria dell’asimmetria otolitica

ELSEVIER

Advances in Space Research

Volume 30, Issue 4, 2002, Pages 835-841

Effects of altered gravity on the swimming behaviour of fish

R. Hilbig, R.H. Anken, G. Sonntag, S. Höhne, J. Henneberg, N. Kretschmer, H. Rahmann

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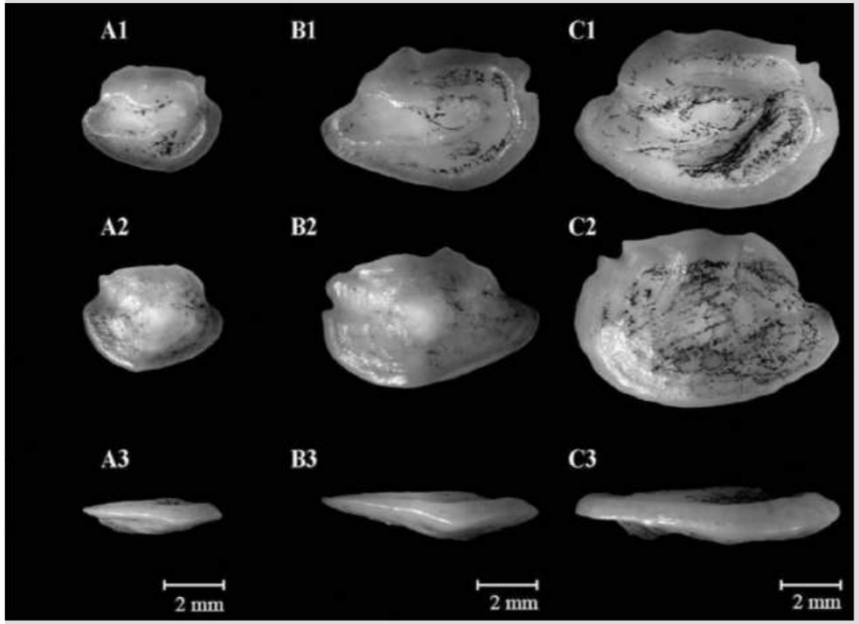
https://doi.org/10.1016/S0273-1177(01)00641-X

Abstract

Humans taking part in parabolic aircraft flights (PAFs) may suffer from space motion sickness-phenomena (SMS, a kinetosis). It has been argued that SMS during PAFs might not be based on microgravity alone but rather on changing accelerations from 0g to 2g. We test here the hypothesis that PAF-induced kinetosis is based on asymmetric statoliths (i.e., differently weighed statoliths on the right and the left side of the head), with asymmetric inputs to the brain being disclosed at microgravity.

Since fish frequently reveal kinetotic behaviour during PAFs (especially so-called spinning movements and looping responses), we investigated (1) whether or not kinetotically swimming fish at microgravity would have a pronounced inner ear otolith asymmetry and (2) whether or not slow translational and continuously changing linear (vertical) acceleration on ground induced kinetosis. These latter accelerations were applied using a specially developed parabel-animal-container (PAC) to stimulate the cupular organs.

The results suggest that the fish tested on ground can counter changing accelerations successfully without revealing kinetotic swimming patterns. Kinetosis could only be induced by PAFs. This finding suggests that it is indeed microgravity rather than changing accelerations, which induces kinetosis. Moreover, we demonstrate that fish swimming kinetotically during PAFs correlates with a higher otolith asymmetry in comparison to normally behaving animals in PAFs.



Otolith Tilt-Translation Reinterpretation (OTTR)

Aviat Space Environ Med. 1985 Jun;56(6):601-6.

Otolith tilt-translation reinterpretation following prolonged weightlessness: implications for preflight training.

Parker DE, Reschke MF, Arrott AP, Homick JL, Lichtenberg BK.

J Vestib Res. 2003;13(4-6):309-20.

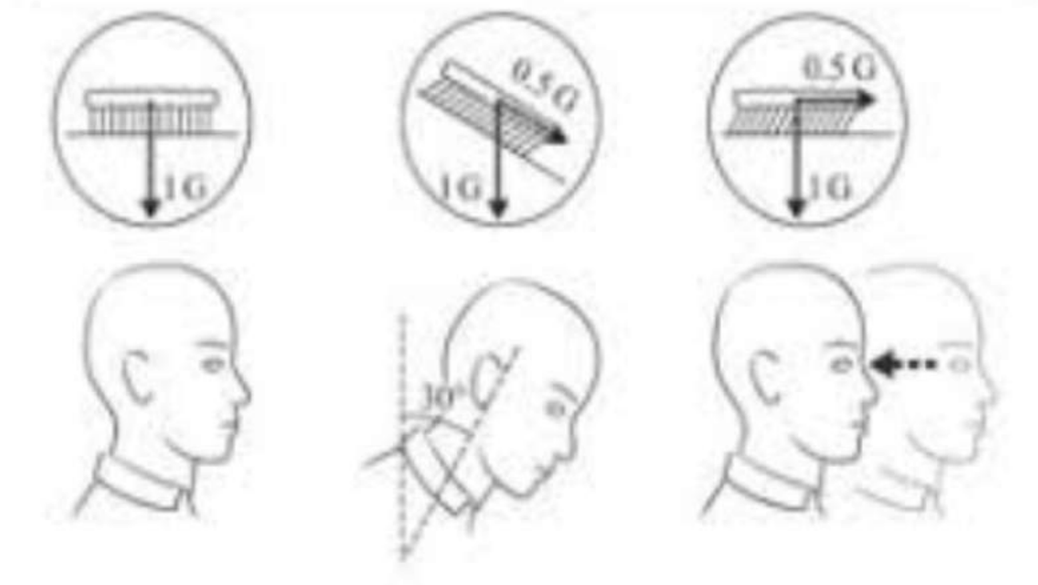
Rotation otolith tilt-translation reinterpretation (ROTTR) hypothesis: a new hypothesis to explain neurovestibular spaceflight adaptation.

Merfeld DM.

Jenks Vestibular Physiology Laboratory, Massachusetts Eye and Ear Infirmary, USA.
dan_merfeld@meei.harvard.edu

Otolith Tilt-Translation Reinterpretation (OTTR)

Ambiguità dei recettori otolitici



Otolith Tilt-Translation Reinterpretation (OTTR)

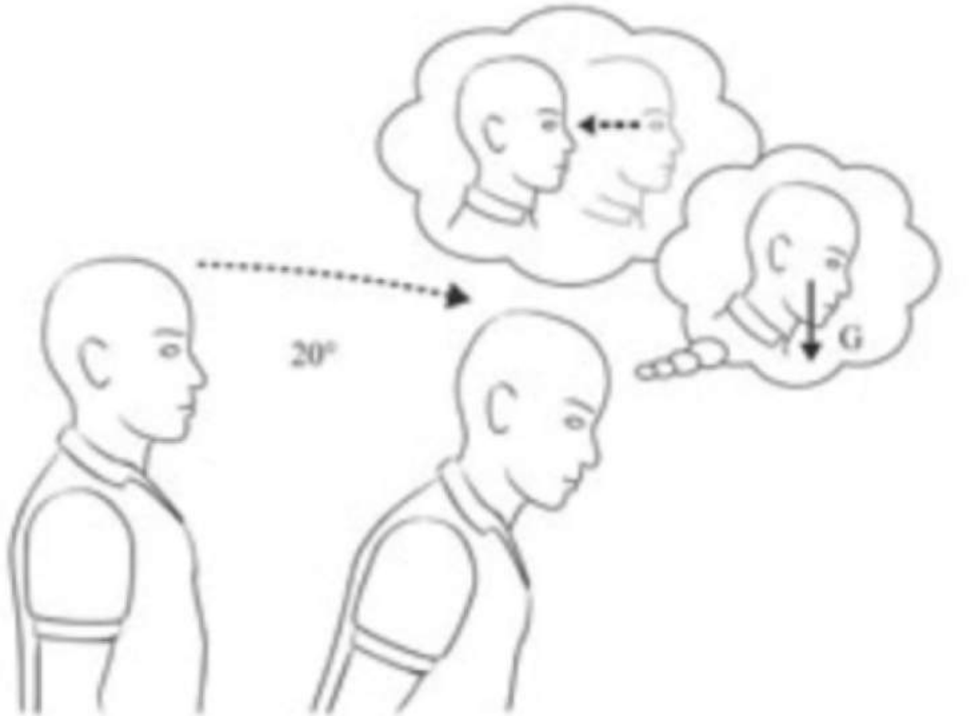


Figure 2. *In microgravity, the otolith organs are stimulated by head translation, but not by head tilt. Consequently, it is hypothesized that, after a period of adaptation, the brain reinterprets all otolith signals as signaling head translation. According to this hypothesis, on return to Earth, a static tilt of the head relative to gravity could be perceived as an actual tilt or a translation in the opposite direction. Drawing Philippe Tauzin, SCOM, Toulouse.*

Trattamento farmacologico SMS

- **Prometazina** (supposte e compresse da 25 mg, fiale i.m. da 50 mg)
- “Scop/dex” (compresse con scopolamina 0,4 mg + d-amfetamina 5 mg)

  Effetto rebound alla sospensione

- D-amfetamina (compresse da 5 mg)

Prevenzione SMS

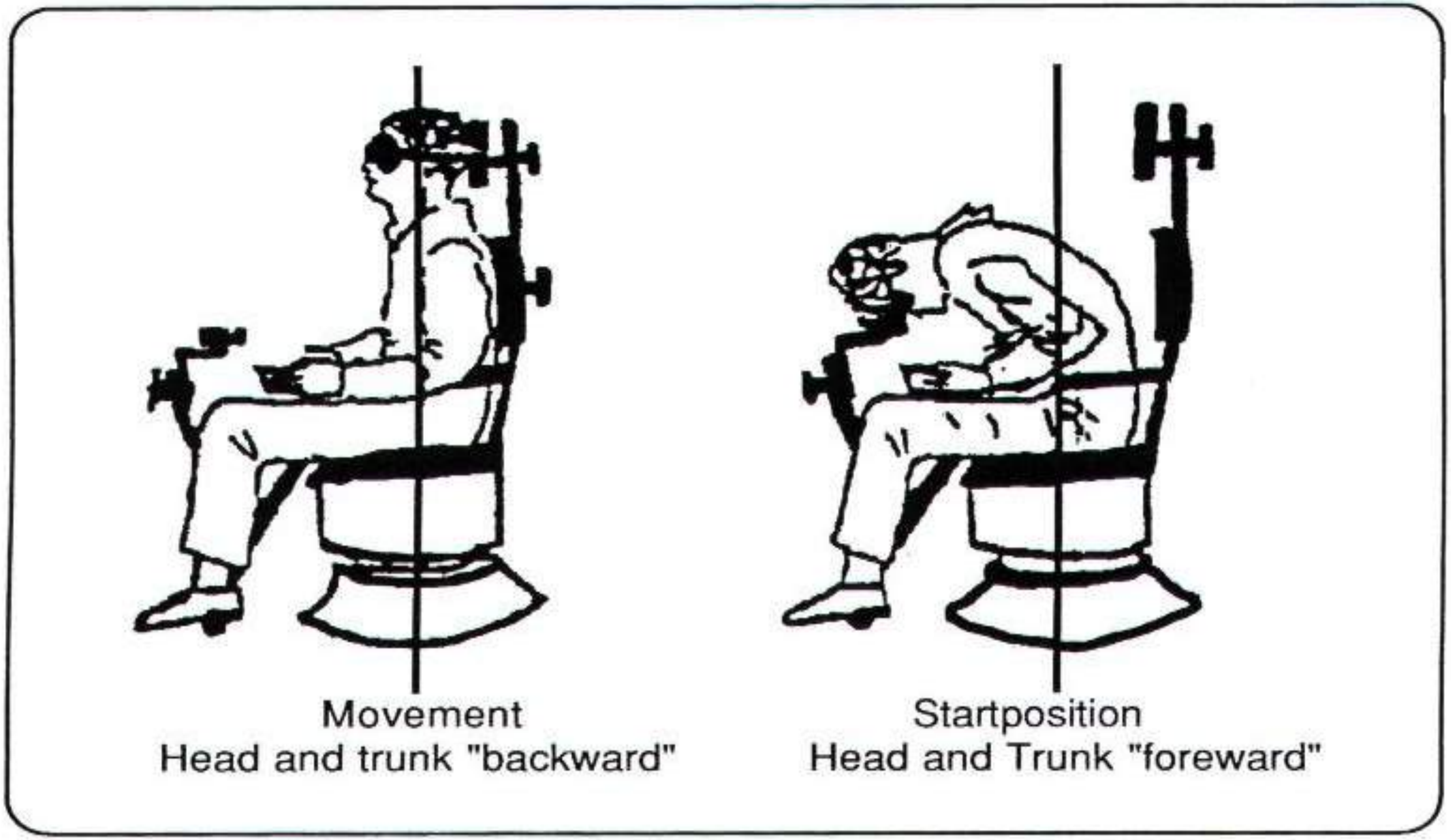
- **Selezione**

  Problema correlazione tra suscettibilità a MS ed a SMS
  - Anamnesi per MS (questionari)
  - Test provocativi: valutazione suscettibilità a MS sperimentale (es.: test di Coriolis)
  - Prospettive: -esame torsione oculare in voli parabolici

    -suscettibilità a MS indotta in centrifuga umana (>1 g)?

- **Addestramento**
  - Adattamento a stimoli provocativi (training vestibolare, uso di speciali simulatori)
  - Apprendimento di tecniche di controllo delle risposte del SNA (biofeedback, training autogeno)

Coriolis Stress Test



Movement pattern during Coriolis Stress Test

Training Vestibolare

Preflight Adaptation Training (PAT)

Device for Orientation and Motion Environments (DOME)

Tilt-Translation Device (TTD)

STS-9 Spacelab 1

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Adv Space Res. 1984;4(10):3-9.

The European vestibular experiments in Spacelab-1.

Kass J[1], von Baumgarten R, Benson A, Berthoz A, Brandt Th, Brand U, Bruzek W, Dichgans J, Probst Th, Scherer H, Vieville Th, Vogel H, Wetzig J.

⊕ **Author information**

Abstract

A series of experiments were performed in the Spacelab-1 mission on November/December, 1983, pre-, in-, and postflight. These experiments covered various aspects of the functions of the vestibular system, the inflight tests comprising threshold measurements for linear movements in three orthogonal axes, optokinetic stimulation, vestibulo-ocular reflexes under linear and angular accelerations, caloric stimulation with and without linear accelerations; pre- and postflight tests repeated the inflight protocol with the addition of subjective vertical and eye counter-rotation measurements using a tilt table. One of the most surprising and significant results was the caloric test: strong caloric nystagmus on the two subjects tested was recorded inflight; this was contrary to what was expected from Barany's convection hypothesis for caloric nystagmus.

Nistagmo calorico a 0 g

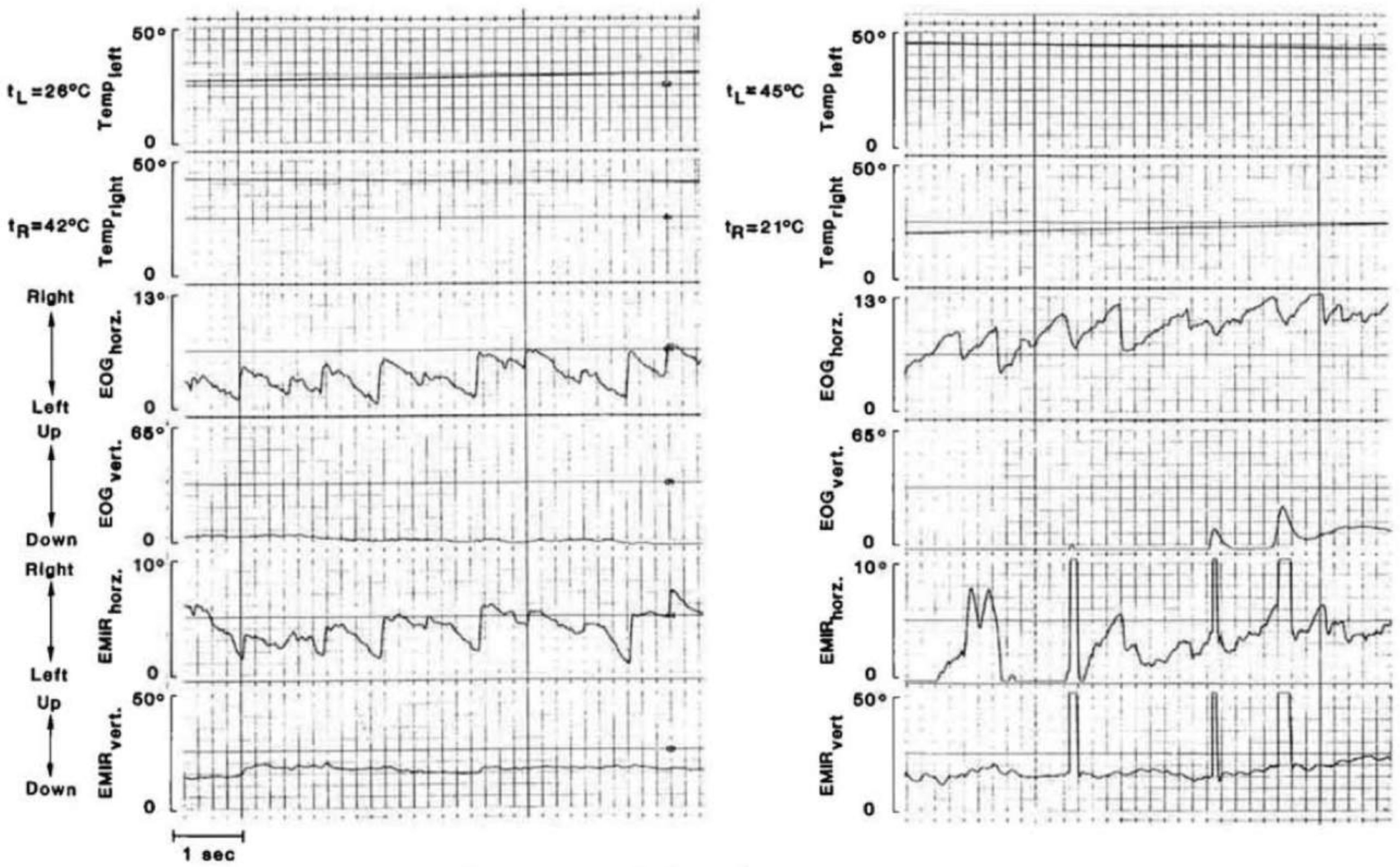


Fig. 1. Effect of inflight caloric stimulation of subject C on day 7.

R. von Baumgarten et al., Science, 1984

CALORIC NYSTAGMUS IN MICROGRAVITY

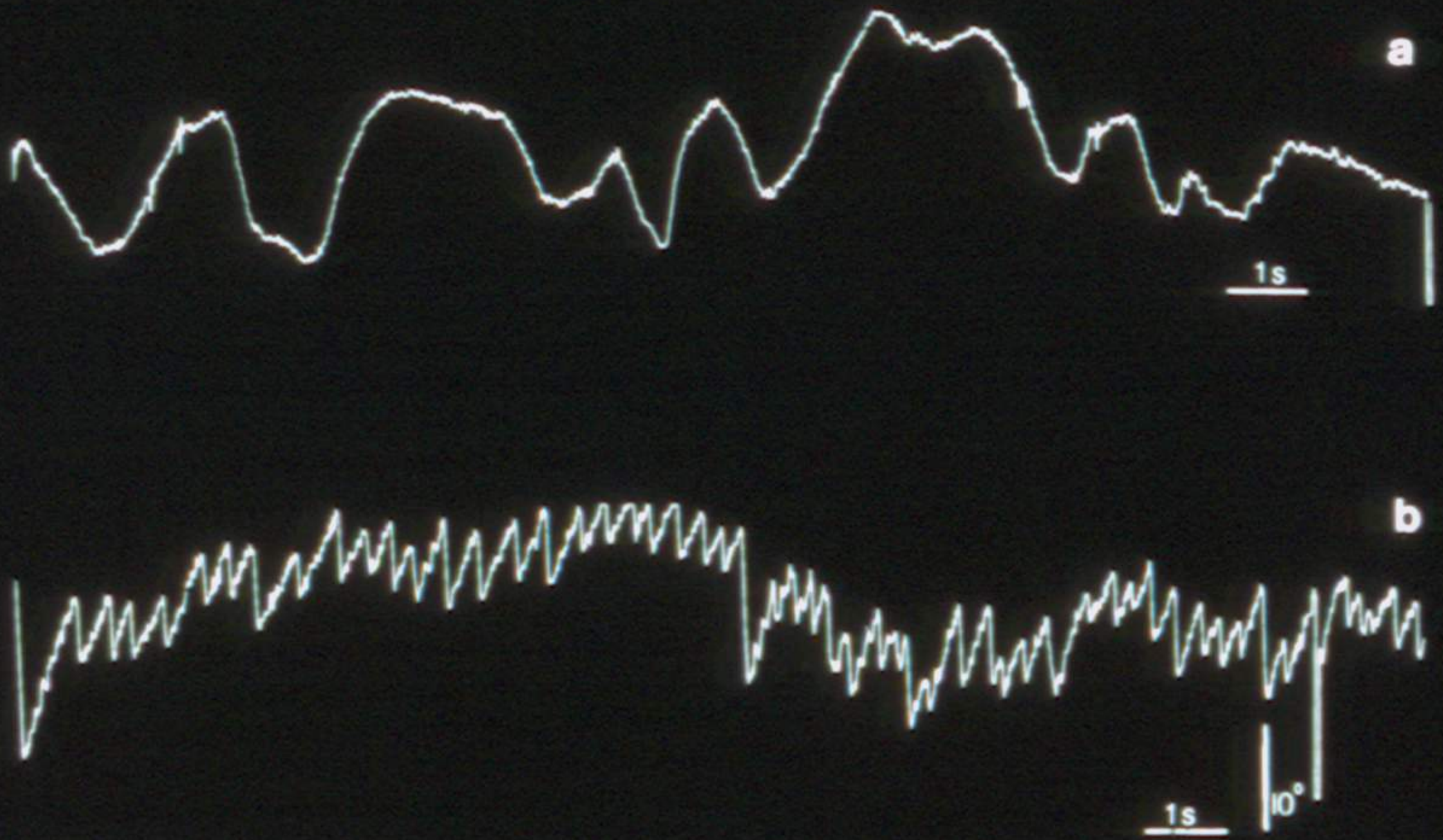


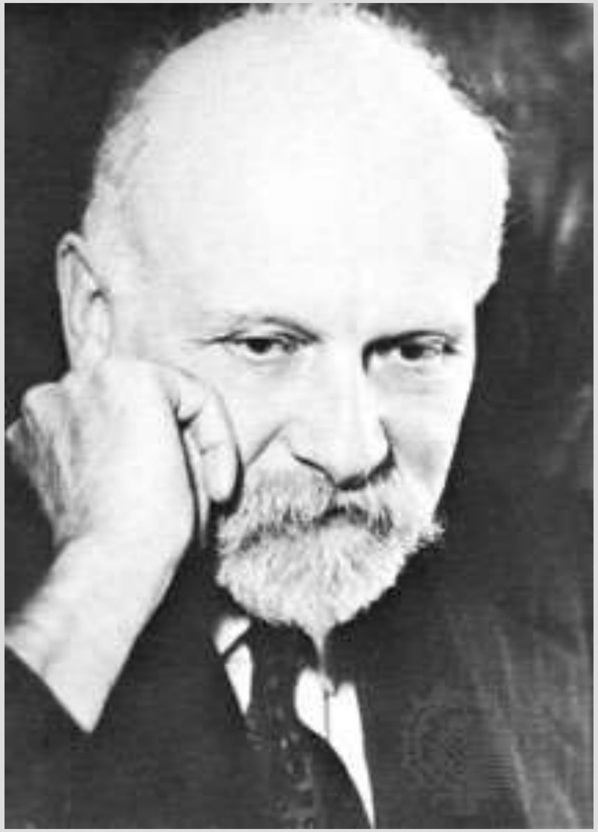
FIG. 2. Subject D: Examples of recorded horizontal eye movements. **(a)** In-flight F0, stimulus 44°R 20°L. **(b)** In-flight F8, stimulus 15°R 44°L. The extracts are taken from the digital video eye image processor.

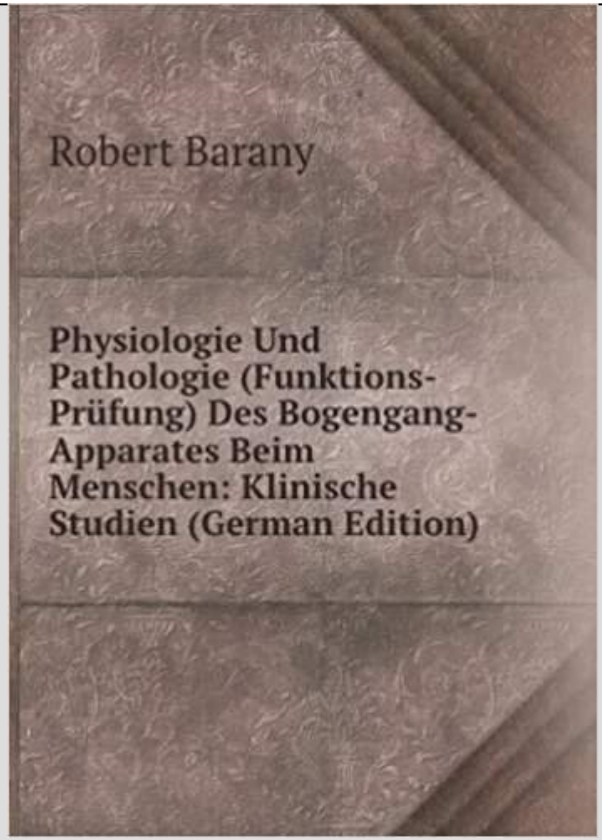
Robert Bárány

The Nobel Prize in Physiology or Medicine 1914

Robert Bárány

"for his work on the physiology and pathology of the vestibular apparatus"





Nistagmo calorico

- I meccanismi termoconvettivi che causano correnti endolinfatiche non sono gli unici meccanismi alla base del nistagmo calorico.
- Altri meccanismi non termoconvettivi ipotizzati:

<u>alterazioni endolinfatiche idrodinamiche</u>
(spostamenti di endolinfa per cambiamenti di densità/volume mediati da cambiamenti di temperatura)

<u>alterazioni endolinfatiche idrostatiche</u>
(cambiamenti di pressione idrostatica nel sistema perilinfa-endolinfa per cambiamenti di temperatura)

<u>effetto termico diretto sulle terminazioni del nervo vestibolare e sulle cellule ciliate</u>

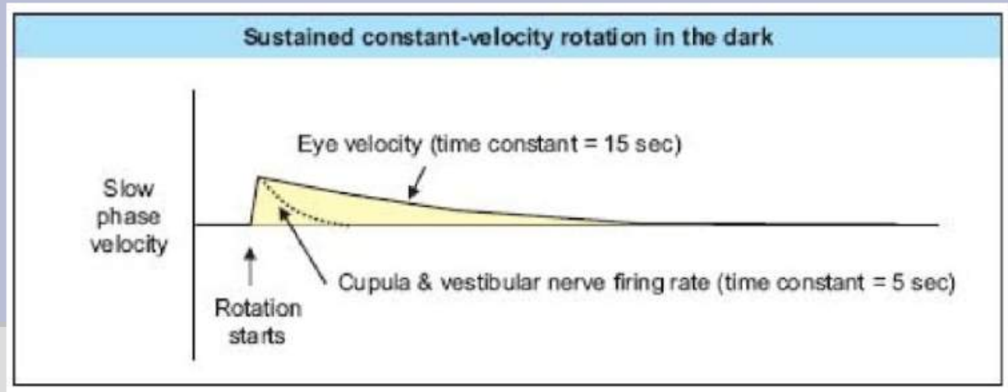
VOR a 0 g

Usa informazioni provenienti dai canali semicircolari e dagli otoliti

In microgravità i segnali otolitici sono alterati, ma non quelli canalari

Il contributo relativo degli otoliti e dei canali semi-circolari nel VOR può essere determinato solo in assenza di gravità

VOR a 0 g



Riduzione precoce del gain (a 0.25 Hz) nel volo orbitale (alla 6^ ora della missione) con successiva normalizzazione dopo alcuni giorni

Riduzione Time Constant (TC) del ny post-rotatorio durante - e per alcuni giorni dopo – il volo orbitale, con gain inalterato

Riduzione gain/TC (dumping) del VOR a 0 G:

- soppressione input vestibolare per superare il conflitto sensoriale
- riduzione del “velocity storage” per rafforzare gli input visivi

VOR a 0 g

Gli astronauti si adattano a 0 G con diversa prontezza:

- alcuni mostrano una TC del VOR uguale o più lunga (122%) di quella pre-volo dopo 4-10 giorni in orbita

- altri mostrano una TC accorciata (69% del valore pre-volo) nello stesso periodo di tempo in orbita

Questa duplice risposta adattativa del VOR (rapido/lento recupero della TC a 0 G) si correlerebbe con l'esperienza del volo orbitale (lento recupero in chi ha già volato nello spazio)

MECCANISMI PER L'ORIENTAMENTO IN ASSENZA DI GRAVITA'

Gli astronauti, in base ai meccanismi sensoriali adottati a fini di orientamento nell'adattamento all'assenza di gravità, si possono distinguere in due categorie:

- **VS ("visuo-spatial")**
- **IZ ("internal z-axis")**

I soggetti VS sviluppano una forte campo-dipendenza, utilizzando prevalentemente i riferimenti visivi (le caratteristiche del veicolo spaziale). Possono accusare fastidi o sintomi di SMS vedendo oggetti con orientamento spaziale insolito (es.: un altro astronauta "a testa in giù")

I soggetti IZ utilizzano invece prevalentemente riferimenti generati internamente - una verticale "egocentrica" (corporea) - ignorando la polarità dell'informazione visiva.

ILLUSIONI NEL VOLO SPAZIALE

DI ORIENTAMENTO *(in volo)*

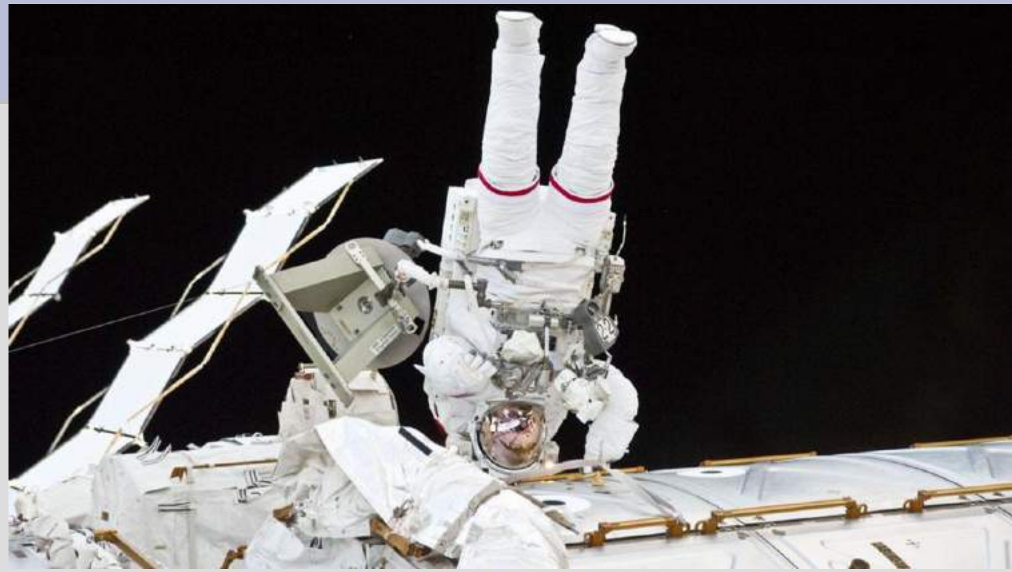
- illusione di inversione
- “the downs”

VISIVE *(in volo, al rientro, post-volo)*

- oscillopsia
- illusioni di movimento (soggettivo/oggettivo)

PROPRIOCETTIVE *(in volo, post-volo)*

- illusioni di movimento:
    - del corpo (associate a vibrazione di muscoli)
    - dell’ambiente (associate a movimenti corporei)



Post-Flight Motion Sickness PFMS (Mal de debarquement)

ALTERAZIONI POSTURALI POST-VOLO

ATASSIA POSTURALE POST-VOLO

- instabilità in stazione eretta e deambulazione

AUMENTATA DIPENDENZA DALLA VISIONE

RECUPERO CON DINAMICA BIMODALE

- più rapido in veterani vs. “*rookies*”

IMPATTO OPERAZIONALE

- evacuazione d’emergenza a terra (Shuttle)
- deambulazione sul suolo di Marte (0.38 g)

Locomozione umana in subgravità

Human Locomotion in Subgravity

R. MARGARIA, and G. A. CAVAGNA

ABSTRACT

The validity of experimental models simulating subgravity on earth is discussed. The mechanical characteristics of human locomotion in subgravity are perhaps better described by extrapolating data obtained at $g = 1$.

Walking at $g = 1$ muscular energy is utilized substantially to lift the body (increase of potential energy) while the forward acceleration (increase of kinetic energy) is obtained mainly through the transformation of the potential energy into kinetic in the second phase of the step; kinetic and potential energy levels are thus mainly in phase opposition.

The shift from walking to running takes place at a critical speed, 8.5 km/hr at 1 g, at which the changes of kinetic energy attain too high a value to be sustained only by the changes of the potential energy which are necessarily limited. For a higher speed to be attained the forward acceleration must be sustained directly by the muscular push, at the initial phase of the step; this involves a simultaneous increase of both potential and kinetic energy: in running, therefore, kinetic and potential energies are substantially in phase.

This investigation was supported by a grant from the Italian National Research Council.

From the Istituto di Fisiologia Umana, Università di Milano, Milano, Italy.

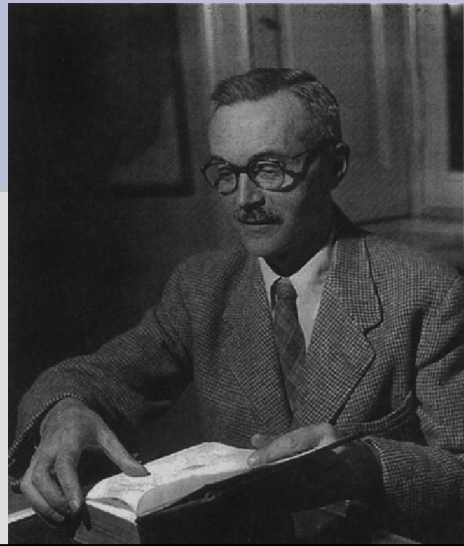
Walking in subgravity, the lift of the body in the first phase of the step requires less energy: correspondingly less potential energy is available to sustain the forward acceleration of the body in the second phase of the step, and the critical speed at which walking is shifted to running will be correspondingly lower than on the earth. In gravity conditions such as the moon (0.16 g) walking should be practically impossible.

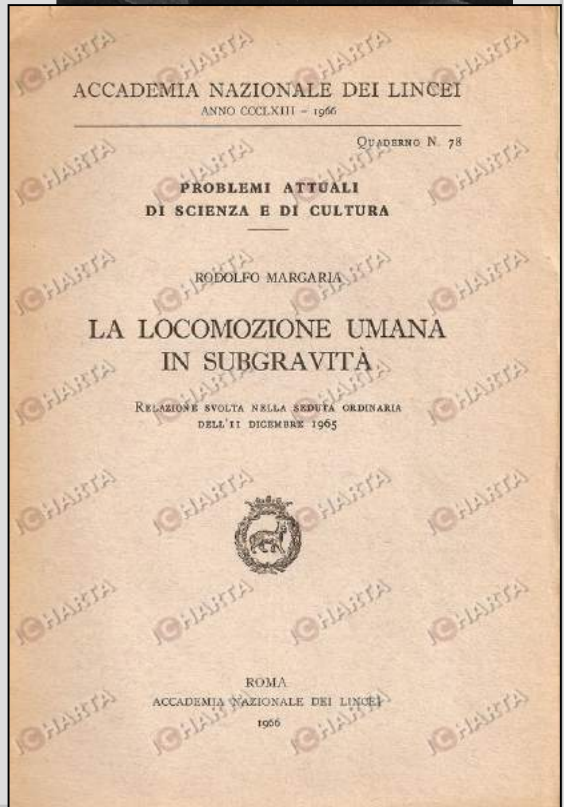
Also maximal speed of running is lower on the moon because, for the lower weight of the subject, the vertical component of the force may be too low to maintain the adherence of the foot on the ground and prevent skidding; this depends on the conditions of the soil: if this is hard, a maximal speed of running of about 13 km/hr can be achieved, if it is covered by a deep layer of dust, the maximal speed will be about 5 km/hr.

A higher speed of progression can be obtained by recurring to another mechanism, namely jumping, which involves a higher vertical component of the push exerted by the limb and obviously a decrease of the frequency of the steps, because of the increased parabula time. Through jumping, similar or higher speed of locomotion as on earth, can possibly be obtained on the moon, depending on the structure of the soil.

The possible utilization of the elastic energy of the contracted muscle is discussed: this, running on earth, is responsible for the 40 per cent of the work performed.

Due to the lower step frequency, the acceleration at the




ACCADEMIA NAZIONALE DEI LINCEI
ANNO CCCLXIII – 1966

QUADERNO N. 78

PROBLEMI ATTUALI
DI SCIENZA E DI CULTURA

RODOLFO MARGARIA

LA LOCOMOZIONE UMANA
IN SUBGRAVITÀ

RELAZIONE SVOLTA NELLA SEDUTA ORDINARIA
DELL'11 DICEMBRE 1965

ROMA
ACCADEMIA NAZIONALE DEI LINCEI
1966

Locomozione umana sulla Luna (0.16 g)

ASPETTI DA CHIARIRE IN ULTERIORI RICERCHE

- l’esatta **caratterizzazione quali-quantitativa e la dinamica temporale delle variazioni del VOR e di altri riflessi oculomotori** durante e dopo esposizione a 0 g
- il possibile **ruolo del sistema vestibolare efferente nel processo di adattamento alla microgravità** e nelle apparenti alterazioni della costante di tempo a livello vestibolare periferico
- **come e perché viene mantenuta, pur in misura variabile, una verticale corporea di riferimento (egocentrica)** e se anch’essa è comunque suscettibile di cambiamenti in assenza di gravità
- l'eventuale **correlazione tra le diverse strategie percettive per l’orientamento spaziale adottate in microgravità e le risposte del sistema vestibolare e/o la suscettibilità alla SMS**

ASPETTI DA CHIARIRE IN ULTERIORI RICERCHE

- se la **programmazione motoria nella stazione eretta e nella deambulazione** sia **memorizzata o** venga **riappresa** al ritorno dal volo spaziale
- il **ruolo specifico degli otoliti**, ed in particolare della supposta reinterpretazione dei segnali otolitici come traslazione invece che come inclinazione (OTTR), **nelle alterazioni posturali post-volo**
- il **ruolo delle alterazioni muscolari (atrofia) e cardiovascolari (ipotensione ortostatica**), in aggiunta a quelle vestibolari, **nei disturbi posturali post-volo**


Grazie per l’attenzione