# Human Cardiovascular Adaptation to Short-term Weightlessness

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# Example of cephalad fluid shift


Pre-flight press briefing

FD-2

# Inflight: Fluid shift

## Cardiac preload:

- Central venous pressure?
- Blood volume?
- Stroke volume – cardiac output?

## Cardiac afterload:

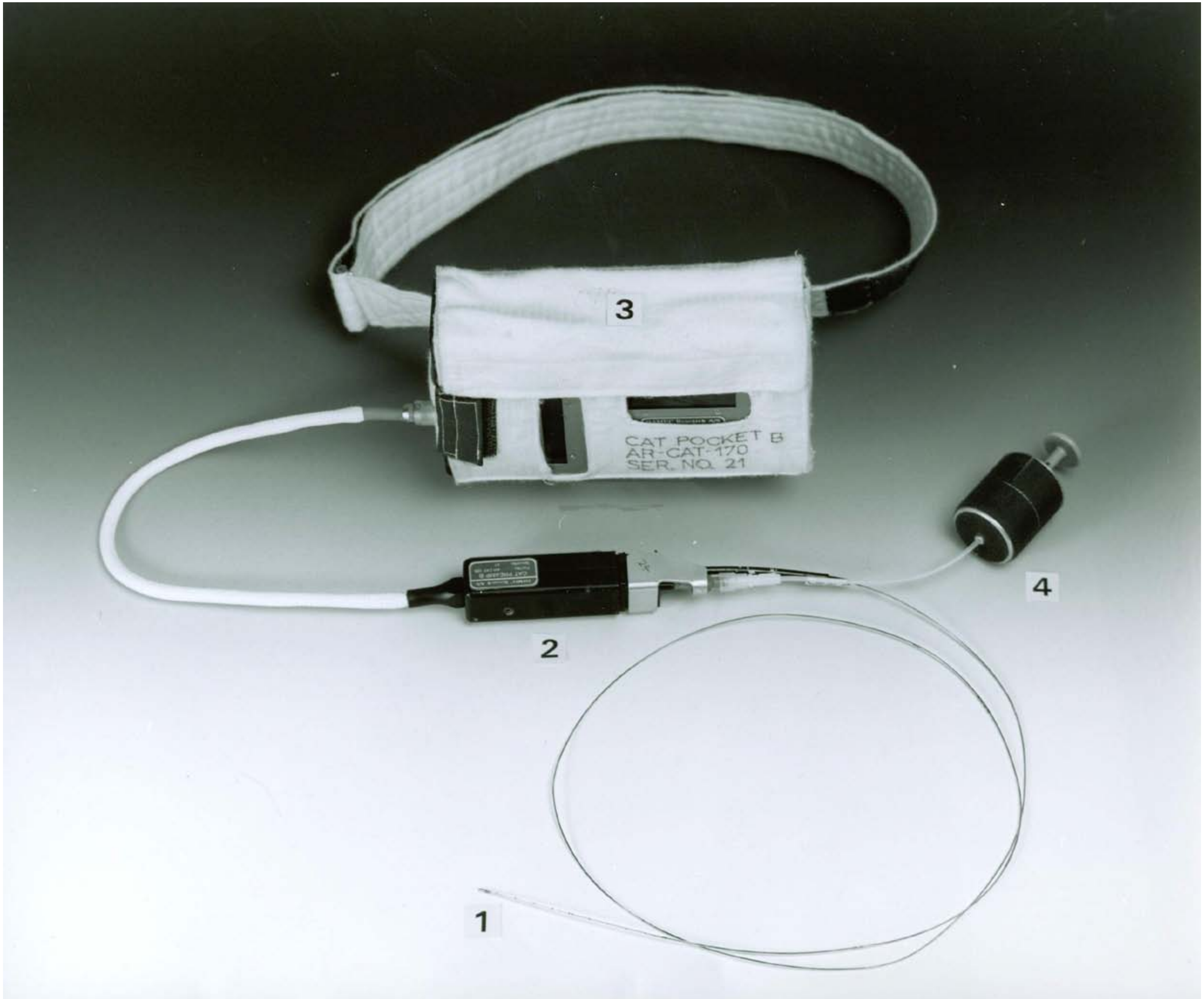
- Blood pressure
- Systemic vascular resistance
- Baroreflexes – sympathetic nervous ac.

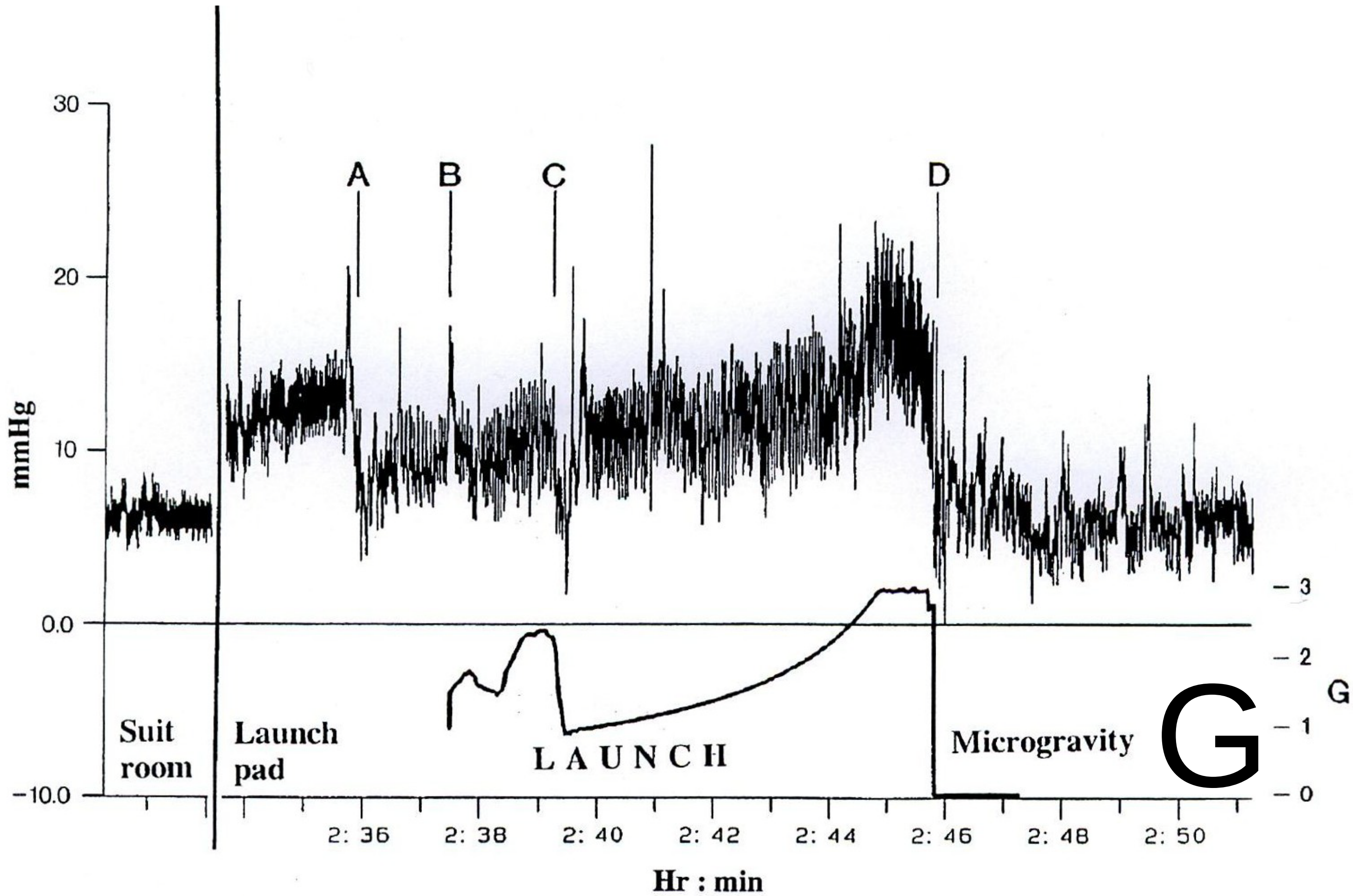
## Cardiac muscle mass

# Central venous pressure in space

| CVP (cm $H_2O$, N = 3) | Seated | Supine,legs-up | 0 G |
|---|---|---|---|
| | 8.4 | 15.0 | 2.5 |

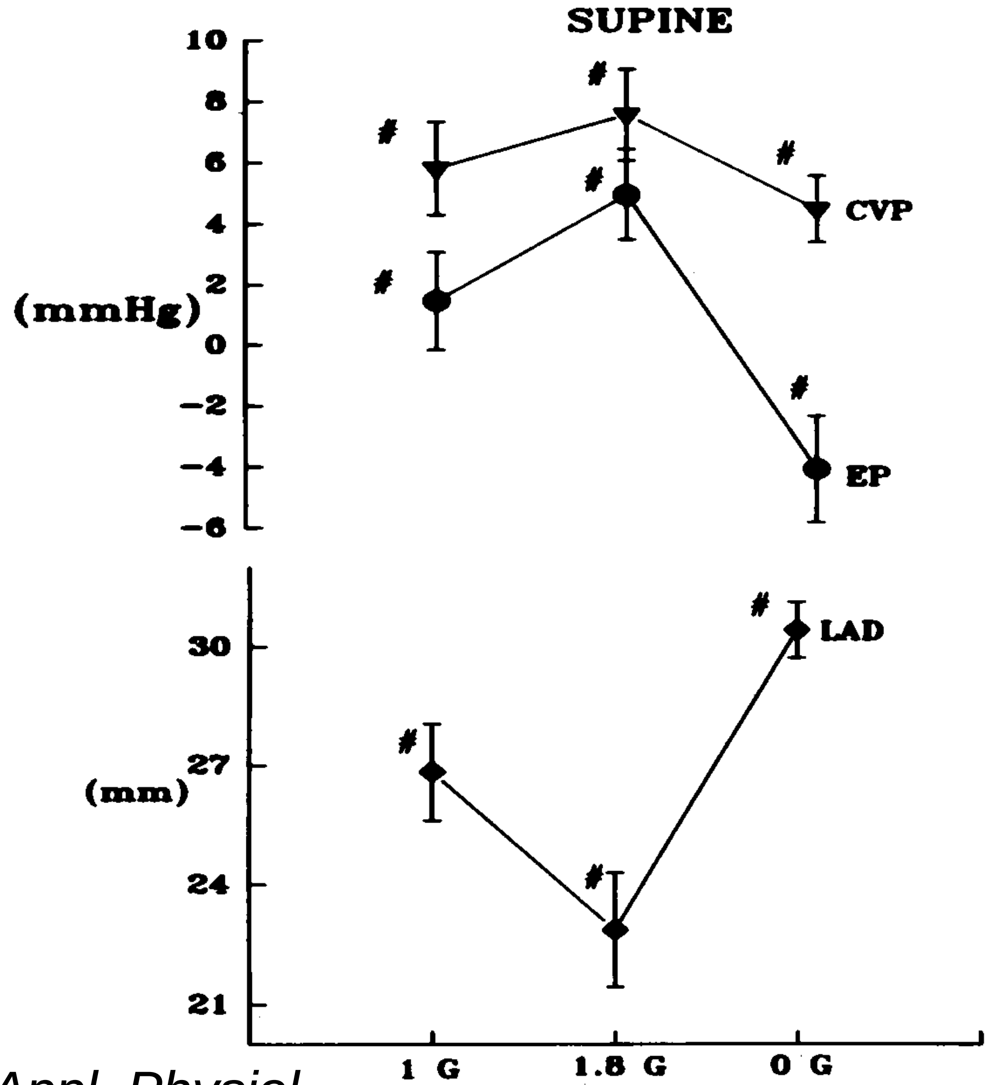
Buckey et al.,
J. Appl. Physiol.
81:19-25, 1996.


3
CAT POCKET B
AR-CAT-170
SER. NO. 21
4
2
1

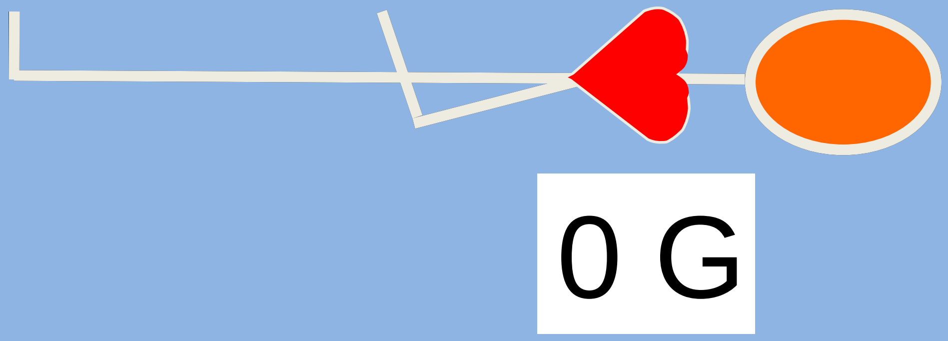



*Foldager et al. J. Appl. Physiol. 81: 408-12, 1996*


cnes

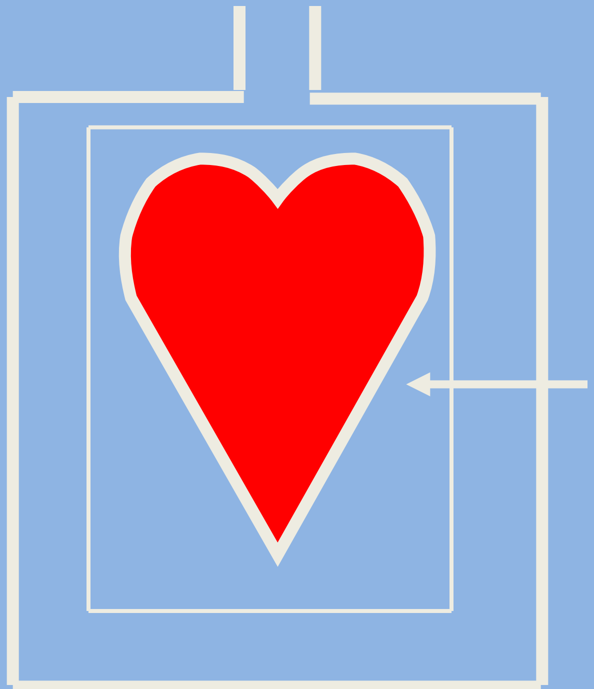



*Videbæk & Norsk , J. Appl. Physiol. 83: 1862-66, 1997*




Heart distension in 0 G

Mechanism?

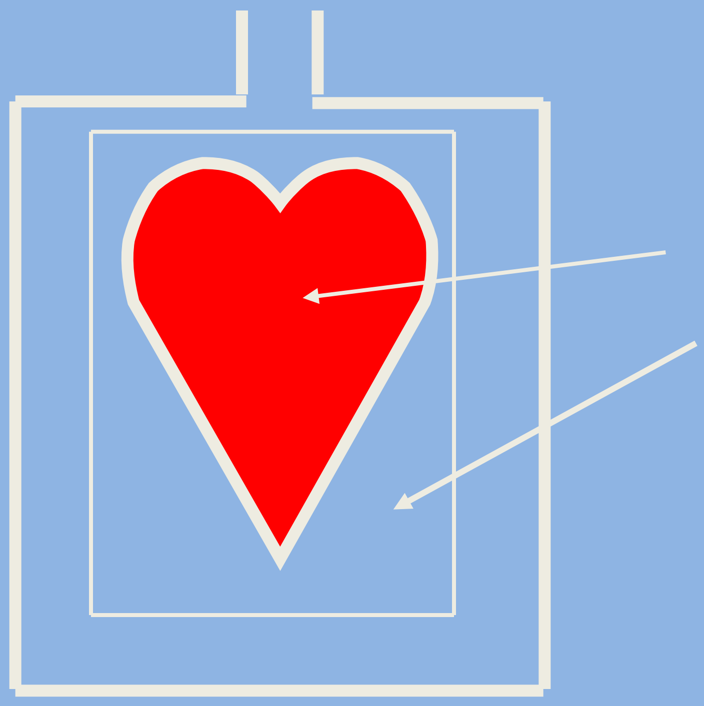


The pressure in the inter-pleural space surrounding the heart is decreased by 0 G.

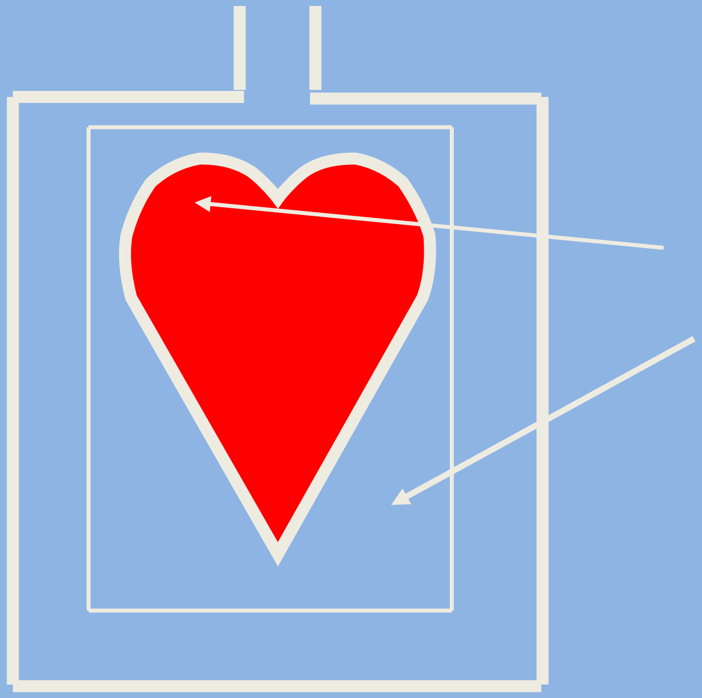
*__Therefore:__*

This pressure must also be measured!

Mechanism?

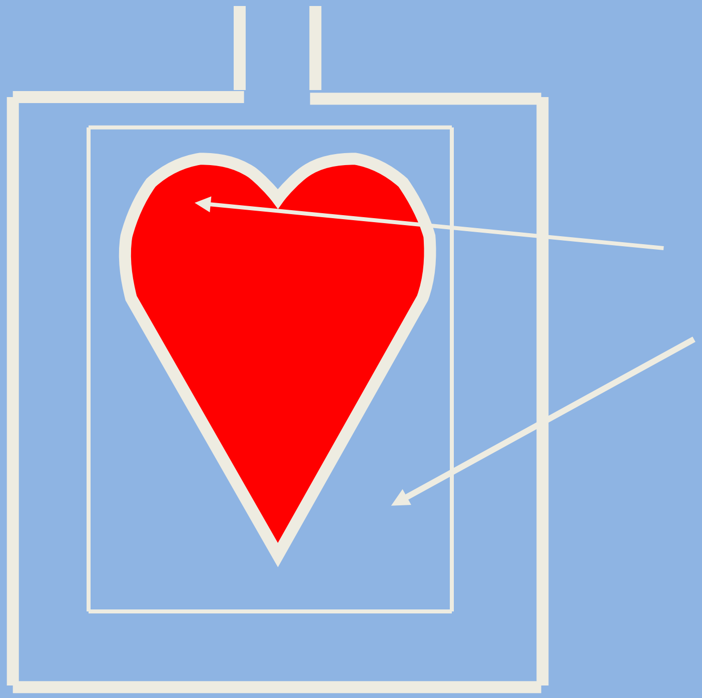


Mechanism?



Atrial distension pressure

Mechanism?



Atrial distension pressure
=
CVP !

TBW results differ between studies, however all spaceflight studies are low “n” studies. Regardless of mechanism, it is known that PV is decreased.

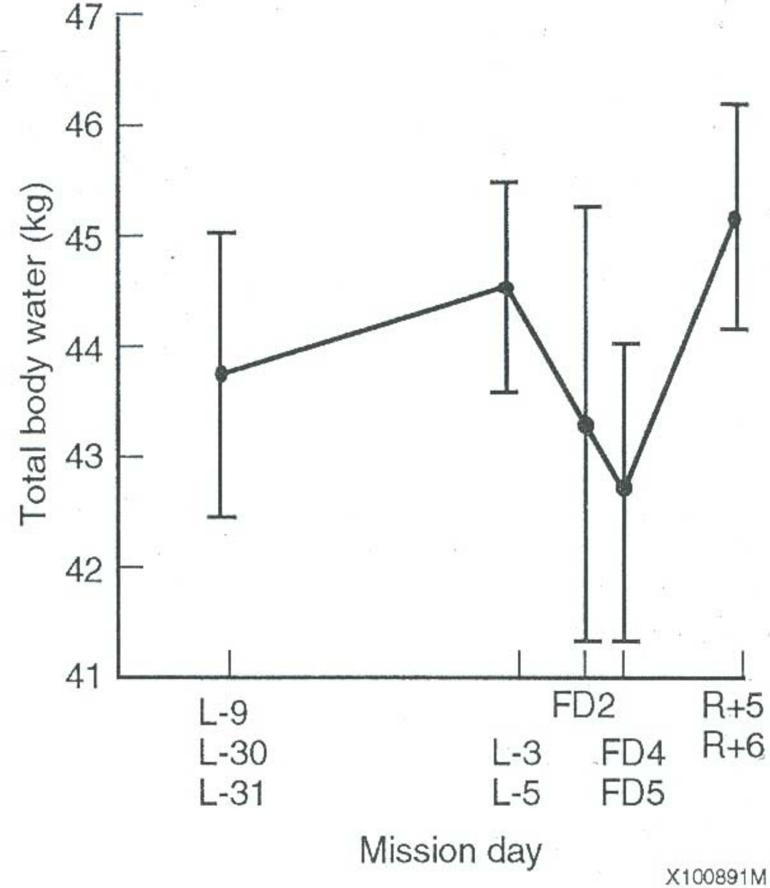
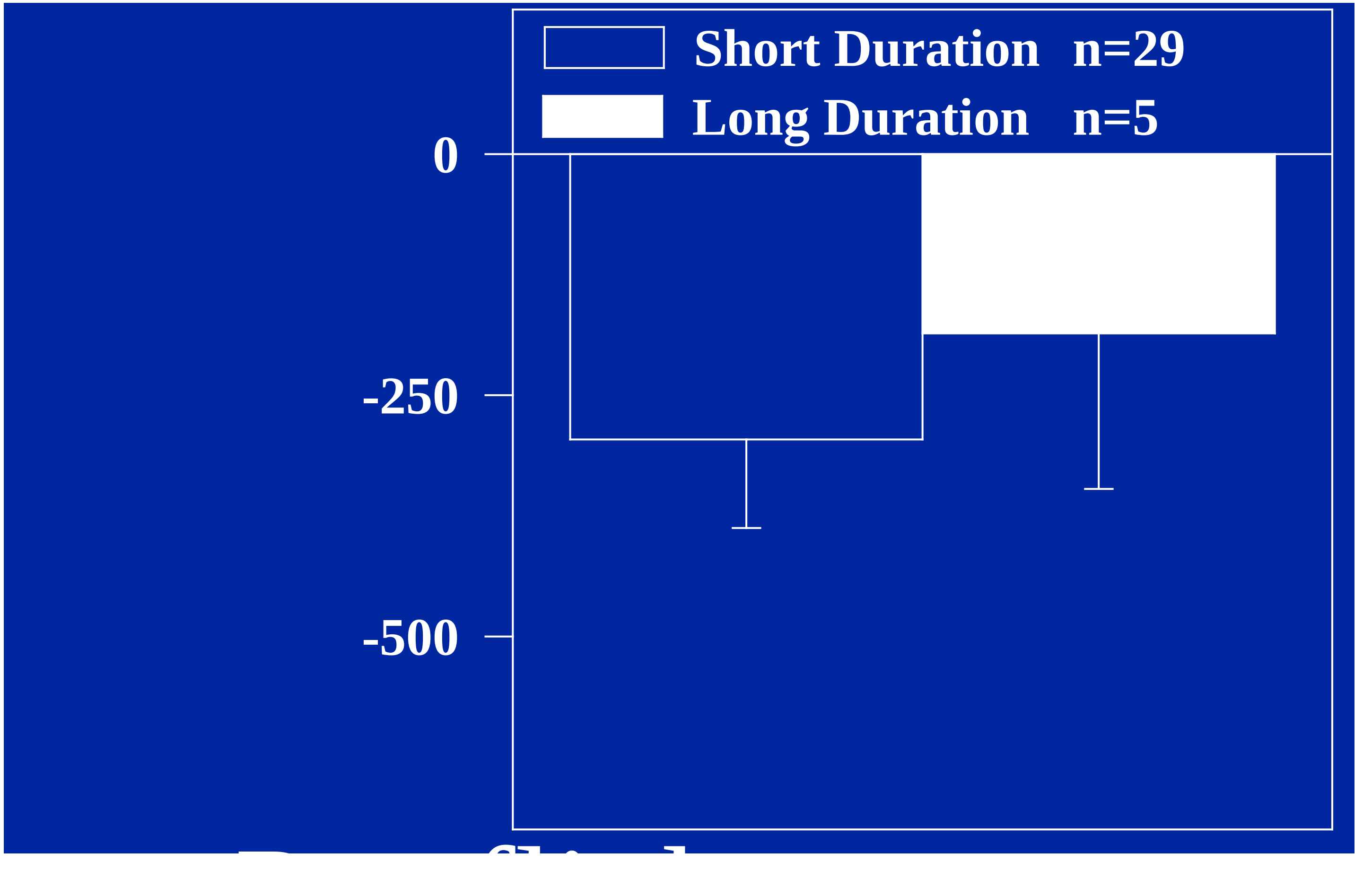



*Figure 7. Mean TBW during space flight. Data are adjusted to 70 kg body mass. The error bars represent the standard error of the mean of the four observations on each of the five mission periods.*

Leach et al., 1991

# Plasma volume losses are similar after short and long-duration spaceflight



# Where does the plasma volume go?

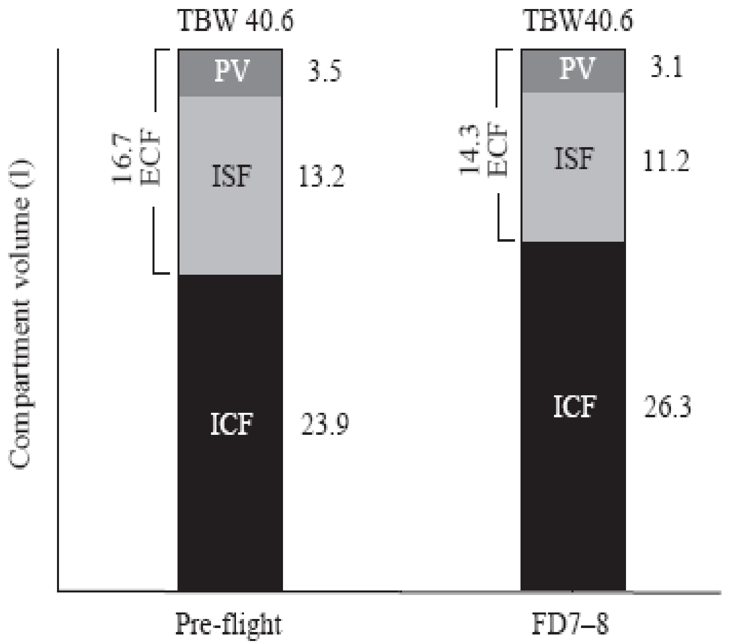



Fig. 3. Mean fluid compartment volumes before and during space flight. Data from Leach and colleagues (Leach et al., 1996) (*N*=6). TBW, total body water; ECF, extracellular fluid; PV, plasma volume; ISF, interstitial fluid; ICF, intracellular fluid; FD7–8, flight days 7–8.

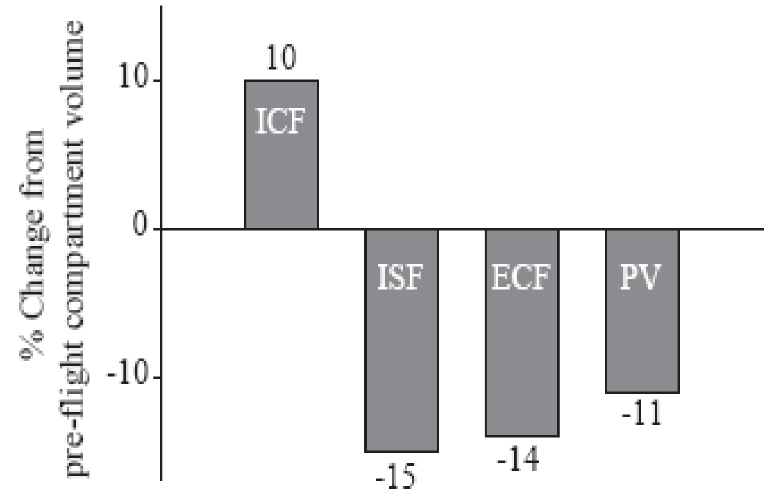
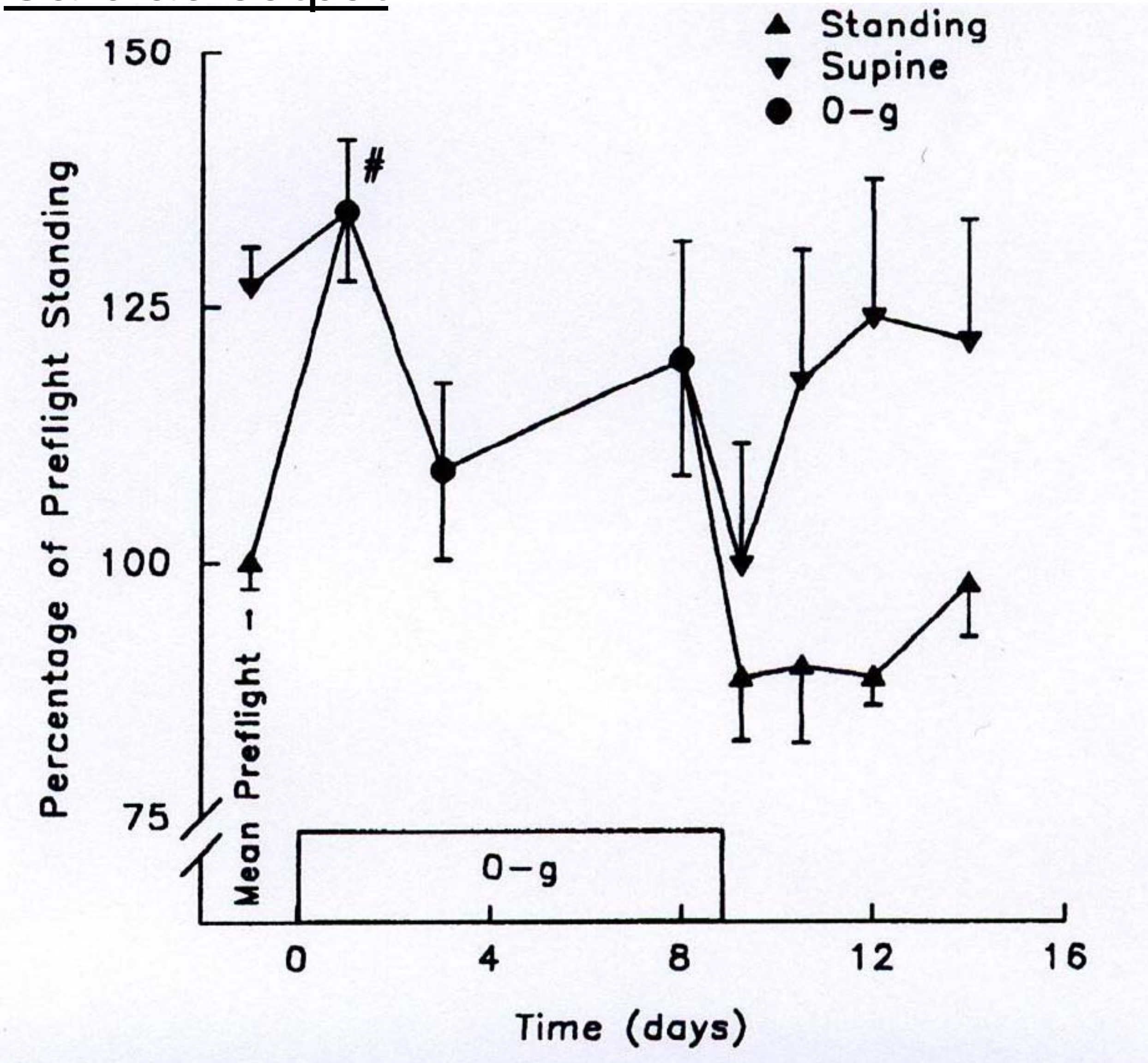


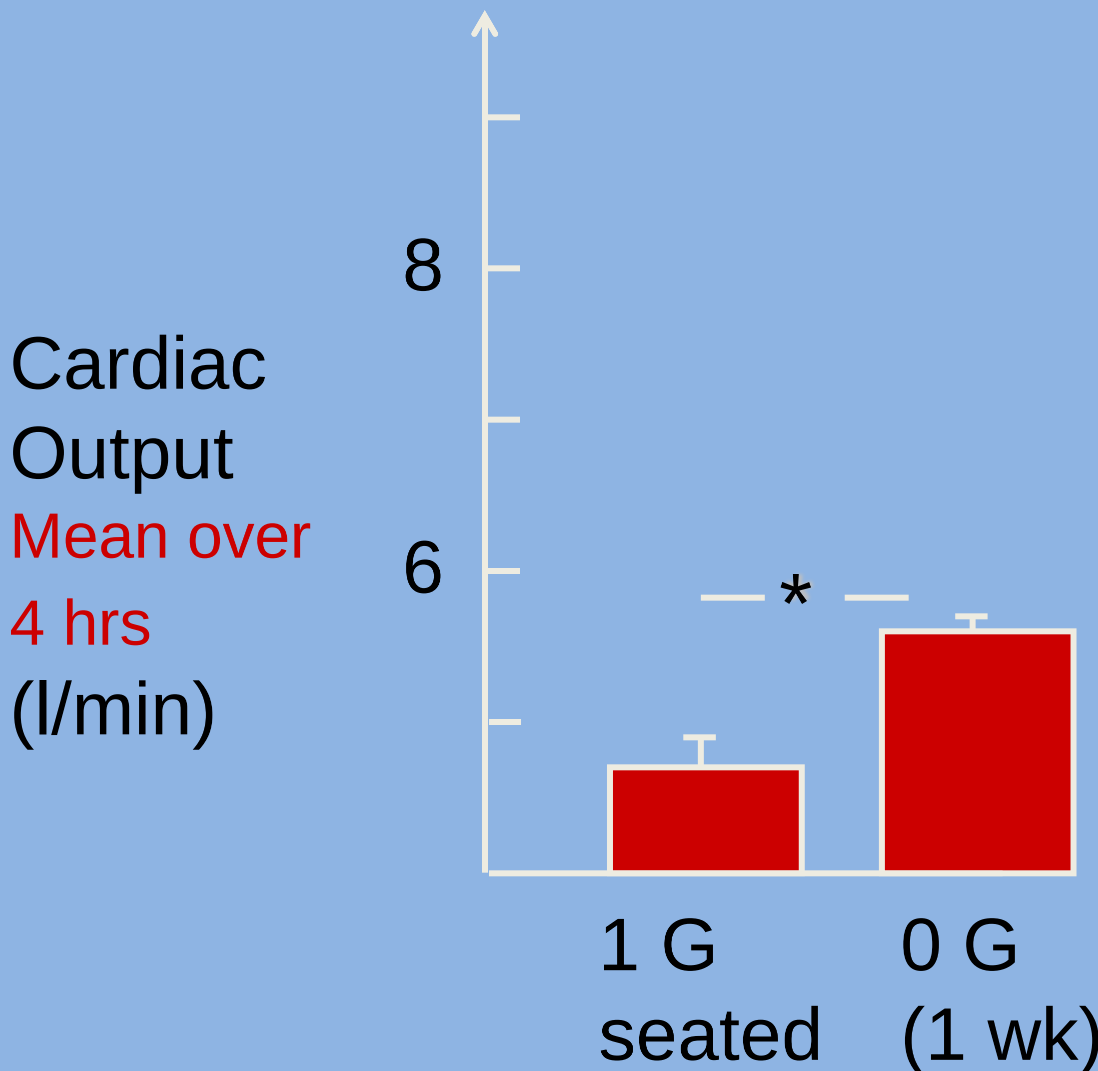

Fig. 4. Mean percentage change in fluid compartment volumes from pre-flight to flight days 7–8. Data from Leach and colleagues (Leach et al., 1996) (*N*=6). ICF, intracellular fluid; ISF, interstitial fluid; ECF, extracellular fluid; PV, plasma volume.

Figures from Leach et al. 1996 in Watenpaugh DE. Fluid volume control during short-term space flight and implications for huma
J Exp Biology 204 (18):3209-3215, 2001.

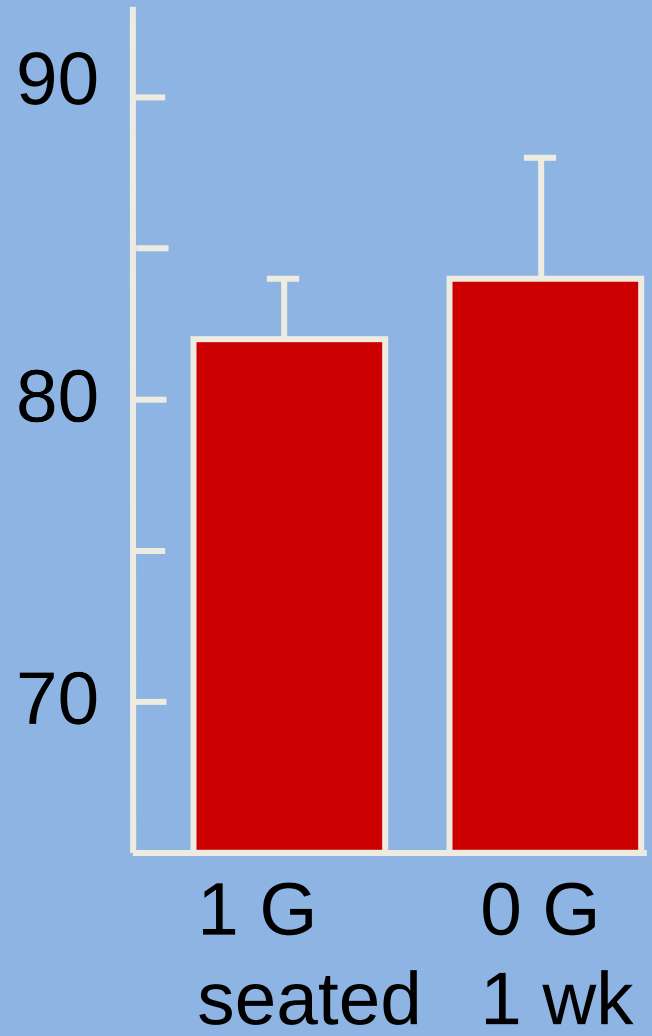
# Cardiac output




*Prisk et al.*
*J. Appl. Physiol.*
*75:15-26,1993.*


Cardiac
Output
Mean over
4 hrs
(l/min)
8
6
*
1 G
seated
0 G
(1 wk)

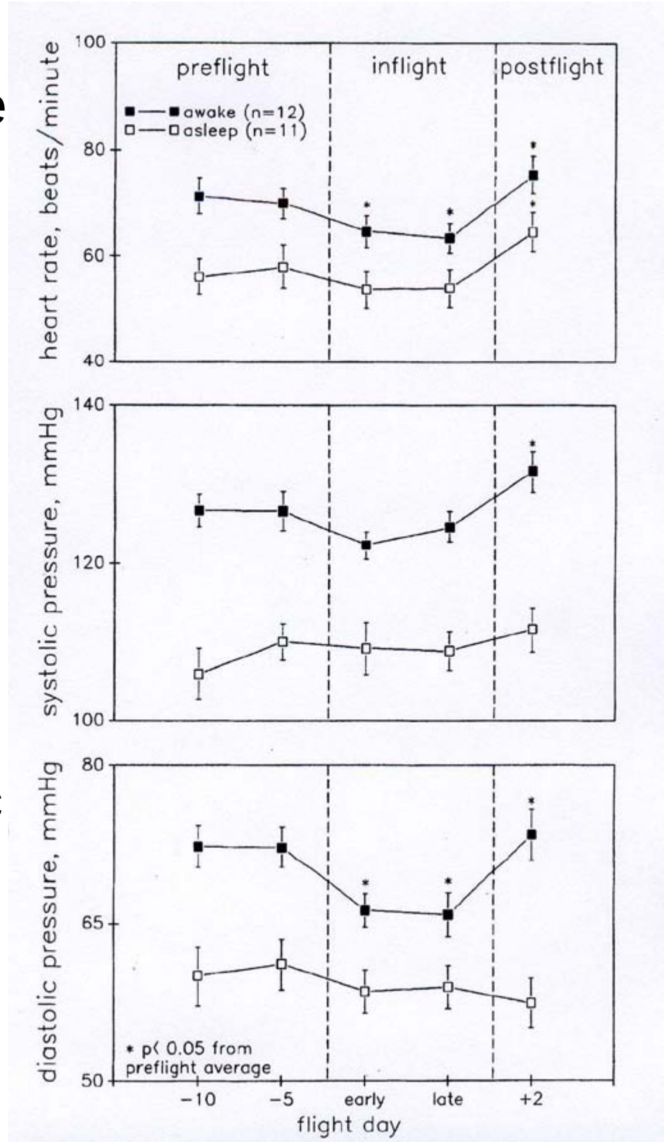
Mean arterial pressure
Mean over 4 hrs
(mm Hg)



Heart rate

Systolic

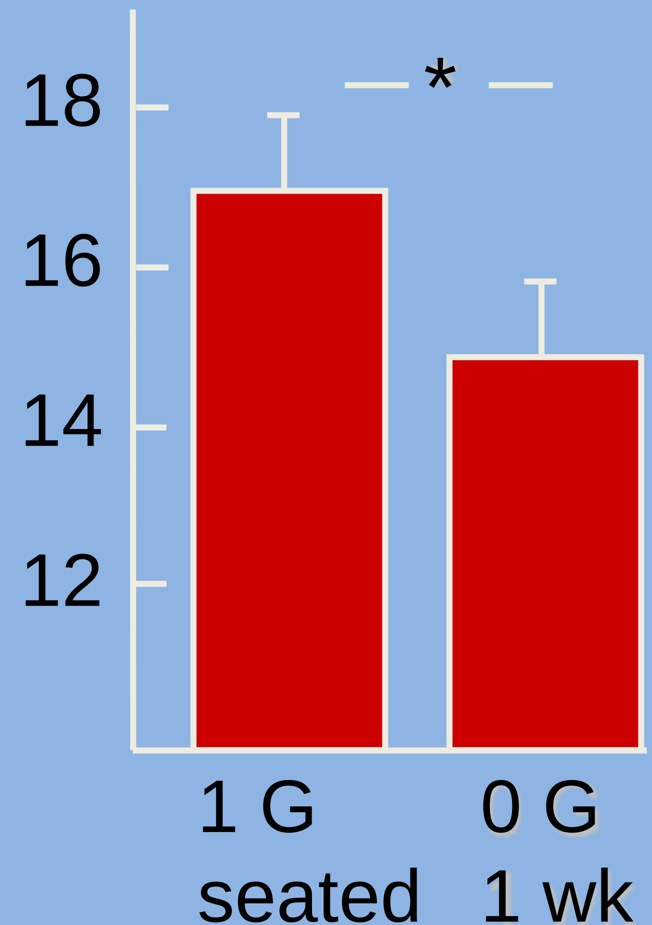
Diastolic



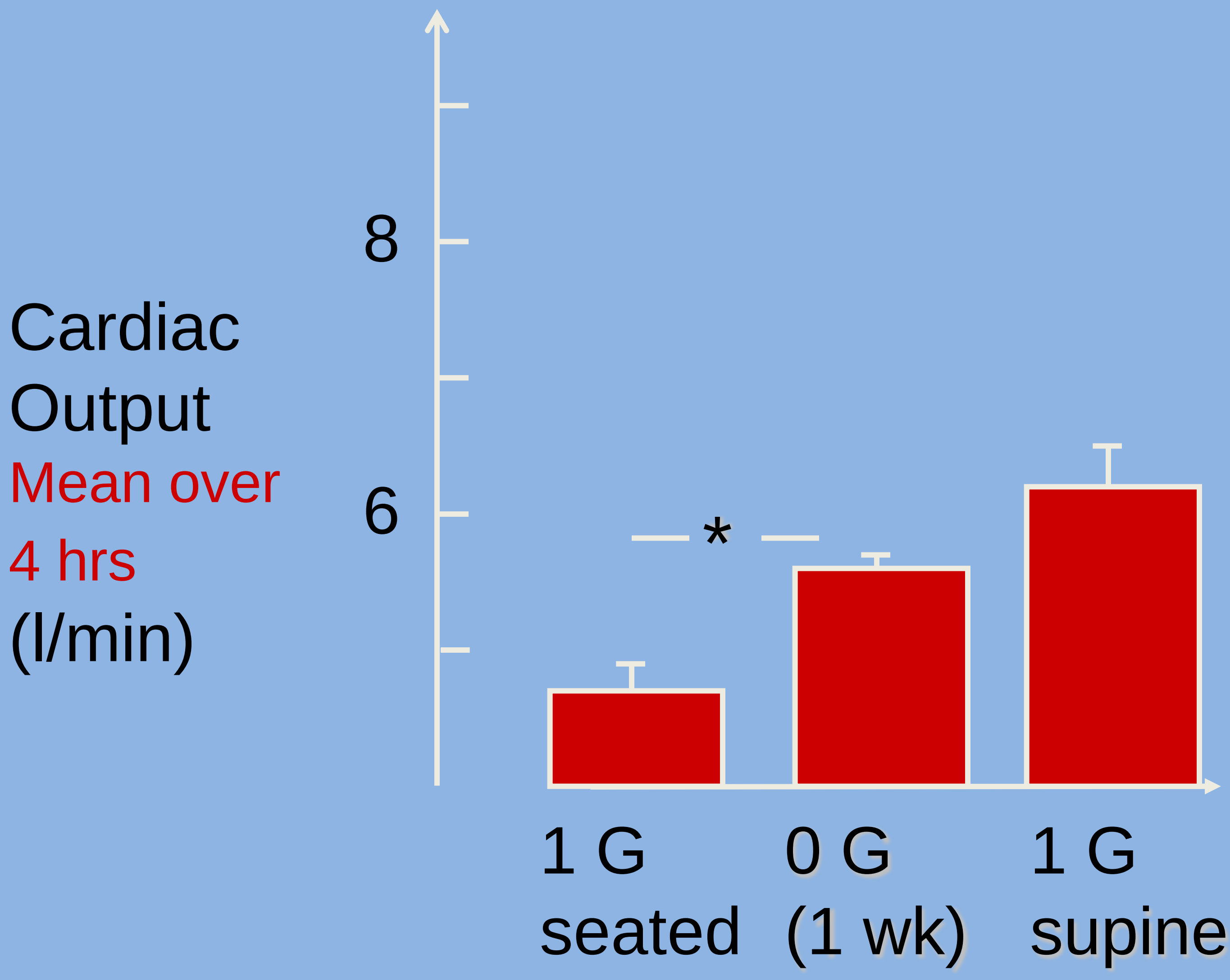

Pre- In- Postflight

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

Systemic Vascular Resistance
Mean over 4 hrs
(mmHg•min/l)



Compared to the supine position?


Cardiac
Output
Mean over
4 hrs
(l/min)
8
6
*
1 G
seated
0 G
(1 wk)
1 G
supine

Systemic
Vascular
Resistance
Mean over 4 hrs
(mmHg•min/l)

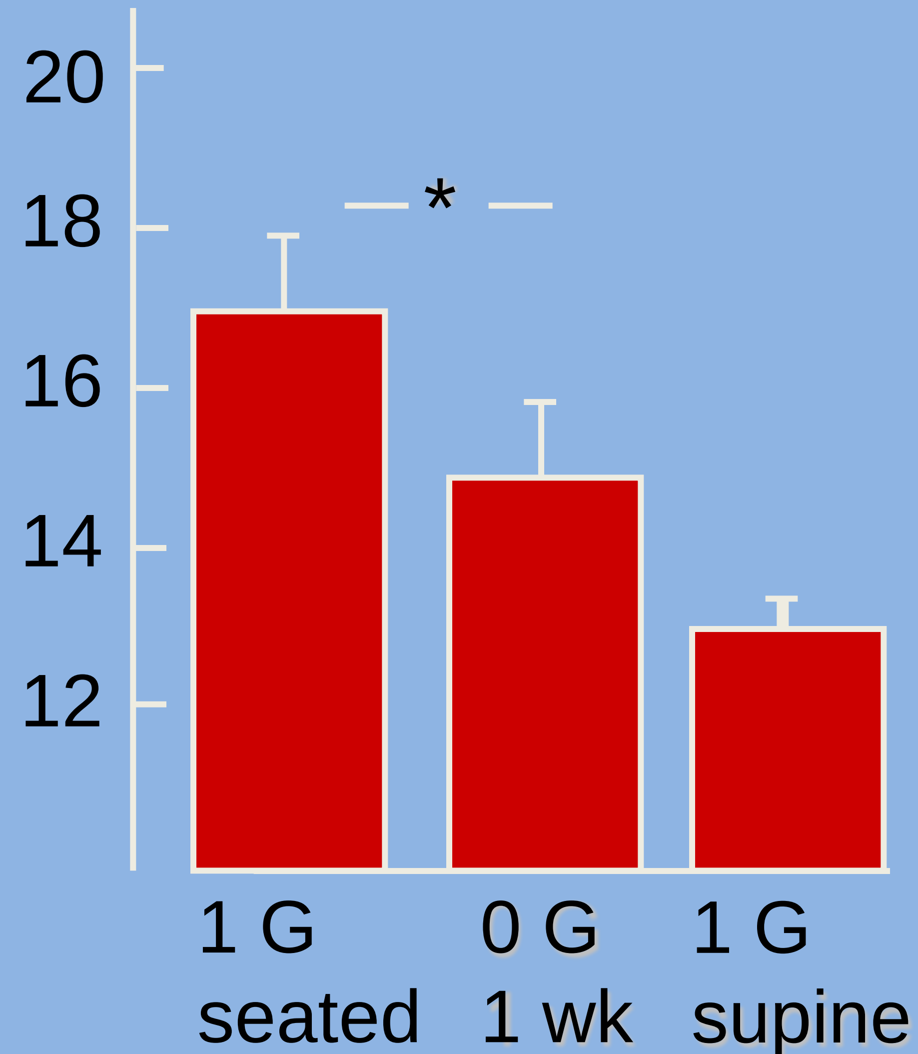
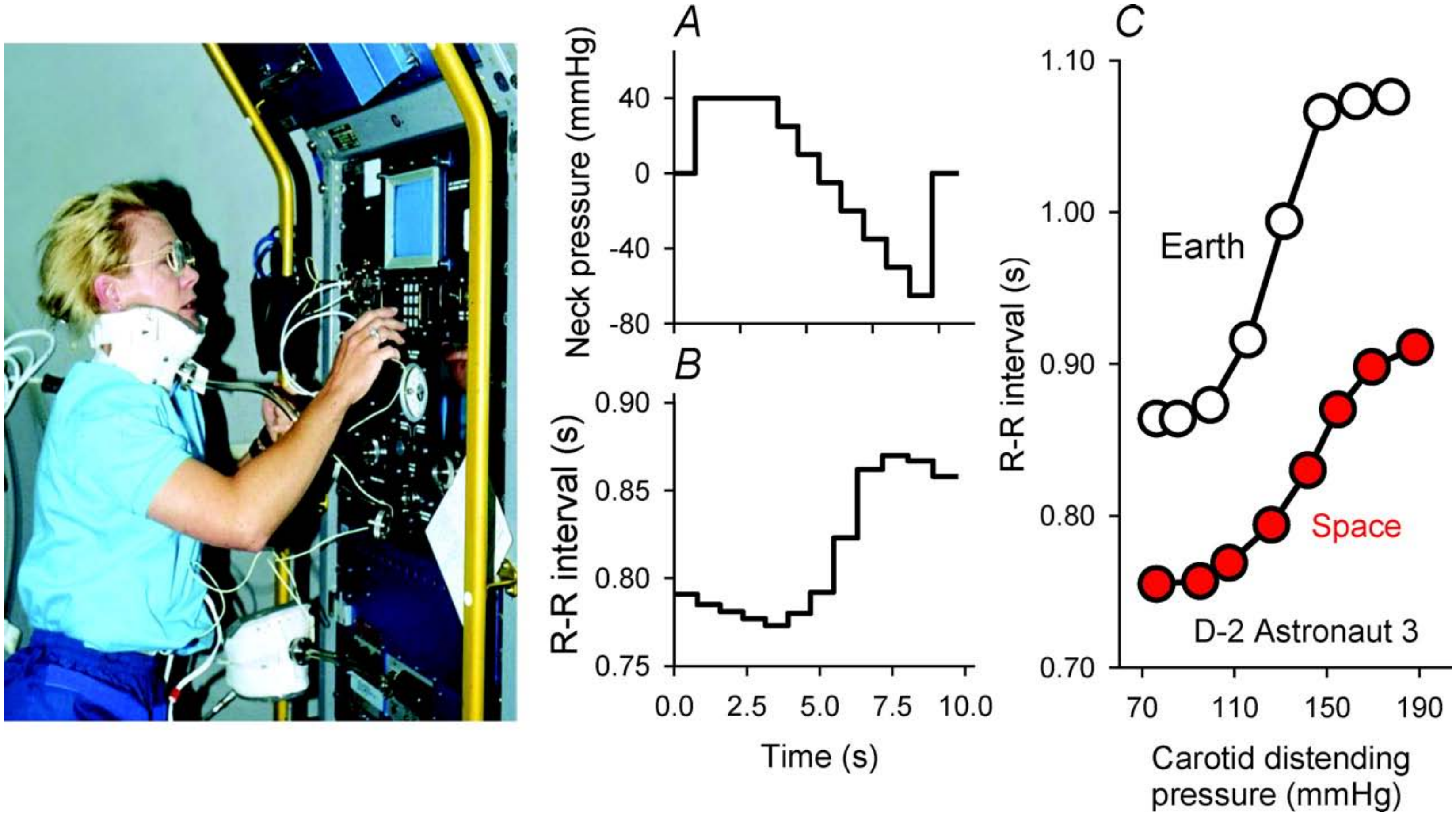


**Figure 1. Baroreflex testing The left panel shows astronaut Rhea Seddon performing baroreflex testing on herself during the SLS-1 mission.**




Eckberg D L et al. J Physiol 2010;588:1129-1138

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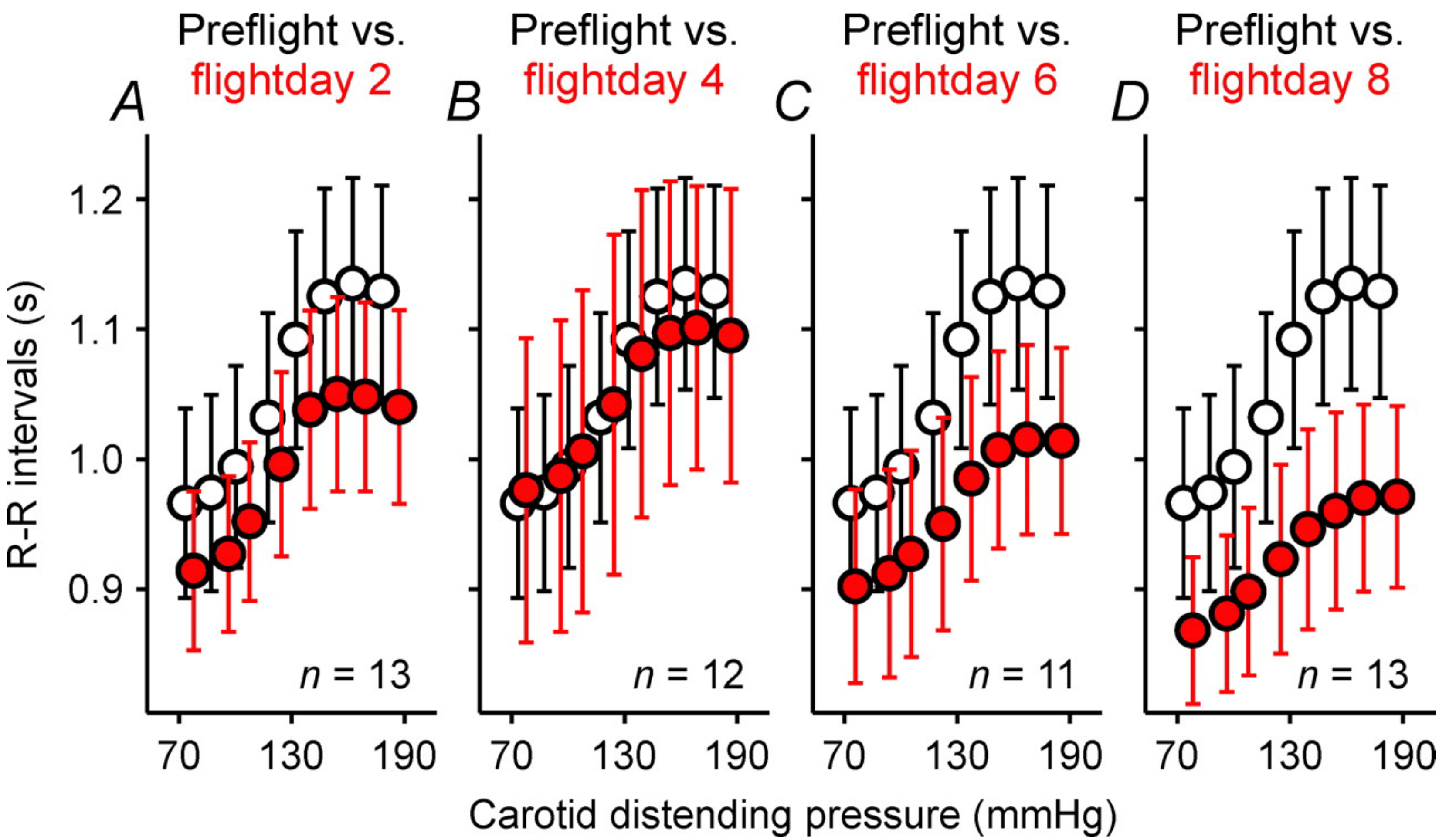
**Figure 3. Mean ± 95% confidence intervals for preflight and inflight vagal baroreflex relations Confidence limits for carotid distending pressures are obscured by the symbols.**




**Eckberg D L et al. J Physiol 2010;588:1129-1138**

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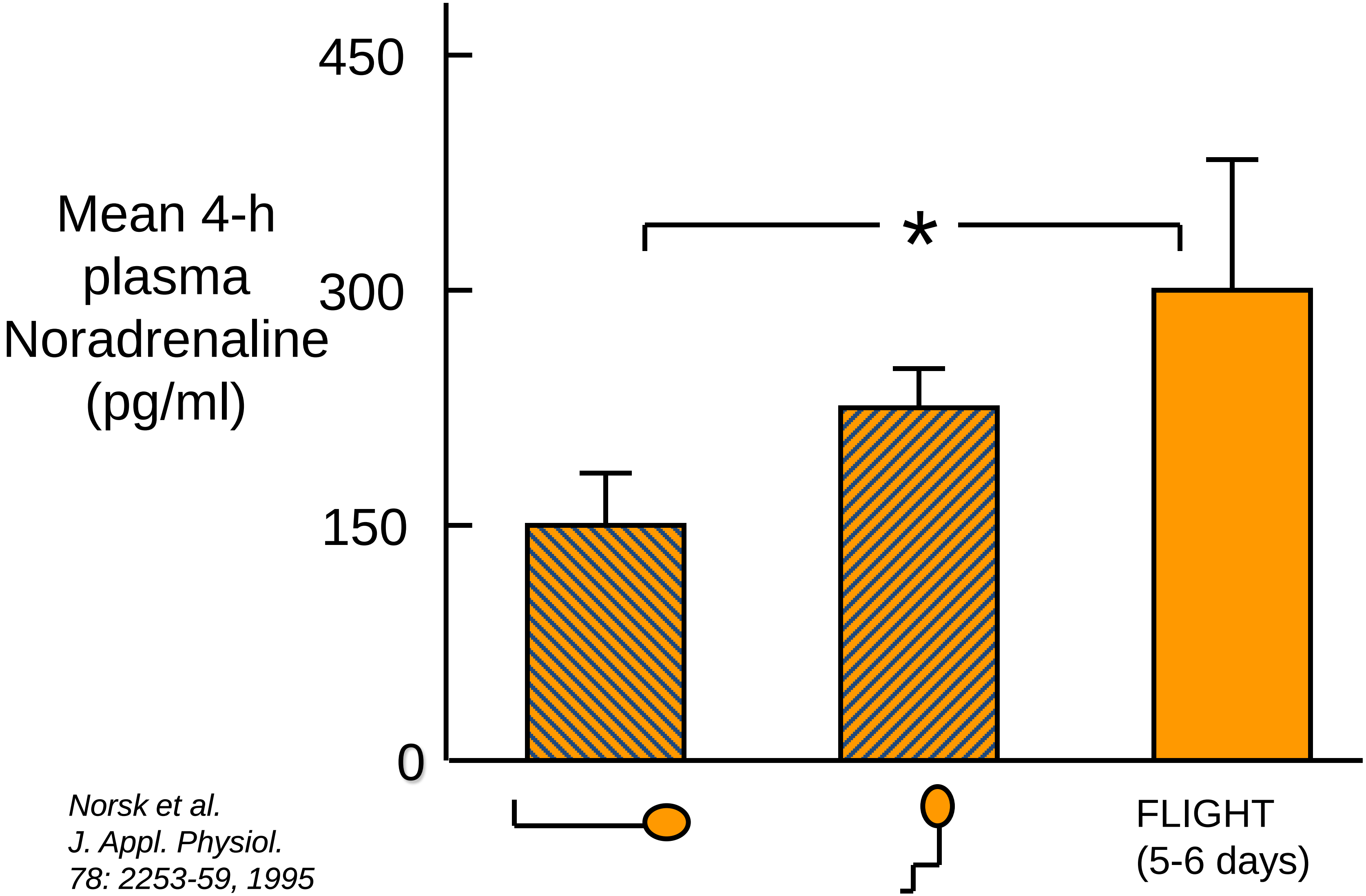
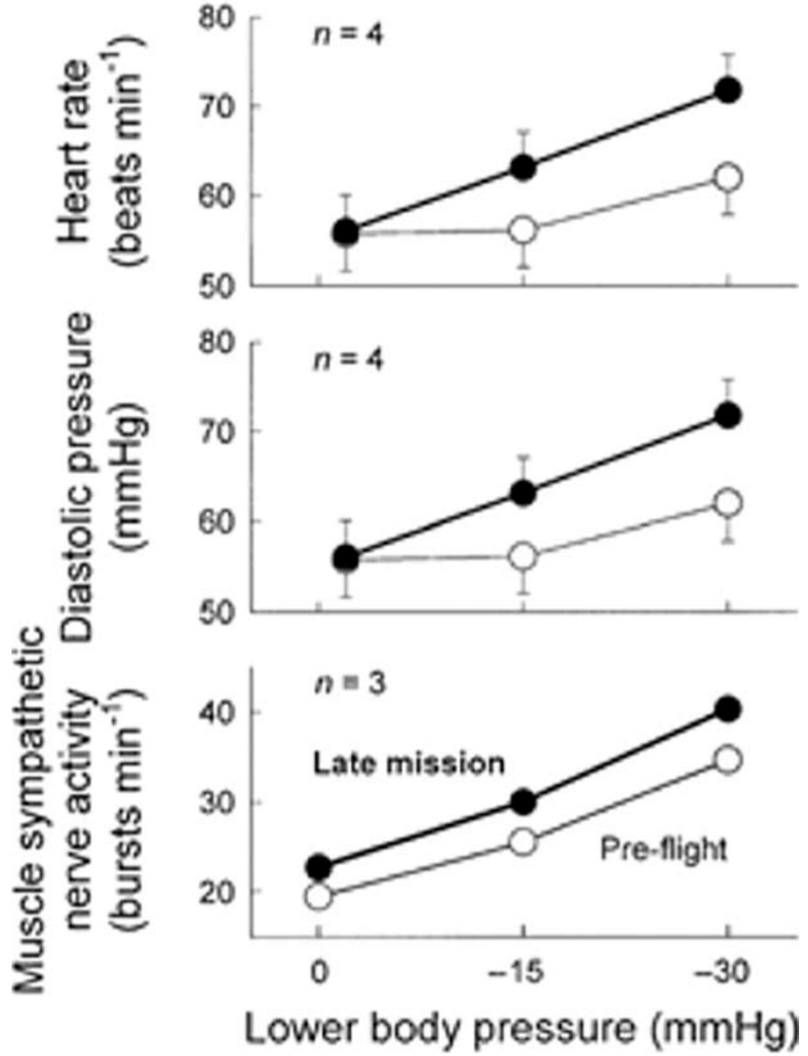



*Norsk et al.*
*J. Appl. Physiol.*
*78: 2253-59, 1995*




Ertl A C et al. J Physiol 2002;538:321-329

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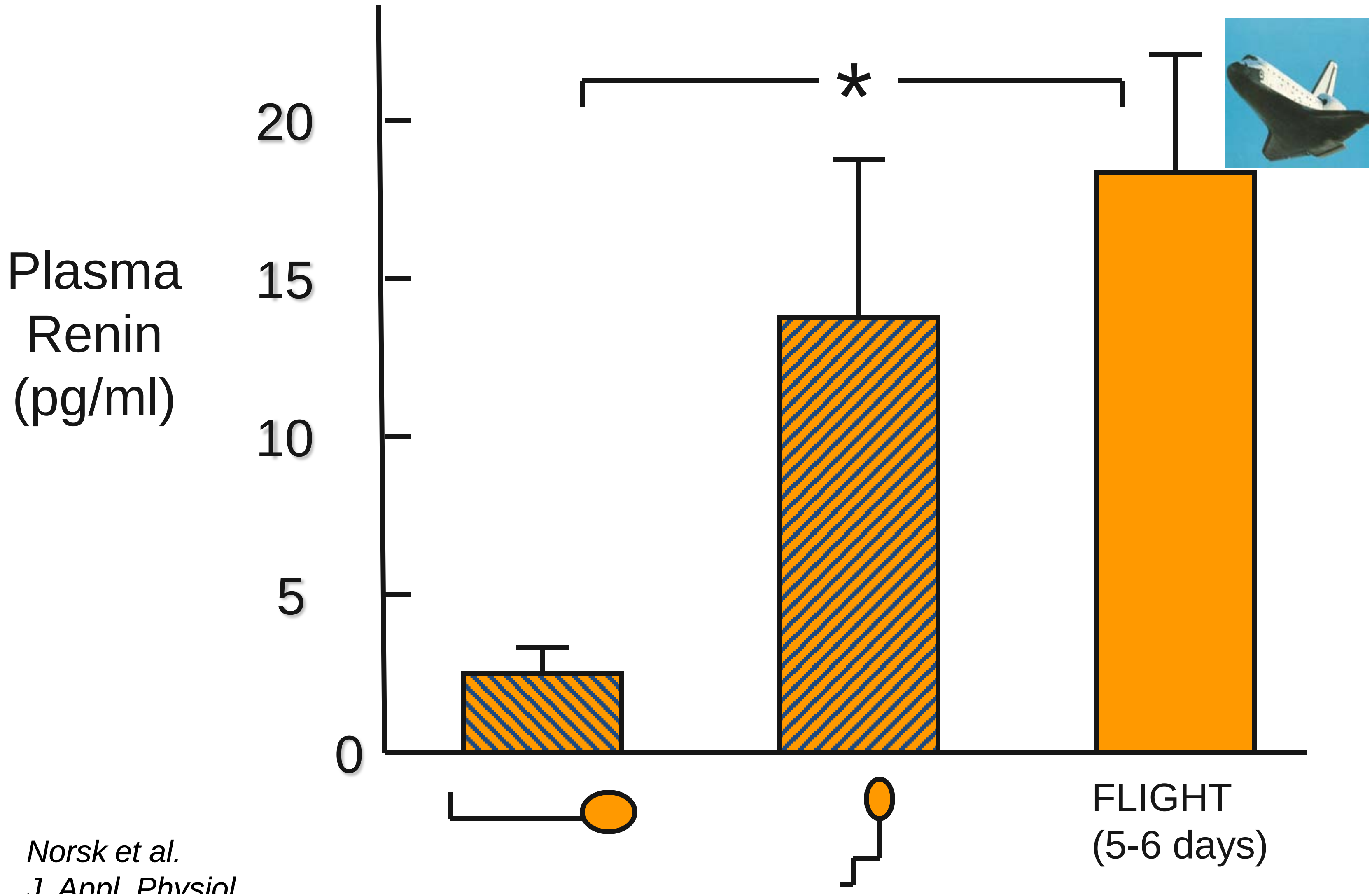



*Norsk et al.*
*J. Appl. Physiol.*
*78: 2253-59, 1995*

# Research Evidence for Decreased LV Mass during Exposure to Microgravity

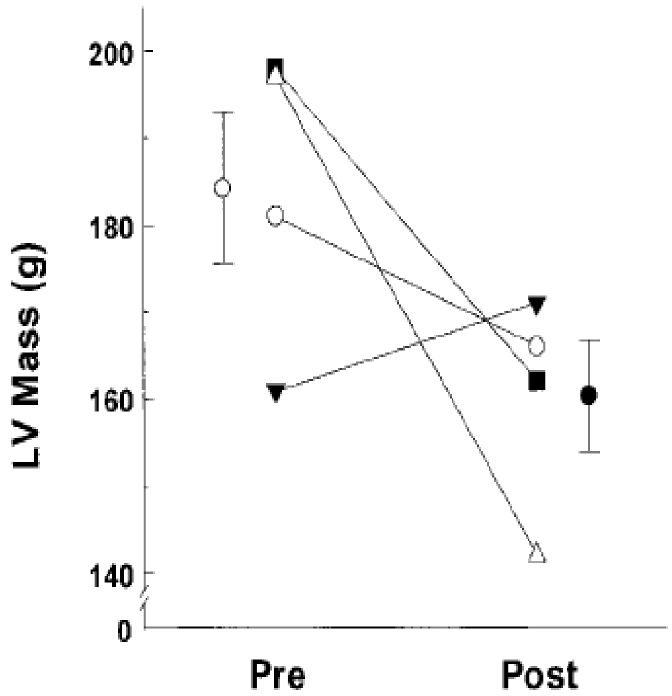



Fig. 3. LV mass measured by MRI before (Pre) and after (Post) the D-2 mission on 4 astronauts. Circles with error bars represent mean ± SE before and after spaceflight.

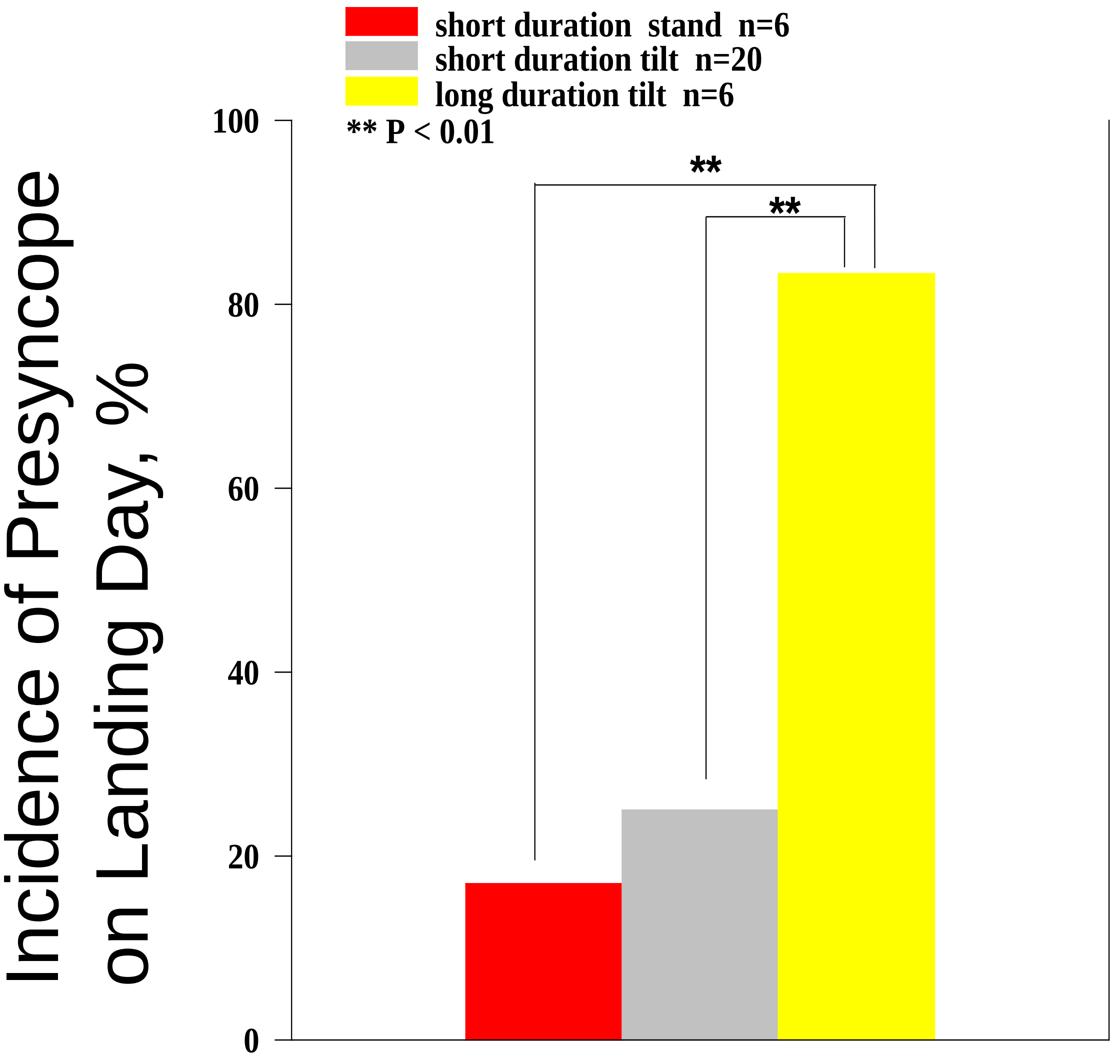
Cardiac MRI was conducted pre-flight and post-flight: 10 days of microgravity exposure
It is unclear on what post-flight day MRI data was acquired and there was no follow-up

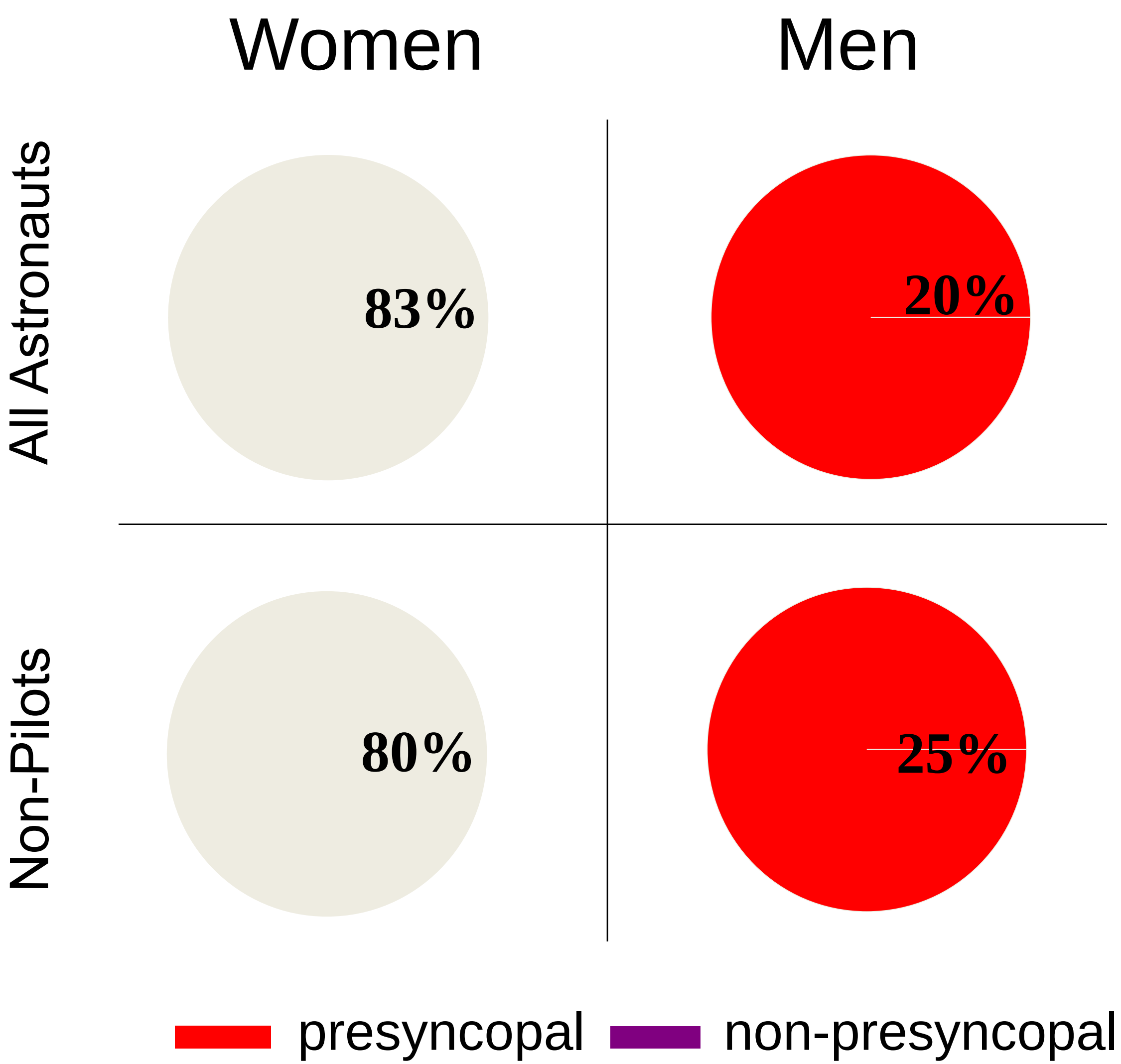

Perhonen MA, Franco F, Lane LD, et al. Cardiac atrophy after bed rest and spaceflight. J Appl Physiol 91: 645-653, 20

# Postflight:

- Orthostatic tolerance
- Aerobic exercise capacity

# Presyncope increases with Flight Duration



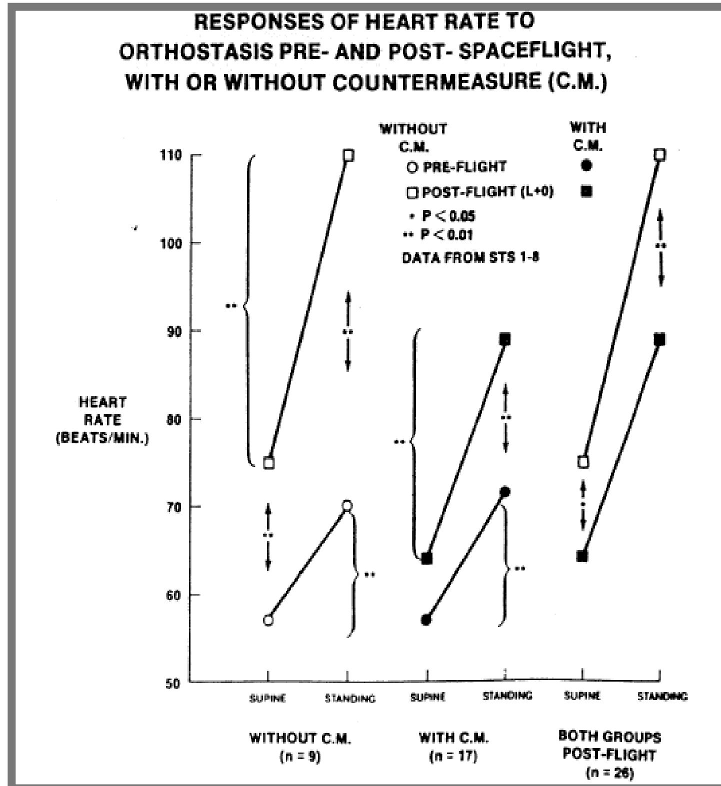

Women
Men
All Astronauts
Non-Pilots
83%
20%
80%
25%
presyncopal
non-presyncopal

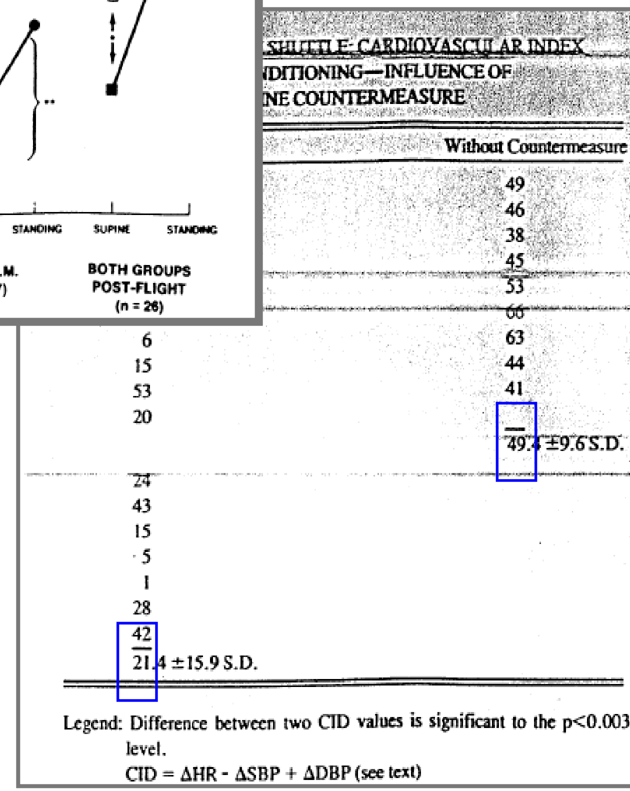
# Isotonic Fluid Load

The operational fluid load (salt tablets and water before landing) was imposed to correct the dehydration. Used static stand test and cardiovascular index of deconditioning (CID) to quantify results.

However, the efficacy of the operational fluid load was not determined: it is unknown how much plasma volume is actually replaced.

Does not restore plasma volume to pre-flight levels: currently, there is approximately a 9% loss





SHUTTLE CARDIOVASCULAR INDEX
...DITIONING—INFLUENCE OF
...NE COUNTERMEASURE

Without Countermeasure

49
46
38
45
53
66
63
44
41
49.4 ±9.6 S.D.

6
15
53
20
24
43
15
5
1
28
42
21.4 ±15.9 S.D.

Legend: Difference between two CID values is significant to the p<0.003 level.
CID = ΔHR - ΔSBP + ΔDBP (see text)

Bungo MW, Charles JB, Johnson PC. Cardiovascular Deconditioning During Space Flight and the Use of Saline as a Countermeasure to Orthostatic Intolerance. Aviat.

# Orthostatic intolerance:

Mitigated by:

- Oral salt and fluid loading
- Antigravity garment
- Additional clinical treatment

Florinef® Does not Correct Post-spaceflight Orthostatic Hypotension

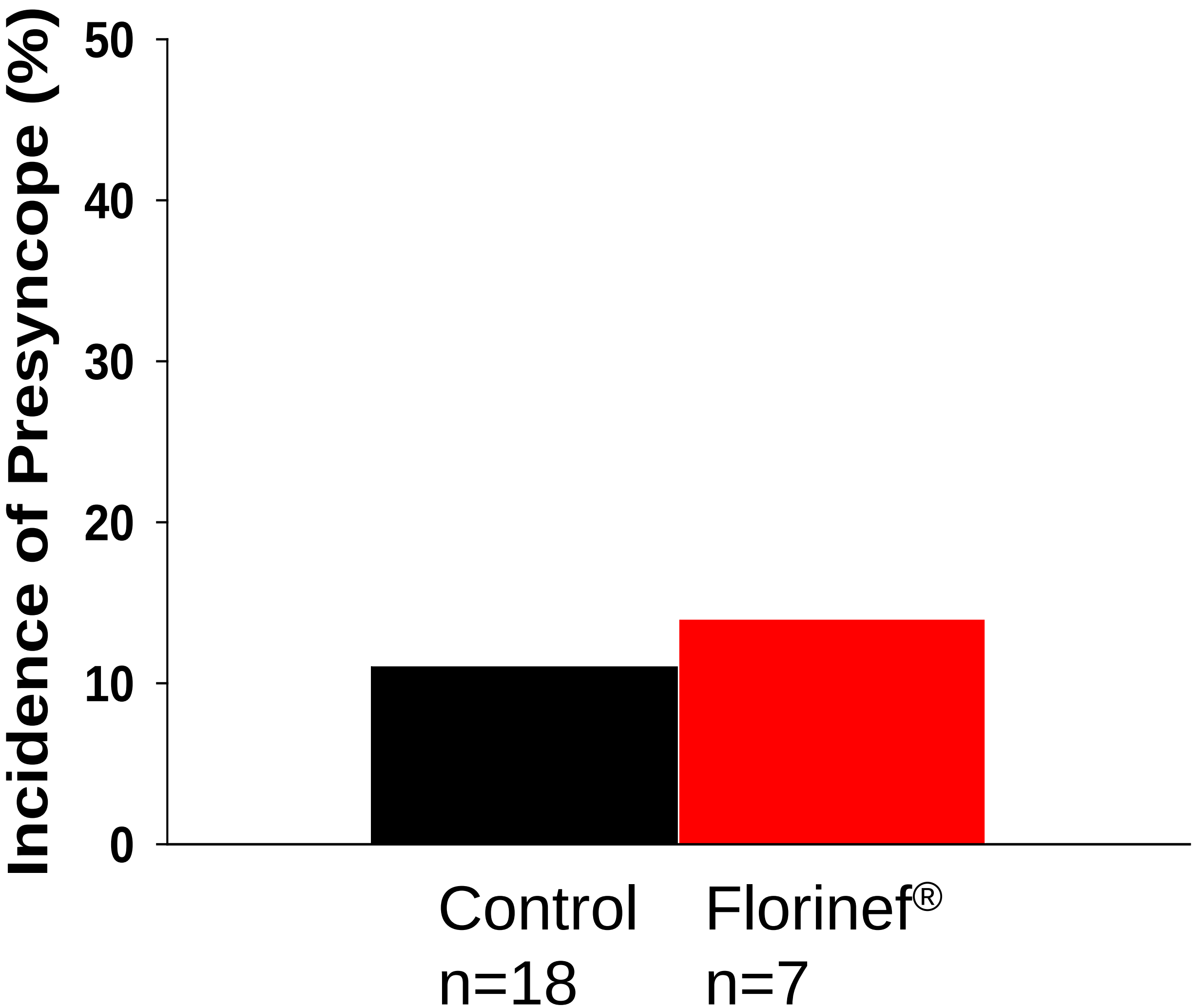


Table 2. *Preflight measurements*

| | Presyncopal on Landing Day ($n = 8$) | | | Nonpresyncopal on Landing Day ($n = 21$) | | |
|---|---|---|---|---|---|---|
| | Supine | Standing | Standing-supine | Supine | Standing | Standing-supine |
| Plasma norepinephrine, pg/ml | 213 ± 28 | 467 ± 42 | 254 ± 37 | 209 ± 15 | 466 ± 44 | 257 ± 38 |
| Peripheral vascular resistance, $mmHg \cdot l^{-1} \cdot min$ | 15.5 ± 0.9* | 22.9 ± 1.8* | 7.4 ± 1.5 | 21.2 ± 1.9* | 31.8 ± 2.3* | 10.6 ± 1.9 |
| Diastolic pressure, mmHg | 66 ± 2† | 69 ± 4† | 3 ± 3 | 73 ± 2† | 77 ± 2† | 4 ± 1 |
| Systolic pressure, mmHg | 109 ± 3* | 99 ± 4† | −10 ± 2* | 114 ± 2* | 108 ± 3† | −5 ± 2* |
| Heart rate, beats/min | 62 ± 2† | 81 ± 5† | 19 ± 5 | 54 ± 1† | 71 ± 2† | 17 ± 2 |
| Stroke volume, ml | 86 ± 5 | 45 ± 5 | −41 ± 3 | 83 ± 4 | 41 ± 2 | −43 ± 3 |
| Cardiac output, l/min | 5.3 ± 0.5* | 3.6 ± 0.4* | −1.7 ± 0.2 | 4.4 ± 0.2* | 2.9 ± 0.2* | −1.6 ± 0.2 |
| Mean flow velocity (middle cerebral artery), cm/s | 58.9 ± 5.7 | 51.2 ± 2.5* | −7.5 ± 1.6 | 53.4 ± 5.5 | 43.1 ± 2.1* | −11.4 ± 2.3 |
| Cerebral vascular resistance, $mmHg \cdot cm^{-1} \cdot s$ | 1.5 ± 0.2 | 1.1 ± 0.2* | −0.4 ± 0.1 | 1.9 ± 0.1 | 1.5 ± 0.1* | −0.4 ± 0.1 |
| Plasma epinephrine, pg/ml | 19 ± 3 | 30 ± 3 | 12 ± 2 | 24 ± 3 | 38 ± 4 | 14 ± 4 |
| Plasma renin activity, $ng \cdot ml^{-1} \cdot h^{-1}$ | 1.7 ± 0.4 | 2 ± 0.5 | 0.3 ± 0.2 | 1.3 ± 0.2 | 1.6 ± 0.2 | 0.2 ± 0.1 |
| Plasma volume, liters | 3.2 ± 0.2 | | | 3.4 ± 0.1 | | |

Values are means ± SE; *n*, no. of subjects. Supine, standing, and standing-supine difference measurements for all variables (plasma volume was only measured supine) separated into presyncopal and nonpresyncopal groups before flight (average of 2 preflight data sessions). * $P \leq 0.05$ between groups. † $P \leq 0.01$ between groups.

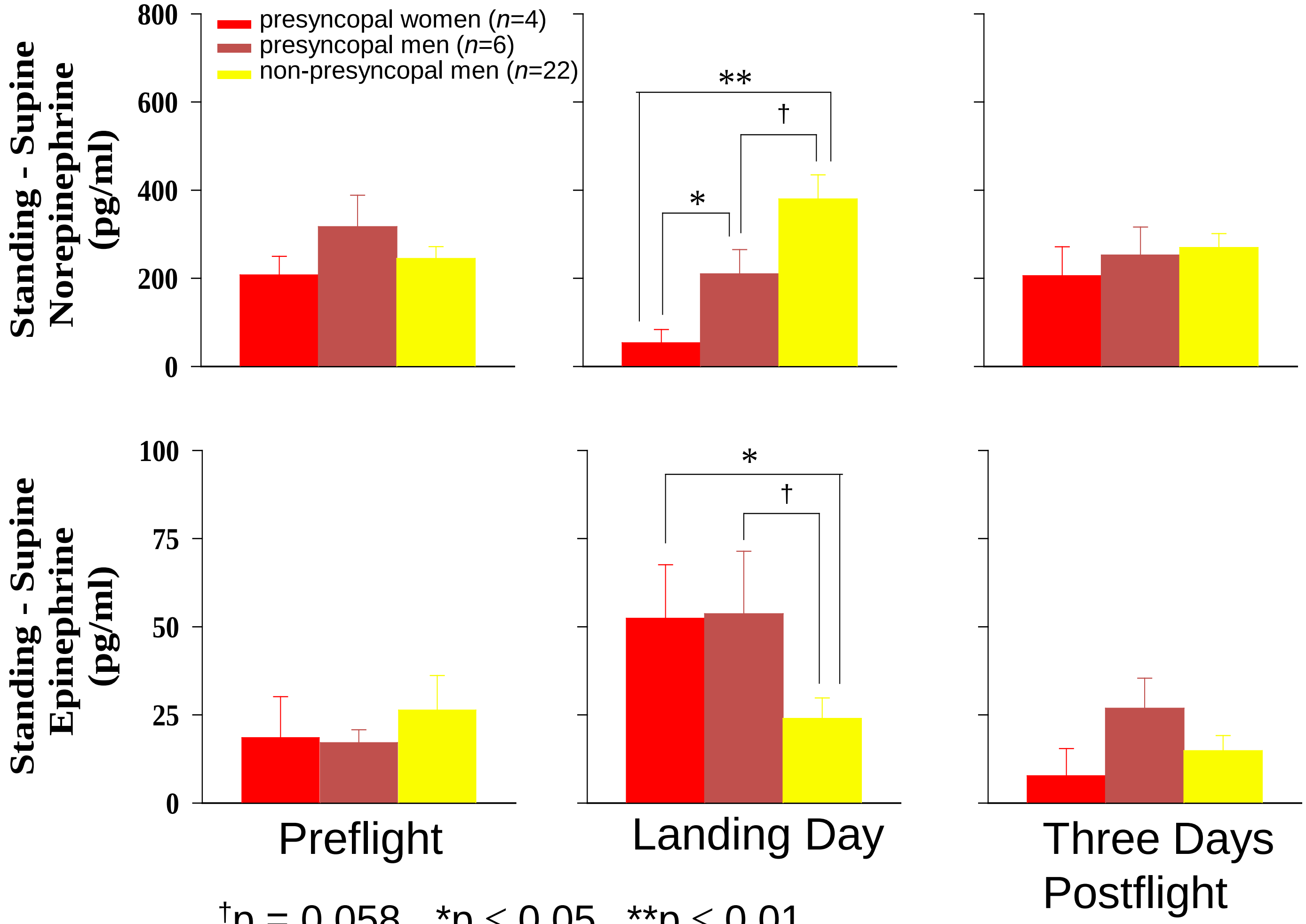
Fritsch-Yelle, JM. et al. 1996

Table 1. *Landing day measurements*

| | Presyncopal on Landing Day ($n = 8$) | | | Nonpresyncopal on Landing Day ($n = 21$) | | |
|---|---|---|---|---|---|---|
| | Supine | Standing | Standing-supine | Supine | Standing | Standing-supine |
| Plasma norepinephrine, pg/ml | 330 ± 67 | 420 ± 46* | 105 ± 41* | 278 ± 18 | 618 ± 88* | 340 ± 62* |
| Peripheral vascular resistance, $mmHg \cdot l^{-1} \cdot min$ | 16.0 ± 1.3 | 22.9 ± 2.5* | 6.4 ± 2.9 | 21.1 ± 1.6 | 33.8 ± 2.7* | 12.6 ± 2.6 |
| Diastolic pressure, mmHg | 74 ± 4 | 61 ± 4† | −14 ± 7† | 76 ± 2 | 81 ± 2† | 3 ± 2† |
| Systolic pressure, mmHg | 110 ± 4* | 80 ± 3† | −28 ± 4† | 120 ± 2* | 109 ± 3† | −11 ± 3† |
| Heart rate, beats/min | 72 ± 5* | 114 ± 8† | 41 ± 6* | 62 ± 2* | 91 ± 4† | 29 ± 3* |
| Stroke volume, ml | 78 ± 4 | 28 ± 2 | −51 ± 5 | 77 ± 5 | 32 ± 9 | −44 ± 5 |
| Cardiac output, l/min | 5.5 ± 0.3 | 3.3 ± 0.3 | −2.4 ± 0.3 | 4.7 ± 0.3 | 2.9 ± 0.2 | −1.8 ± 0.3 |
| Mean flow velocity (middle cerebral artery), cm/s | 52.4 ± 4.7 | 40.0 ± 2.9 | −12.4 ± 2.2 | 47.6 ± 2.3 | 39.7 ± 1.6 | −7.5 ± 1.2 |
| Cerebral vascular resistance, $mmHg \cdot cm^{-1} \cdot s$ | 1.7 ± 0.3 | 1.1 ± 0.1† | −0.7 ± 0.2 | 2.0 ± 0.1 | 1.6 ± 0.1† | −0.4 ± 0.1 |
| Plasma epinephrine, pg/ml | 42 ± 5 | 66 ± 12 | 20 ± 13 | 23 ± 2 | 48 ± 6 | 25 ± 7 |
| Plasma renin activity, $ng \cdot ml^{-1} \cdot h^{-1}$ | 2.7 ± 1.2 | 3.4 ± 1.5 | 1.3 ± 0.6 | 2.2 ± 0.3 | 3.7 ± 0.6 | 1.5 ± 0.3 |
| Plasma volume, liters | 2.7 ± 0.2 | | | 3.2 ± 0.2 | | |

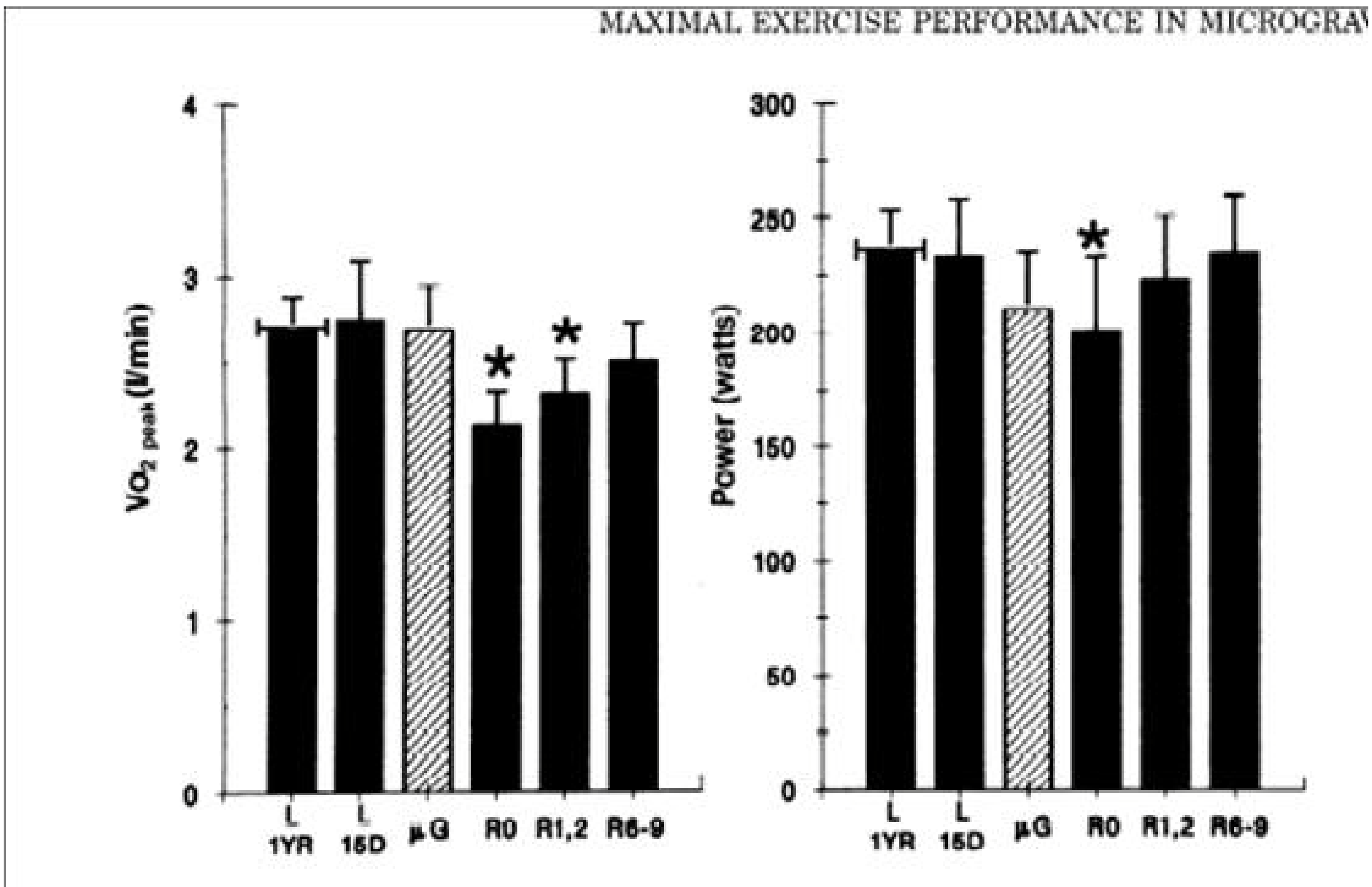
Values are means ± SE; *n*, no. of subjects. Supine, standing, and standing-supine difference measurements for all variables (plasma volume was only measured supine) are separated into presyncopal and nonpresyncopal groups on landing day. * $P < 0.05$ between groups. † $P < 0.01$ between groups.

# Catecholamine Responses to Standing




†p = 0.058 *p ≤ 0.05 **p ≤ 0.01

# Maximum Oxygen Uptake Preflight, In-flight and Postflight (all max tests)




Levine et al., Maximal exercise performance after adaptation to microgravity. JAP 81(2): 686-694, 1996.

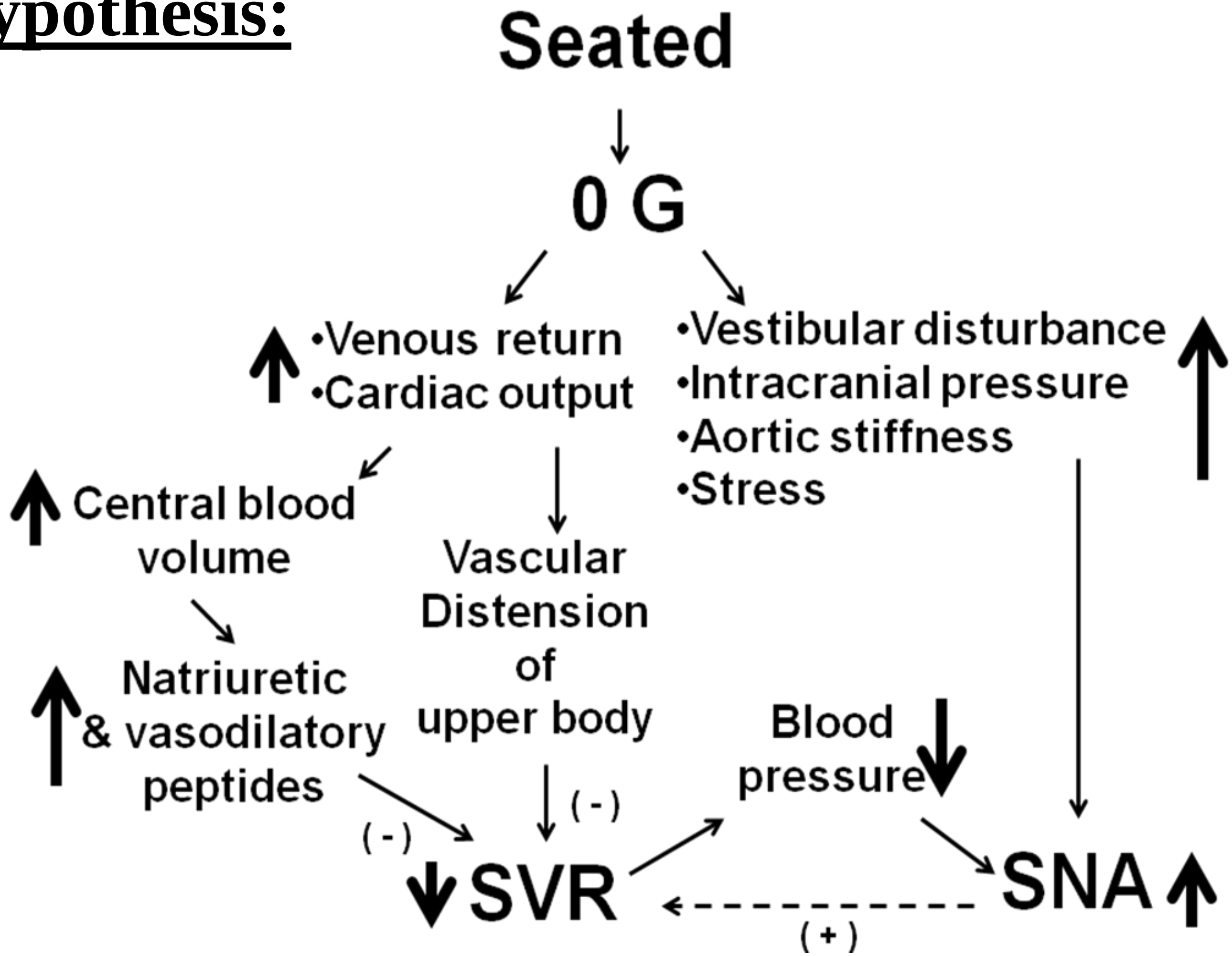
However -

Sympathetic nervous activity is high in space!

Vasodilatation
and
sympathetic
activation

how?

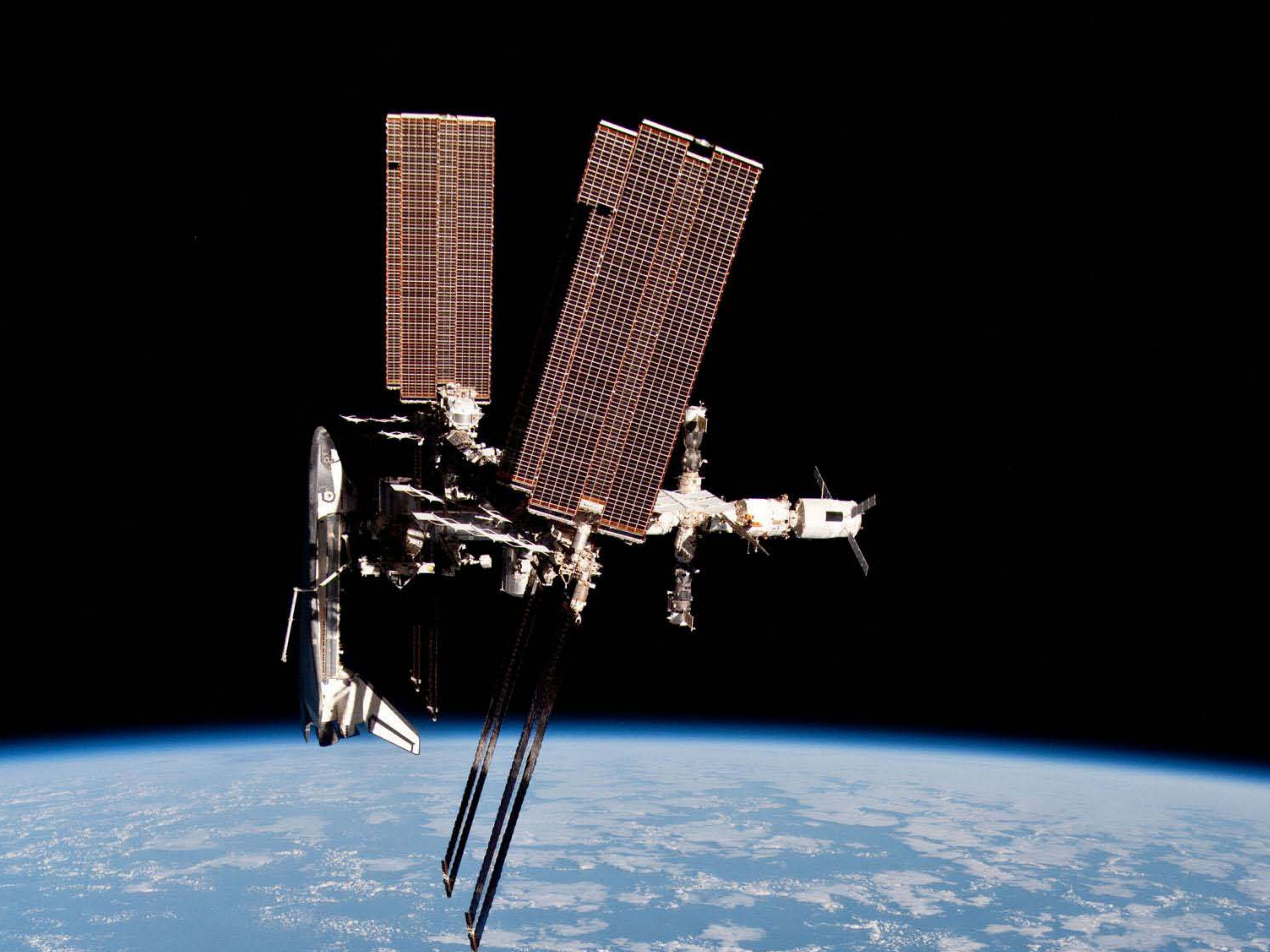
# Hypothesis:




Norsk & Christensen
Respir .Physiol. Neurobiol.
169 (Suppl. 1):S26-9, 2009.

ISS026E012919

**Paoli Nespoli**
European Space Agency astronaut



# Acknowledgements:

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Niels J. Christensen (Herlev Univ. Hosp., Denmark)
Ali Asmar (Univ. CPH, Denmark)
Morten Damgaard (Univ. CPH, Denmark).

**Laboratory technical assistance**

Jakob Utzon-Frank (Univ. ,CPH, Denmark)
Inge H. Petersen (Univ., CPH, Denmark)

**ESA assistance**

Poul Knudsen (Damec ApS)
Thomas A. E. Andersen (Damec ApS)

Allain Maillet (Cadmos, CNES)
Stephanie Herr (Cadmos, CNES)

Simone Thomas (ESA)
Astronauts (ESA)

**NASA assistance**

Clinic at NASA-Johnson Space Center
Astronauts

# Thank you