Effects of mental stress on autonomic cardiac modulation during weightlessness

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Submitted 16 September 2009; accepted in final form 29 October 2009

Aubert AE, Verheyden B, d’Ydewalle C, Beckers F, Van den Bergh O. Effects of mental stress on autonomic cardiac modulation during weightlessness. Am J Physiol Heart Circ Physiol 298: H202–H209, 2010. First published November 13, 2009; doi:10.1152/ajpheart.00865.2009.—Sustained weightlessness affects all body functions, among these also cardiovascular control mechanisms. How this may influence neural response to central stimulation by a mental arithmetic task remains an open question. The hypothesis was tested that microgravity alters cardiovascular neural response to standardization cognitive load stimuli. Beat-to-beat heart rate, brachial blood pressure, and respiratory frequency were collected in five astronauts, taking part in three different short-duration (10 to 11 days) space missions to the International Space Station. Data recording was performed in supine position 1 mo before launch; at 11 days (or 1 mo) before and 11 days (or 1 mo) after. Heart rate variability (HRV) parameters were obtained in the frequency domain. Measurements were performed in the control condition for 10 min and during a 5-min mental arithmetic stress task, consisting of deducting 17 from a four-digit number, read by a colleague, and orally announcing the result. Our results show that over all sessions (pre-, in-, and postflight), mental stress induced an average increase in mean heart rate (Δ7 ± 1 beats/min; P = 0.03) and mean arterial pressure (Δ7 ± 1 mmHg; P = 0.006). A sympathetic excitation during mental stress was shown from HRV parameters: increase of low frequency expressed in normalized units (Δ8.3 ± 1.4; P = 0.004) and low frequency/high frequency (Δ1.6 ± 0.3; P = 0.001) and decrease of high frequency expressed in normalized units (Δ8.9 ± 1.4; P = 0.004). The total power was not influenced by mental stress. No effect of spaceflight was found on baseline heart rate, mean arterial pressure, and HRV parameters. No differences in response to mental stress were found between pre-, in-, and postflight. Our findings confirm that a mental arithmetic task in astronauts elicits sympathovagal shifts and, accordingly, influence autonomic cardiac control.

The removal of gravitational stress in space induces a number of adaptive changes within the cardiovascular system (2, 17, 34). Consequently, on return to Earth, many astronauts have reduced orthostatic tolerance (10) and exercise capacity (14). The underlying mechanisms remain unclear, although impairment of neural cardiovascular regulation after spaceflight is thought to contribute to this problem. Impaired sympathetic vasoconstrictor regulation has been put forward as an important contributor to reduced orthostatic tolerance after spaceflight (10). Previous spaceflight studies have primarily focused on the effectiveness of sympathetic neural responses to baroreceptor (17) and peripheral afferent sensory stimulation (24) by using provocative maneuvers including Valsalva (15), lower body negative pressure (19), cold pressor (20), static (20), and dynamic exercise with (24) and without (17) occlusion. None of these studies provided evidence of impaired sympathetic responsiveness during and after exposure to microgravity. One aspect that has only been barely touched upon, especially in space studies (31), is the central activation of sympathetic outflow, which can be mediated by cognitive tasks (23).

Mental stress is routinely used in autonomic function testing and commonly provokes changes in cardiac function after increased sympathetic arousal (46). Mental stress can be induced by mental arithmetic, numbers reading backward, computer quiz, speech stress, and reaction time stress. In this study, the verbal form of mental arithmetic stress with performance feedback is used. Stress induced by a heavy mental task load can be enhanced by adding feedback on the performance (8) and, accordingly, influence autonomic cardiac control.

Direct microneurographical measure of muscle sympathetic nerve activity (MSNA) has shown that mental stress produces sympathoexcitatory and pressor responses with increasing MSNA (1, 11). Thus mental stress shows an impact on MSNA (1). Mental stress elicited under laboratory conditions increases heart rate and arterial pressure (16, 18, 21, 26, 42– 45). In our study a noninvasive evaluation of autonomic control during mental stress was performed with heart rate variability (HRV) tools. Cardiovascular variability estimated by power spectrum analysis [low frequency (LF), 0.04–0.15 Hz; and high frequency (HF), 0.15–0.4 Hz] has been proved to be a useful tool to investigate the autonomic balance, particularly when the LF-to-HF ratio and the LF and HF normalized units are computed (1a).

Space is also a very hostile and stressful environment (2, 33): living in closed quarters and in confinement, feeling of isolation, lack of privacy, occurrence of interpersonal conflicts, multicultural crew, situation-induced stress, background noise level, circadian dysynchrony, sleep disturbances, high work load, and fatigue, all inducing elevated levels of sympathetic nervous activity (13, 19, 20). Therefore, the question arises: “Will artificially induced stress under spaceflight conditions modify adaptive changes within the cardiovascular system?” If so, in which sense and to what extent? We wanted to test this by inducing mental stress in a standardized way before, during, and after microgravity.

In view of the limited data about mental stress in space, only one study in one astronaut (31), we focused on this largely
unexplored issue. We investigated autonomic cardiovascular control responses to mental arithmetic stress before, during, and after spaceflight. In this study, the hypothesis is tested that microgravity alters cardiovascular neural response to standardized cognitive load stimuli. We further hypothesize that these alterations will persist after return to Earth, until at least 4 days (5).

METHODS

Subjects.

This study was performed during three scientific European Space Agency (ESA)-Soyuz missions to the International Space Station (ISS; Odyssea, Cervantes, and Delta: 10- to 11-day missions). Five male astronauts were studied before, during, and after spaceflight. Mean age of the subjects at the time of the preflight data collection was 40 ± 3 yr, height was 180 ± 4 cm, and weight was 76 ± 10 kg.

In space, the astronauts had a busy scientific schedule and had neither physical exercise nor counter measures programmed. Upon return to Earth, there was also no specific rehabilitation program; in their spare time they were advised to rest.

The experimental protocol was approved by the local ethical committee and the ESA Medical Board. Each subject was informed of the experimental procedures and signed an informed consent form after reading a layman’s version of the protocol. The study complies with the Declaration of Helsinki.

Experimental Procedure

Pre- and postflight. The pre- and postflight data collection was performed in the morning (before 11 AM) in supine position. Initially, a period of at least 10 min was provided for instrumentation, calibration, and hemodynamic equilibration and 10-min recording in rest. Subjects were instructed to maintain their regular breathing depth and rhythm, which was verified by the operators using a respiratory sensor.

Preflight data collection was performed 1 mo before launch (L-30). Postflight data collections were performed at 1, 4, and 25 days after return to Earth (R+1, R+4, and R+25).

The tests were performed at ambient room temperature (21–23°C) in a quiet room at the Gagarin Cosmonaut Training Center in Moscow, Russia. Late postflight R+25 (between 25 and 28 days after landing) data collection was performed in a temperature-controlled laboratory (21–23°C) in the University Hospital Gasthuisberg of Leuven, Belgium. The subjects were asked to refrain from alcoholic or caffeinated beverages for at least 9 h before the measurements.

After baseline recording, a mental arithmetic stress task of 5 min required subjects to subtract 17 from a four-digit number, displayed in a matrix and read to them by an investigator, and orally announce the result. In case of a correct answer, a new number was read; in case of a wrong answer, a verbal error message was given and a new number was read. There was no time pressure exerted by the investigator. During the mental arithmetic task the subjects were silent while another person read the numbers after they calculated the result. Mean timing of the latter period was 3.8 s (0.26 Hz). The result was then announced verbally, with a mean timing of 3 s (0.34 Hz).

Postflight. The crew of the ISS live according to Universal Time with three 8-h shifts (work, leisure, sleep), although one orbit takes only 90 min. After self-instrumentation of the astronaut, several minutes (5–10 min) passed before the start of the actual baseline data recording. Data collection in space was performed in the morning during 10 min in floating conditions with the feet of the astronauts under a belt to keep position on day 5 and/or day 8 in the ISS. The astronauts were carefully trained to perform the inflight measurements by themselves. They were guided through the experiment by dedicated software (6), allowing standardization of test procedures. The mental arithmetic stress test in space was exactly the same as pre- and postflight, with the numbers read by a colleague.

Measurements and Data Processing

Pre- and postflight. Heart rate was measured continuously in the supine position using a standard ECG apparatus (amplifier/programmer, Medtronic 9690; Minneapolis, MN). Brachial arterial pressure was obtained from a sphygmomanometer at the left arm (STBP-780; Colin, Komaki, Japan). The average of three readings was calculated to obtain representative values of systolic arterial pressure (SAP) and diastolic arterial pressure (DAP). Mean arterial pressure (MAP) was calculated with the standard formula: MAP = (2 × DAP + SAP)/3. Respiration movement was measured by an abdominal pressure sensor connected to the MR10 Respiration Monitor (Graseby Medical Limited, Hertfordshire, UK).

These signals were sampled using an external analog-to-digital converter (DI220PGH, 12-bit precision; Dataq Instruments, Akron, OH) at a frequency of 1,000 Hz per channel, thus giving a time resolution of 1 ms and stored on a personal computer for later offline processing.

Inflight. A spaceflight-certified ECG device was used to record heart rate continuously (Cardioscience, TNO-BMI, Amsterdam, The Netherlands). Reference values for blood pressure were obtained with an automatic sphygmomanometer (Puritan Bennett D500; Pleasanton, CA). Respiratory movements were assessed by an inductance plethysmograph, incorporated into the cardioscience equipment. Inflight data were sampled at 100 Hz per channel and stored on a flash memory for offline analysis. The personal computer hard disk was later downloaded from space for further offline analysis.

Data analysis: HRV. After peak detection on the ECG signals, a file consisting of consecutive RR interval (RR) values was created. Adequacy of peak detection was controlled by an expert before the time series were exported as a spreadsheet file. Subsequent analysis was performed offline with methods previously published (4). The resulting beat-to-beat hemodynamic time series were interpolated using a third order cubic-spline approximation and were resampled at 2 Hz to construct equidistant time series. Power spectra were obtained using a fast Fourier transform (FFT). FFT was calculated in windows of 256 points with 50% overlap. Power spectral density (PSD) in squared milliseconds per Hertz for tachograms was then computed. The spectral resolution for all estimates equaled 0.0078 Hz. Two frequency bands were defined as recommended by the Task Force (1a): a low-frequency (LF) band from 0.04 to 0.15 Hz and a high-frequency (HF) band from 0.15 to 0.4 Hz. Power (in squared milliseconds) in these frequency bands was computed by integrating the PSD between these limits. To correct for large variations in total power (0.078–0.5 Hz), LF and HF are expressed in normalized units ([LFnu = LF × 100/(LF + HF); and HFnu = HF × 100/(LF + HF)]) and as a low-frequency-to-high frequency (LF-HF) ratio.

Statistical analysis

Statistical analysis was performed with SPSS 13.0 for Windows (Scientific Packages for Social Sciences, Chicago, IL). Data are given as means ± SE. Heart rate and MAP changes due to arithmetic stress were calculated as the differences between heart rate and MAP at rest (baseline) and measured during mental stress. A two-way repeated-measures ANOVA was used to compare dependent variables with study effects of stress (factor condition: baseline vs. stress) and timing (factor timing: pre-, in-, and postflight). Mauchly’s test of sphericity was conducted with Greenhouse-Geisser correction if necessary. Values of the responses of the HRV parameters were tested for normal distribution with the Kolmogorov-Smirnov test and log transformed when necessary. Preflight data (L-30) were compared with postflight (R+25) with a paired t-test. Means were considered significantly different when P < 0.05.
RESULTS

Learning or habituation effects were excluded since no significant differences were found between data obtained pre-flight at L-30 and postflight on R/H110025, when effects of microgravity have already disappeared.

Mean values for RR interval length, DAP, SAP, and MAP and HRV parameters, both in absolute and in normalized units, for baseline and mental stress conditions during pre-, in-, and postflight periods are found in Table 1. The results of repeated-measures ANOVA show that both the baseline cardiovascular data as well as cardiovascular responses to mental arithmetic stress did not differ significantly across pre-, in- and postflight experimental sessions (no significant interaction effect).

Globally, included over all sessions (pre-, in-, and post-flight), mental arithmetic stress significantly increased heart rate by 90 ± 1 beats/min (P = 0.03; indicated by shortened RR interval in Table 1) and MAP by 7 ± 1 mmHg (P = 0.006). In addition, LFnu increased significantly by 8.3 ± 1.4 (P = 0.004), and HFnu decreased significantly by 8.9 ± 1.4 (P = 0.004). Consequently, the LF-to-HF ratio significantly increased by 1.6 ± 0.3 (P = 0.001). No significant difference in HF (in absolute units) was shown before/after mental stress over the conditions. The power spectrum was not significantly different between baseline and stress.

During baseline recording the subjects were breathing freely at a mean rate of 15 breaths/min (0.25 Hz). The data of the breathing frequency during control and stress conditions (Fig. 4) were used to verify that the respiratory frequency was well within the HF limits (0.15–0.4 Hz).

Table 1. Values of RR, heart rate variability parameters, and blood pressure in supine position before spaceflight, during spaceflight, and supine position during recovery after return to Earth, all in the control situation and during arithmetic stress

<table>
<thead>
<tr>
<th>Parameter and Condition</th>
<th>30 Days Before Spaceflight</th>
<th>Space</th>
<th>Days After Return to Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SE</td>
<td>Mean</td>
</tr>
<tr>
<td>RR, ms</td>
<td>999</td>
<td>51</td>
<td>990</td>
</tr>
<tr>
<td>Control</td>
<td>999</td>
<td>50</td>
<td>869</td>
</tr>
<tr>
<td>Power spectrum, ms²</td>
<td>2,957</td>
<td>1,264</td>
<td>2,870</td>
</tr>
<tr>
<td>Control</td>
<td>4,752</td>
<td>2,035</td>
<td>3,876</td>
</tr>
<tr>
<td>Stress</td>
<td>1,250</td>
<td>574</td>
<td>1,620</td>
</tr>
<tr>
<td>LF, ms²</td>
<td>2,250</td>
<td>988</td>
<td>2,068</td>
</tr>
<tr>
<td>Control</td>
<td>71</td>
<td>3</td>
<td>74</td>
</tr>
<tr>
<td>Stress</td>
<td>82</td>
<td>2</td>
<td>83</td>
</tr>
<tr>
<td>HF, ms²</td>
<td>462</td>
<td>168</td>
<td>435</td>
</tr>
<tr>
<td>Control</td>
<td>675</td>
<td>325</td>
<td>414</td>
</tr>
<tr>
<td>Stress</td>
<td>29.5</td>
<td>3.3</td>
<td>23.0</td>
</tr>
<tr>
<td>LF/HF</td>
<td>18.3</td>
<td>1.8</td>
<td>13.0</td>
</tr>
<tr>
<td>Control</td>
<td>2.6</td>
<td>0.4</td>
<td>3.9</td>
</tr>
<tr>
<td>Stress</td>
<td>5.0</td>
<td>1.2</td>
<td>5.6</td>
</tr>
<tr>
<td>Arterial pressure, mmHg</td>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Control</td>
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<td>5</td>
<td>69</td>
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<tr>
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<tr>
<td>Systolic</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>116</td>
<td>5</td>
<td>118</td>
</tr>
<tr>
<td>Stress</td>
<td>129</td>
<td>3</td>
<td>130</td>
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<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
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<td>5</td>
<td>82</td>
</tr>
<tr>
<td>Stress</td>
<td>88</td>
<td>4</td>
<td>92</td>
</tr>
</tbody>
</table>

LF and HF, low and high frequency, respectively; LFnu and HFnu, LF and HF expressed in normalized units, respectively.
DISCUSSION

The present study is the first to examine cardiovascular responses to mental arithmetic stress in five astronauts before, during, and after spaceflight with methods derived from HRV. Our primary findings are twofold.

First, changes in cardiac neural response to mental arithmetic stress in astronauts preflight are not modified in space or after spaceflight, since no changes in heart rate, MAP values, and HRV parameters (Table 1 and Figs. 1–3) were observed.

Finally, we found no evidence of enhanced sympathovagal modulation on baseline recordings during or after spaceflight, as obtained from cardiovascular data or from HRV parameters, as we have also shown previously (5, 48, 49). This finding seems in contrast with the previously reported high levels of sympathetic nervous activity during spaceflight (13, 19). However, in the latter study heart rate at rest in space was also not increased relative to preflight.

Thus our hypothesis that sympathoexcitation during and after spaceflight will alter cardiovascular neural responses to mental arithmetic stress has to be rejected.

Autonomic Cardiac Control and Arithmetic Mental Stress on Earth

The cardiovascular system in healthy humans at rest is to a large extent under vagal control (40). Therefore, in this study a mental arithmetic task was carried out to modify the sympathovagal balance. It was chosen since it consistently induces sustained psychological stress, resulting in an autonomic profile of sympathetic activation (increase in LF) and parasympathetic inhibition (decrease in HF) and consequently resulting in a shift of the sympathovagal balance (increased ratio LF to HF), manifested by a sustained increase in heart rate and in blood pressure (16, 18, 21, 26, 30, 42–45). Similar increases of heart rate and blood pressure and results of HRV parameters were also observed in
this study (Table 1 and Figs. 1 and 2), proving the validity of the mental arithmetic stress test as used in our astronaut group. A standardized task was imposed that could easily be performed on Earth and in space (6). A basic problem comparing data from the literature is the lack of standardization of stressors (see also section on breathing) (12).

Values obtained in this study for heart rate increase (Δ7 beats/min) and MAP increase (Δ8 mmHg) are similar to values on Earth obtained by Guasti et al. (21) in 24 subjects (Δ7 beats/min) and Mezzacappa et al. (35) in 27 subjects (Δ5 beats/min and Δ9 mmHg).

On the other hand, our data are slightly lower than Berntson et al. (9) in 16 subjects (Δ11 beats/min) and Isowa et al. (26) in 53 subjects (Δ15 beats/min and Δ24 mmHg). Because astronauts are a highly selected group, for their cognitive function and psychological equilibrium, and are highly trained individuals to be stress resistant, it can be assumed that their cardiac response to induced stress is less than in a general population. Various methodologies for applying mental arithmetic stress tests could also lead to scattering in reported data.

Rapid increase in heart rate during mental stress is mostly due to vagal withdrawal (32). Arterial pressure increase during mental stress is mostly induced by means of peripheral α-adrenergic vascular stimulation, mediated by central activation (50, 51), although some influences of cardiac β-adrenergic stimulation combined with vagal withdrawal should also be considered (25). These concepts are supported by observations of sympathetic neural activation during mental stress (18, 27) and by HRV data of autonomic cardiovascular control: increase of LF, decrease of HF, and increase of the ratio LF to HF (21, 26, 42). In response to mental arithmetic stress, Moriguchi et al. (36) also observed enhanced LF power and LF-to-HF power ratio, which are both indexes of sympathetic activity to some extent (1a).

All published results so far describing the influence of mental arithmetic stress on autonomic cardiac control are in agreement with previous statements (16, 21, 26, 42, 43) with, however, the exception of one study by Sloan et al. (45), where it was shown that the LF component decreased but LF/HF remained constant when comparing baseline and stress condition. The level of induced stress was most probably too small to enhance sympathetic modulation.

**Arithmetic Mental Stress and Real and Simulated Microgravity by Head Down-Bed Rest**

During spaceflight in microgravity conditions, heart rate and blood pressure remain similar (5, 49) as well as a stable sympathovagal balance (17), all compared with supine pretight values. Differences in LF/HF, generally considered to reflect sympathovagal balance (3, 32), are not different between pre-, in-, and postflight conditions (5).

To the best of our knowledge there has been only one previous anecdotal report about one astronaut (31), who was subjected to mental arithmetic stress before, during, and after spaceflight. Plasma epinephrine and norepinephrine levels were measured to determine the sympathoadrenal response to arithmetic stress. In contrast with our results, no alterations of the sympathoadrenal system were found on Earth during the mental stress test and in space the authors found an activation of the sympathoadrenal system as shown by an increase in plasma catecholamine levels (epinephrine and norepinephrine) during mental stress. However, since only one subject was concerned, no significance levels could be given.

Because life science studies in space are difficult and expensive to perform, head down-bed rest (HDBR) has been proposed as a ground-based analog of microgravity. HDBR is similar to spaceflight in so far that a reduction of the Gz gravitational vector and lying continuously under an angle of 6° (with head down) mimic spaceflight as it reproduces some adaptations on body responses that occur in microgravity. These include an upward shift of body fluids (in space leading to puffy face), absence of changes in posture, unloading of the body’s upright weight, the absence of working against the force of gravity, reduced energy requirements, the absence of linear acceleration, reduced proprioceptive stimulation, altered social interactive and work/rest cues, and a reduction in overall sensory stimulation. Data on heart rate during HDBR are few with no change or a progressive increase over time, as well as for MAP (27, 39).

Therefore, HDBR has often been used as an alternative to spaceflight and, in some cases, to study influence of mental stress. In a few studies where subjects were submitted to a stress test during HDBR, the following results for heart rate and MAP increase were reported: Durocher et al. (18) found Δ12 beats/min and Δ11 mmHg in 11 subjects, Pagani et al. (38) found increases of Δ15 beats/min and Δ8 mmHg in eight subjects, and Kamiya et al. (27) showed an increase of Δ9 beats/min and Δ15 mmHg in 24 subjects.

In our study for mental stress during real spaceflight and, thus, weightlessness, we found, respectively (Table 1 and Figs. 1 and 2), Δ8 beats/min and Δ10 mmHg, values comparable or slightly less than values obtained during simulation studies.

Pagani et al. (38) determined arithmetic stress during HDBR on day 38 in seven subjects using HRV methods. They reported an increase in LFnu of Δ22 and a decrease in HFnu of Δ23, to be compared with our values of, respectively, Δ9 and Δ10 during microgravity. A possible reason for their large values could be a shift in respiration frequency from 0.25 Hz to 0.16 Hz, leading already to some overflow into the LF band (between 0.04 and 0.15 Hz). Moreover, comparison of data with this study is hampered since no details are given of the methodology used for the mental arithmetic stress.

**Mental Arithmetic, Verbalization, and Breathing**

The question arises whether talking or reading (silently or aloud) can in itself lead to effects on HRV parameters, unrelated to induced stress by a specific task (5, 7). Respiratory changes produced by speech can markedly alter the variability and the spectral content of RR. Indeed, slow breathing can shift the respiratory frequency (respiratory sinus arrhythmia) into the LF band (below 0.15 Hz), thus increasing LF and decreasing HF power spectral density, without a concomitant sympathetic activation (7, 37, 49). Novak et al. (37) studied coupling between the respiratory and cardiovascular systems by continuously slowing respiration rate from 0.46 to 0.05 Hz. They showed that at respiration rates from 0.25 to 0.35 Hz the RR power spectral density remained fairly constant. Thus our results (Table 1 and Fig. 3) about HRV parameters reflect true influence of the arithmetic task on the autonomic cardiovascu-
lar control mechanism and are not influenced by a change in respiratory rate. Previously, we showed in astronauts that in the supine control situation during spontaneous breathing for preflight, in space and during recovery respiration frequency varied between 0.25 and 0.3 Hz (5) in line with our results for baseline recording (Fig. 4). A similar value (0.25 Hz) was shown in normal volunteers for spontaneous breathing (7).

Some conflicting data have been presented concerning respiration rate and mental stress: a large reduction in respiratory rate from 0.29 Hz to within the LF band (below 0.14 Hz) (7), a small decrease from 0.28 to 0.19 Hz (22), or no change (0.27 Hz for baseline as well as for stress) (9). In our study we found an increase in respiration rate from 0.25 Hz (15 breaths/min) for baseline to about 0.35 Hz (20 breaths/min) during stress under all circumstances (preflight, inflight, and recovery); both frequencies are well within the HF limit (0.15–0.4 Hz). A possible explanation for this discrepancy comes possibly from various methodologies used during the tests to be used by the subject: the arithmetic task is often quite different from one experiment to another such as verbalization (35, 52) or silence (27) during the task; different numbers of digits (from 2 to 4) (52); duration of stress test from 1 min (35), 5 min (22, 38), 8 min (52), 10 min (27), or even 15 min (26); or race against time (9). In our case, the astronauts first had to listen to a number (silent period) followed by silent determination of the result and loud announcement of the result, which is in contrast with continuous speaking. Most probably, respiration rate was imposed by the length of the verbalization period at 0.34 Hz.

Limitations

Many confounding factors may come into play when interpreting results from different human life science experiments conducted in space. A common problem is the small number of subjects (15, 17, 19, 20, 24, 31, 34, 49) and/or space missions allowing specific flight-related psychological stressors affecting the study outcome. However, our number of five subjects is well within numbers of subjects usually presented in cardiovascular studies in space (15, 17, 19, 20, 24, 31, 34, 49). Hence, we present the individual data as much as possible. Moreover, astronauts are a highly selected and homogeneous population and, therefore, conclusions can already be drawn from a much smaller population compared with the numbers required for clinical and sociological studies (41). Another problem involves the impact of standard operation procedures on the experimental protocols in space. For obvious reasons the reader of the investigators) compared with in space (a colleague astronaut). How far this procedure could influence the elicited stress level remains an open question.

In this study we performed a well-controlled experiment, using a standardized computer-guided protocol on Earth and in space (6) across three short duration space missions, with the ground-based supine position as a reference. We, therefore, feel confident with the present results in assuring high quality control of our data. It has been acknowledged that the various stress tests used for clinical and experimental purposes may induce different cardiovascular responses and that laboratory stressors are not highly reproducible (9). Mental arithmetic task is a widely used task to induce stress, and our data follow the generally accepted consequences and results of mental stressors (21, 33). The subjective level of stress was not determined, although it has been shown that induced stress is not related to a determination of the stress level (7, 28, 29).

Conclusion

This investigation is the first study to examine the cardiovascular responses with HRV methods to mental stress during spaceflight and exposure to real microgravity and under controlled conditions in five astronauts. We conclude that a mental arithmetic task is a valid mental stress tool in astronauts on Earth, since it elicits sympathovagal shifts toward enhanced sympathetic modulation and reduced vagal modulation. However, these responses are not changed in space during microgravity or after return to Earth. No evidence of sympathoexcitation during or after spaceflight was found.

Acknowledgments

We thank the astronauts and cosmonauts from the ESA Odissea, Cervantes, and Delta flights for reliable and outstanding efforts both as researchers and as subjects in space. Special acknowledgment must also be made of the efforts of the European and Russian Space Agencies in supporting these missions. A special thanks to the persons at European Space Research and Technology Centre (Noordwijk, The Netherlands) and Gagarin Cosmonaut Training Center (Star City, Moscow, Russia), whose help before and after the spaceflights was invaluable.

Grants

This work was funded by granting from the European Space Agency Council and Programme de Développement d’Experiences scientifiques (ESA-PRODEX) from the Belgian Federal Office of Scientific Affairs. F. Beckers is a postdoctoral researcher of the Research Fund Katholieke Universiteit Leuven. B. Verheyden is a postdoctoral researcher from ESA-PRODEX grants from the Belgian Federal Office of Scientific Affairs.

Disclosures

None.

References

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and mental stress with or without verbalization on heart rate variability. 


