Human physiology during exposure to cave environment: a systematic review and potential future implications for aerospace medicine

Lucrezia Zuccarelli, L. Bessone, E. Coffey, R. Turner, G. Strapazzon

ICASM 2017, Roma, Italy
Long term goals of space agencies
Terrestrial space analogues

NEEMO
NASA Extreme Environment Mission Operations

Antarctica stations
ESA Cooperative Adventure for Valuing and Exercising human behavior and performance Skills

CAVES

Mars500 facility

EnviHab

terraXcube

Pagel et Choukèr JAP 2016
Terrestrial space analogues

- NEEMO
  NASA Extreme Environment Mission Operations
- Mars500 facility
- EnviHab
- terraXcube
- CAVES
  ESA Cooperative Adventure for Valuing and Exercising human behavior and performance Skills
- Antarctica stations

Pagel et Choukèr JAP 2016
Terrestrial space analogue

The ESA CAVES program:

- What is it?
- What do the astronauts do?
  - Cave environment
  - Relevance for the space

Strapazzon et al. WEM 2014
CAVES: training for the space
CAVES: training for the space
CAVES: training for the space
CAVES: training for the space
From the past ... to the present ...
From the past ... to the present ...

Some problems of desynchronisation of sleep-wakefulness and circadian rhythms for long duration spaceflights,

Michel SIFFRE

*Proceedings of the Space & Sea Colloquium, Paris, 24–26 September 1990, ESA SP-312*

---

**Effects of Isolation on Interferon Production and Hematological and Immunological Parameters**

GERALD SONNENFELD,1 JOHN MEASEL,2 MICHAEL R. LOKEN,3 JOSEPH DEGIOANNI,4 STEFANIA FOLLINI,5 ANDREA GALVAGNO,5 and MAURIZIO MONTALBINI5

*JOURNAL OF INTERFERON RESEARCH 2:75-81 (1992)*
Mary Ann Liebert, Inc., Publishers
Aim of the study

to systematically review the human studies associated with cave environment,
and thereby to facilitate to understand the results of studies
and to extend the results to implications
for human planetary exploration missions and space medicine
Methods

PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines: specific research question, eligibility criteria, explicit and systematic method

Methods

Studies on **acute effect** were define if the permanence in the cave was up to 72 h, whereas studies on **chronic effect** if the permanence was more than 72 h.
Classification

- Atmospheric Science
- Emergency Medicine
  - Human Factor
- Human Physiology
- Psychological Aspects
  - Radiation

NASA JSC - Medical Sciences Division. Medical Aspects of Exploration Missions
Hansen et al. Human anatomy and physiology for the European Astronaut Team
Classification

- Atmospheric Science
- Emergency Medicine
  - Human Factor
  - Human Physiology
- Psychological Aspects
  - Radiation

NASA JSC - Medical Sciences Division. Medical Aspects of Exploration Missions
Hansen et al. Human anatomy and physiology for the European Astronaut Team
Summary of Bibliographic Research

PRISMA 2009 Flow Diagram

- **Identification**
  - Literature search
    - Database searching: Pubmed, Medline, Worldcat, OPAC, Nasa TRS

- **Screening**
  - Records after duplicates removed
    - (n = 2,097)

- **Eligibility**
  - Article screened on bias of title and abstract
    - (n = 156)
    - Records excluded
      - (n = 1,941)
      - Microbiology
      - Animal-related
      - Geology
  - Full-text articles assessed for eligibility
    - (n = 37)
    - Full-text articles excluded, with reasons
      - (n = 8)

- **Included**
  - Studies included in qualitative synthesis
    - (n = 29)
Results

Acute effects (<72 h): 12 published between 1994 and 2017 and included a total of 130 subjects, all performing exercise in different cave/lab study setting.

Chronic effects (>72 h): 17 published between 1963 and 2010 and included a total of 29 subjects, all except one exposed to cave environment for more than 30 days.
Results – Acute studies
Results – Acute studies

CAVING PHYSIOLOGICAL RESPONSES

HORMONAL
- GH, CORTISOL, FT4, FT3, TSH
  - Cortisol peak before entering, rise in GH, FT4 during exploration
  - marked anticipatory stress
  - great physical intensity and long duration activity
  - endurance exercise

HAEMATOLOGICAL
- RBC, Hb, MCV, PV, Hp, Platelets
  - Initial haemoconcentration, reduced PV, later haemodilution, Hp dropped with minimum level after the ascent and rise in the platelets

MUSCULAR
- CK, LDH
  - Rise in CK and LDH during exploration, peak level at the end of the ascent. High level also a few days after

CARDIOVASCULAR
- HR, BP, ECG, HRV
  - HR and BP increase before exploring and during the ascent. Reduction of HRV and a shift in the sympathetic excitation

TEMPERATURE
- Internal and external
  - Rise in temperature, in particular during the ascent

ENERGY EXPENDITURE
- METS, VO2
  - Rise in METs and Kcal/h during caving

VISUAL FUNCTION
- Visual acuity, visual symptoms
  - Blurry vision and visual irritability
  - Not visual pathologies in cave environment

- Moderate physical activity
  - Very strenuous sport with possible transpiration problem
  - Ascent much more difficult

- Anticipatory stress
  - Not dangerous limits
  - Intensive and traumatic sport with muscle damage
  - Ascent much more difficult

- Heavy exercise
  - Local inflammation

- Marked anticipatory stress
  - Great physical intensity and long duration activity
  - Endurance exercise
Results – Acute studies

CAVING PHYSIOLOGICAL RESPONSES

**HORMONAL**
- GH, CORTISOL, FT4, FT3, TSH
- Initial haemoconcentration, reduced PV, later hemodilution, Hp dropped with minimum level after the ascent and rise in the platelets
- Cortisol peak before entering, rise in GH, FT4 during exploration
- Marked anticipatory stress
- Great physical intensity and long duration activity
- Endurance exercise

**HAEMATOLOGICAL**
- RBC, Hb, MCV, PV, Hp, Platelets
- Rise in CK and LDH during exploration, peak level at the end of the ascent. High level also the days after
- Intensive and traumatic sport with muscle damage
- Anticipatory stress
- Not dangerous limits

**MUSCULAR**
- CK, LDH
- HR and BP increase before exploring and during the ascent.
- Reduction of HRV and a shift in the sympathetic excitation
- Anticipatory stress
- Very strenuous sport with possible transpiration problem
- Moderate physical activity

**CARDIOVASCULAR**
- HR, BP, ECG, HRV
- Rise in temperature, in particular during the ascent
- Not visual pathologies in cave environment
- Blurry vision and visual irritability

**TEMPERATURE**
- Rise in MEtS and Kcal/h during caving
- Rise in temperature, in particular during the ascent

**ENERGY EXPENDITURE**
- Blurry vision and visual irritability

**VISUAL FUNCTION**
- Visual acuity, visual symptoms
Results – Acute studies

Main scientific challenges:

- Small sample size number
- Same subjects in different studies
- Lack of multidisciplinary approach
- Different study protocols (e.g., time, distance, temperature, exercise, training level)
Results – Chronic studies

360 days of isolation-Lunar cave habitat
Results – Chronic studies

CAVING PHYSIOLOGICAL RESPONSES

- SLEEP-WAKEFULNESS RHYTHM
  - WAKENING TO WAKENING CYCLE
    - Desynchronized, with a period somewhat longer than 49 hrs
  - HAEMATOLOGICAL RHYTHM
    - RBC, Hb, HCT, MCV, WBC, Plateles, IFNy, NK
  - RENAL RHYTHM
    - NaU, NaP, KU, KP, URINE VOLUME
  - CARDIOVASCULAR RHYTHM
    - HR, BP
  - TEMPERATURE RHYTHM
  - ENDOCRINE RHYTHM
  - VISUAL FUNCTION
    - 17-oHCS, MENSTRUAL CYCLES
    - VISUAL ACUITY, BINOCULAR VISION, CHROMATIC PERCEPTION

- Desynchronized with a period somewhat longer than 24 hrs
- Irregular with a period somewhat longer than 24 hrs
- Desynchronized with the period increased
- Desynchronized, with a period somewhat longer than 24.8 hrs
- Desynchronized
- Transient modification in the speed of chromatic vision and in binocular vision, altered
Main scientific challenges:

- Small sample size number
- Same subjects in different studies
- Lack of operative scenario
- Artificial environment
- Different study protocols (e.g., isolation period, light exposure, temperature, exercise, training level)
- Low paper quality
Discussion and conclusion

- Acute exposure to cave environment could offer a real operative scenario with atypical, strenuous and three dimensional human movements.

- Alterations of circadian rhythms have important and practical consequences in organizing and understanding implications of astronaut expeditionary training courses in space analogue environment taking place in underground environments.

- Future studies with new technologies are needed to better understand the physiological responses and adaptations to the cave environment.
Thanks for the attention

lucrezia.zuccarelli@ibfm.cnr.it
Future Space Analogues: Perspective research

Extend terrestrial space analogue models with dynamic environmental simulation facilities

Take lessons learned from existing programs and delve deeper into physiological mechanisms and risk reduction in potential mission scenarios

Cluster expertise regarding optimisation of physiological performance for human planetary exploration missions and space medicine