Walking on the moon

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How do humans adapt to varying gravitational environments?
A project proposed by

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The moon, a step towards Mars …but also an interesting value for studies of the effect of gravity on life.

- International Space station: 0 g
- Moon: 1/6 g
- Mars: 1/3 g
- Earth: 1 g
The travel to the moon also provides an interesting set of varied gravity conditions

- Pre-flight: 1 g
- In-flight: 0 g
- Landing on the moon: 0.165 g
- In-flight: 0 g
- Post-flight: 1 g
Goals for « walking on the moon » project

Understand the **human adaptation** to this unusual environment and return to earth.

Contribute to **fundamental knowledge** about how gravity constrained the life of man and animals on earth.

Contribute to a better understanding of the development and **pathology** of locomotion on earth.

Design robotic **humanoids** who will walk on the moon or on other planets in purely robotic environments, or in cooperation with humans.
Earth gravity-constrained human perception and action

How to adapt to different g?
Adapted Space Perception (ASP)

Adapted Space Motion (ASM)

Cognitive control

Perception-Based Adaptation

Definition of a global reference frame (like the subjective vertical) $\rightarrow$ spatial orientation

Action-Based Adaptation

Definition of local reference frames (task-related RFs $\rightarrow$ motor control)

Sensorimotor recalibrations
Gravity sensors in humans and animals are «calibrated» to 1g
The problem of multisensory sensory integration: how to construct a coherent perception with so many sensors and reference frames?
The vestibular system
- An inertial navigation sensor
- A basic euclidian reference frame for perception of motion.

- rotations by 3 semi-circular canals
- translations and HEAD ORIENTATION by the otoliths

\[
\dot{f} = \omega \times f + \alpha - \omega \times \omega
\]

(From B. Hess and D. Angelaki 1999)
Motor strategies in humans and animals are related/constrained to a 1g environment
Gravity plays an important role in locomotion

The creation of a mobile reference frame by head stabilisation


See also Graf Vidal, erthoz Exp. Brain Res; and The head neck sensorimotor system. OUP
Does the brain model Newton’s law?

Mc Intyre, Zago, Berthoz & Lacquaniti
Nature Neurosciences 2001
A 17-day Space Shuttle Mission dedicated to the Neurosciences to celebrate the Decade of the Brain

April - May 1998
Ball Catching Experiments in 0g / 1g

Collaboration between:

Pr A. Berthoz, Dr J. Mc Intyre, Dr P. Senot

CNRS-Collège de France, Paris

Pr F. Lacquaniti, Dr M. Zago,

IRCSS Santa Lucia, University of Rome:

• Mc Intyre et al., Nat. Neurosc. (2001)
• Senot et al., J. Neurophys. (2005)
1 g-related EMG activity recorded even in 0 g

Mc Intyre et al. 2001
On the moon and Mars these internal models have to be modified.

It would be interesting to repeat these experiments on the moon to see if/how the brain adapts to 1/6 g.
Gravity-constrained human locomotion and spatial orientation
Generation and control of the locomotor pattern

- The neural control of locomotion:
  - From neuronal networks…
  - Motoneurons
  - Muscular activity
  - Legs’ movements
  - Reaction Forces
  - …to Whole body motion

- The mechanics of locomotion:
  - Pendulum-like behaviour of human walking
  - Limits of this approach

From Ivanenko YP (2006)
We propose to simplify the problem and to consider TWO main levels:

- The motor level *(stepping)*
- The formation of locomotor trajectory *(spatial navigation)*
From terrestrial locomotion...

- Neural tuning of the muscular activity
- Passive mechanics: interplay between gravity and inertia
- Optimal gaits on earth (Alexander et al. Minetti et al., since 1995)
- Control of the whole-body trajectory

Motor level
Stepping

Spatial Navigation
Trajectory
The pendulum-like human walking is a **LEARNT** process: we progressively internalize gravity and inertia in order to implement optimal gaits.

Ivanenko YP et al., J. Exp. Biol., 2004
How do we **optimize terrestrial gaits:**
Example: by benefiting from passive dynamics hence reducing
the amount of neuro-muscular activation

Since the regulation of the neuro-muscular command
is an acquired process, we can re **ADAPT** to different physical contexts
... to lunar locomotion

- Neural tuning of the muscular activity after the CNS adaptation to reduced gravity

- Mechanics: how to deal with this new gravity/inertia interplay

- Optimal gaits on moon?

What is being optimized?

Biomechanical predictions do not inform about new locomotor synergies...

The dynamic similarity hypothesis (Alexander RM, since 1970s).

Minetti AE., Nature 2001
On the moon, how do we locomote ??
Is it more appropriate/economical

to jump, to run… ?

How are new locomotor synergies implemented ?
The global and **predictive** nature of locomotor trajectory formation during a sequence of jumps

Dunbar, VieilIdent, Kerlirzin, Berthoz (2005)
Local, sequential, egocentric

Global, goal directed allocentric

Dunbar, Vieilldent, Kerlirzin, Berthoz (2005)
Post-adaptation studies...

Motor and perceptual troubles experienced by astronauts are *(behaviorally)* comparable to troubles observed in some neurological patients and in elderly people...

...countermeasures’ programs should benefit also to non-astronauts...

Future...
SPACE ADAPTATION SCHEME

Cognitive control

Perception-Based Adaptation

Definition of a global reference frame (like the subjective vertical) → spatial orientation

Adapted Space Perception
ASP

Adapted Space Motion
ASM

Action-Based Adaptation

Definition of local reference frames (task-related RFs → motor control)

Sensorimotor recalibrations
Spatial navigation in humans:
the formation of trajectories

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Spatial Navigation

**Trajectory**

How do we build a trajectory:

a succession of foot placement on the ground?
A same task « cross over a distant doorway », performed by different subjects
Variable foot placement

Stereotyped trajectories

Adaptive Behaviour Stepping

Spatial Navigation Trajectory
Problem statement

One trajectory is chosen among a lot of possible ones: why that one?

What are the invariants of the locomotor trajectories?
“Theorem”: In terrestrial environment, humans also learnt to generate optimal trajectories.

Simulation results: 90% of 1430 trajectories with error less than 10cm.

“Corollary”: Locomotor trajectories are locally made of clothoid arcs.

IEEE Transaction on Robotics (in press)
What about a lunar environment?

How to move there?

How to navigate there?

Apollo (NASA)
How to live there?

Humans in interaction with walking robots
Motion Planning and Control for humanoid robots

© LAAS-CNRS (France), AIST (Japan), Laumond JP, Yoshida E.
Human-robot interaction: how to teleoperate a robot via natural language?

Give him the Purple Ball
Joint French-Japanese Robotics Laboratory
JRL

E. Yoshida, A. Mallet, F. Lamiraux, O. Kanoun,
O. Stasse, M. Poirier, P-F. Dominey, J-P. Laumond, K. Yokoi

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Laumond JP, Mallet A, Yoshida E.
Walking on the moon: Guidelines for the future

- **Approaches**
  - Scientific studies of the role of gravity on perception and action
  - Help astronauts to adapt rapidly and perform complex tasks
  - Help develop Human-robot interfaces

- **Plans**
  - Experiments on astronauts
  - Design of a lunar-based life sciences lab.
  - Teleoperation of robots walking on the moon !!

- **Collaborations:**
  - Indispensable !!!...
Visual steering of locomotion