Entering weightlessness (0 G) induces immediately a shift of blood and fluid from the lower to the upper parts of the body inducing expansion of the cardiac chambers (Bungo et al. 1986; Charles & Lathers 1991; Videbaek & Norsk 1997). For many years the effects of sudden 0 G on central venous pressure (CVP) was discussed, and it puzzled researchers that CVP compared to the 1-G supine position decreased during the initial hours of spaceflight, when at the same time left atrial diameter increased (Buckey et al. 1996). By measuring esophageal pressure as an estimate of inter-pleural pressure, it was later shown that this pressure decreases more than CVP does during 0 G induced by parabolic flights (Videbaek & Norsk 1997). Thus, transmural CVP is increased, which distends the cardiac chambers. This unique lung-heart interaction whereby 1) inter-pleural pressure decreases and 2) central blood volume is expanded is unique for 0 G. Because transmural CVP is increased, stroke volume increases according to the law of Frank-Starling leading to an increase in cardiac output, which is maintained increased during months of 0 G in space to levels of some 25 % above that of the 1-G seated position (Norsk unpublished). Simultaneously, sympathetic nervous activity is at the level of the upright 1-G posture, which is difficult to explain based on the high stroke volume and decreased blood pressure and systemic vascular resistance. This paradox should be explored and the mechanisms revealed, because it might have implications for estimating the cardiovascular risk of travelling in space.

Human Cardiovascular Adaptation to Weightlessness

Peter Norsk
USRA/NASA-Johnson Space Center, Houston, Texas, USA.
<table>
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</table>
Heart rate

Systolic

Diastolic

Pre- In- Postflight

Fritsch-Yelle et al.
J. Appl. Physiol.
80:919-914, 1996.
## Background

### Short-term spaceflight (< 2 weeks):

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Cardiac output

Prisk et al.
J. Appl. Physiol.
## Background

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</table>
Mean 4-h plasma Noradrenaline (pg/ml)

* Norsk et al. J. Appl. Physiol. 78: 2253-59, 1995
Plasma Renin (pg/ml)

Norsk et al.
J. Appl. Physiol.
78: 2253-59, 1995
# Background (2):

## Long-term spaceflight (> 3 months):

<table>
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**Background (2):**

**Long-term spaceflight (> 3 months):**

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Purpose

To investigate how 24-h ambulatory blood pressure and the cardiovascular system adapt to long-term (3-6 months) space flight and thus, how the daily load of gravity here on Earth affects our ambulatory blood pressure.
Hypothesis

Despite an increase in cardiac output (CO), 24-h ambulatory brachial blood pressure (BP) is unchanged or decreased by chronic systemic arterial vasodilatation during long-term (months) space flight.
Paoli Nespoli
European Space Agency astronaut
Blood pressure
Cardiac output
Blood sample
24-h urine
Cardiac output by rebreathing Freon
Blood soluble gas
Blood insoluble gas
Oxygen

innocor™
Blood soluble gas
Blood insoluble gas
Oxygen

innocor™
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<tr>
<td>Time</td>
<td>19:55:36</td>
</tr>
<tr>
<td>Test Set</td>
<td>test3</td>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Lung Tissue Vol</td>
<td>569</td>
</tr>
<tr>
<td>Izero</td>
<td>3.27</td>
</tr>
<tr>
<td>Cardiac Output</td>
<td>5.15</td>
</tr>
<tr>
<td>Tmax</td>
<td>3.78</td>
</tr>
<tr>
<td>Tmix</td>
<td>9.78</td>
</tr>
<tr>
<td>Oxygen Consump.</td>
<td>33.7</td>
</tr>
<tr>
<td>Tend</td>
<td>20.49</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.56/min</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.06</td>
</tr>
<tr>
<td>ΔT</td>
<td>30 ms</td>
</tr>
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</table>

![Graph Image]
## Experimental protocol

**Pre-flight:** Launch minus 2 months or more  
**In-flight:** Launch + 3 to 6 months  
**Post-flight:** Landing + 2 months or more.

<table>
<thead>
<tr>
<th>Time</th>
<th>12:00</th>
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<th>20:00</th>
<th>24:00</th>
<th>04:00</th>
<th>08:00</th>
<th>12:00</th>
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<tbody>
<tr>
<td></td>
<td>14:00</td>
<td>18:00</td>
<td>22:00</td>
<td>02:00</td>
<td>06:00</td>
<td>10:00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Blood pressure: (Ambulatory)</th>
<th>X X X X X X X X X X X X X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac output: (Seated)</td>
<td>X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>Blood sampling: (Seated)</td>
<td>X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>Urine collection: (Ambulatory)</td>
<td>&gt;-----------------------------------------------------------------------&lt;</td>
</tr>
</tbody>
</table>

X: Execution.
## Experimental protocol

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**Blood pressure:**  
(Ambulatory)  
X X X X X X X X X X X X X X X X X

**Cardiac output:**  
(Seated)  
X X X X X X X

**Blood sampling:**  
(Seated)  
X

**Urine collection:**  
(ambulatory)  
>---------------------------------------------------------------<

X: Execution
Results

(N = 6 males)
24-h mean arterial pressure

mm Hg

PRE                  FLIGHT               POST

*
24-h mean arterial pressure

<table>
<thead>
<tr>
<th></th>
<th>PRE</th>
<th>FLIGHT</th>
<th>POST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>103 3</td>
<td>93 31</td>
<td>105 3</td>
</tr>
</tbody>
</table>

* Significant difference
24-h systolic arterial pressure
24-h diastolic arterial pressure
Cardiac output

PRE                          FLIGHT                        POST

L min⁻¹
Cardiac output

HR = 62.3 (bpm)

HR = 63.2 (bpm)

HR = 67.4 (bpm)
Stroke volume

ml

PRE  FLIGHT  POST
Systemic vascular resistance

PRE                          FLIGHT                        POST

mm Hg L⁻¹min

*
Systemic vascular resistance

NE = 0.72  0.17  (ng·ml⁻¹)

NE = 0.69  0.11  (ng·ml⁻¹)

NE = 0.73  0.13  (ng·ml⁻¹)
Day MAP vs. night MAP

mm Hg

<table>
<thead>
<tr>
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<th>PRE</th>
<th>FLIGHT</th>
<th>POST</th>
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<tbody>
<tr>
<td></td>
<td>100</td>
<td>100</td>
<td>120</td>
</tr>
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</table>

* denotes statistical significance.
Conclusions:

Months of space flight on the ISS:

- 24-h ambulatory BP ↓
- SV and thus CO ↑
- Systemic vascular resistance ↓
- SNA →
- Night dip of BP →
Mechanisms:

Weightlessness?
    Chronic pulsatile baroreceptor stimulation by increased central blood volume (increased SV and thus CO).
    But what about the high SNA?

Exercise training effect?
    But HR and plasma NE unchanged!

High salt intake?
    But 24-h renal Na⁺ excretion unchanged!

Other factors (radiation, oxidative stress etc.)?
Mechanisms:

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    But HR and plasma NE unchanged!

High salt intake?
    But 24-h renal Na\(^+\) excretion unchanged!

Other factors (radiation, oxidative stress etc.)?
Hypothesis:

Seated

↓

0 G

• Venous return
• Cardiac output

↑

Central blood volume

↑

Natriuretic & vasodilatory peptides

↑

Vascular distension of upper body

(-)

SVR

(-)

Blood pressure

(+)

SNA

• Vestibular disturbance
• Intracranial pressure
• Aortic stiffness
• Stress

Norsk & Christensen
Gravity effects:

- Blood pressure: 100 mm Hg, 80 mm Hg, 215 mm Hg

A mechanism for hypertension???
Acknowledgements:

**Co-authors**

Niels J. Christensen (Herlev Univ. Hosp., Denmark)
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Inge H. Petersen (Univ., CPH, Denmark)

**ESA assistance**

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Allain Maillet (Cadmos, CNES)
Stephanie Herr (Cadmos, CNES)
Simone Thomas (ESA)
Astronauts (ESA)

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Astronauts
Thank you