Marked Exacerbation of Orthostatic Intolerance After Long- vs. Short-Duration Spaceflight in Veteran Astronauts

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Objective: The incidence of postflight orthostatic intolerance after short-duration spaceflight is about 20%. However, the incidence after long-duration spaceflight was unknown. The purpose of this study was to test the hypothesis that orthostatic intolerance is more severe after long-duration than after short-duration flight. **Methods:** We performed tilt tests on six astronauts before and after long-duration (129–190 days) spaceflights and compared these data with data obtained during stand tests before and after previous short-duration missions. **Results:** Five of the six astronauts studied became presyncopal during tilt testing after long-duration flights. Only one had become presyncopal during stand testing after short-duration flights. We also compared the long-duration flight tilt test data to tilt test data from 20 different astronauts who flew on the short-duration Shuttle missions that delivered and recovered the astronauts to and from the Mir Space Station. Five of these 20 astronauts became presyncopal on landing day. Heart rate responses to tilt were no different between astronauts on long-duration flights and astronauts on short-duration flights, but long-duration subjects had lower stroke volumes and cardiac outputs than short-duration presyncopal subjects, suggesting a possible decrease in cardiac contractile function. One subject had subnormal norepinephrine release with upright posture after the long flight but not after the short flight. Plasma volume losses were not greater after long flights. **Conclusion:** Long-duration spaceflight markedly increases orthostatic intolerance, probably with multiple contributing factors. **Key words:** autonomic nervous system, long-duration spaceflight, microgravity, plasma volume, presyncope, tilt testing.

bpm = beats per minute.

INTRODUCTION

The best documented consequence of the cardiovascular changes associated with short-duration spaceflight is postflight orthostatic intolerance. About 20% of astronauts are unable to complete 10 minutes of unassisted standing after 4 to 18 days of spaceflight (1, 2). Recent studies have indicated that both plasma volume losses (3, 4) and autonomic dysfunction (5–7) may contribute to this problem. At least two studies (7, 8) have noted that some astronauts are more susceptible to postflight orthostatic intolerance than others, and one (7) showed that the more susceptible astronauts display a subnormal release of norepinephrine on standing on landing day.

These perturbations may be even more apparent or severe after long-duration (4–6 months) spaceflight. To date, however, no data exist on the incidence or severity of orthostatic intolerance after long-duration spaceflight. The purpose of this study was to test the hypothesis that orthostatic intolerance is more severe after long-duration than short-duration flight. Tilt tests were performed on six veteran astronauts after long-duration spaceflight, and the data were compared with two types of short-duration data: first, retrospective comparisons were made with the stand test data previously obtained from the six astronauts after their previous short Shuttle flights; and second, comparisons were made with tilt test data from 20 astronauts who flew on the short Shuttle flights that delivered and recovered the long-duration astronauts to and from the Mir.

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Received for publication September 12, 2000; revision received February 5, 2001.

METHODS

This protocol was approved by the Johnson Space Center Institutional Review Board.

Subjects

Subjects were 26 American astronauts aged 33 to 55 years. Six of the 26 (5 men, 1 woman) were veteran astronauts; these 6 were studied before and after their 129- to 190-day missions, which included stays aboard the Russian Space Station Mir. To make intraindividual comparisons in these six astronauts, we retrieved stand test data collected when they had flown on short-duration Shuttle flights 2.5–4.5 years earlier. If they had flown on more than one Shuttle flight, the data from the most recent flight were used for analyses. In addition to these comparisons, because of the problems inherent in comparing stand test and tilt test data, tilt test data from 20 different astronauts (15 men, 5 women) who flew on the Shuttle flights that carried the long-duration crew members to and from the Mir were also used. Interindividual comparisons were thus made using tilt data from short- and long-duration flights. All subjects launched on the American Shuttle. Long-duration flight subjects were transferred from the Shuttle to the Mir, stayed for about 4 to 6

0033-3174/01/6306-0865

months, were then transferred back to a different Shuttle that had been launched to pick them up, and landed 7 to 9 days later.

On landing days, all subjects consumed the equivalent of an isotonic saline solution (14 ml of fluid per kg of preflight body weight) 1 to 2 hours before landing (the standard fluid loading procedure). Between landing and the time of the tilt tests, they drank water ad libitum, and most had a light snack shortly after landing. Aboard the Mir, individual experiences varied. The prescribed exercise regimen consisted of two 1-hour sessions on a treadmill or cycle ergometer daily. However, this protocol was not always possible because of numerous operational constraints.

Orthostatic Tolerance Testing

Testing schedules for all subjects are presented in Table 1. At the start of each tilt test, subjects were instrumented for an electrocardiogram, manual blood pressure (sphygmomanometer), and beat-to-beat finger blood pressure (Finapres, Ohmeda, Englewood, CO). Two-dimensional and M-mode echocardiography were used to determine aortic cross-sectional diameter at cusp insertion, and aortic flow was measured with continuous-wave Doppler ultrasound. The arm with the hand on which the Finapres was attached was strapped to an arm board, which was adjusted so that the finger remained at heart level during upright posture. Measurements were taken during 5 minutes of supine rest and continued while subjects were tilted to an 80-degree upright position for 10 minutes or until presyncopal symptoms (lightheadedness, dizziness, graying out, or systolic blood pressure below 70 mm Hg) occurred, at which time the test was terminated. Five long-duration flight subjects also allowed measurements of plasma and red cell volumes while supine. Of those five, one long-duration subject also allowed measurements of supine and upright plasma catecholamine levels.

The stand tests, which previously had been performed on the six long-duration crew members before and after their short flights, consisted of only 5 minutes supine and 10 minutes standing, electrocardiogram, and manual blood pressure. However, in one crew member, supine and standing stroke volume, cardiac output, peripheral vascular resistance, and plasma catecholamines, and supine red cell and plasma volume also had been measured. This crew member was the same individual who allowed these additional measurements during the tilt testing before and after the long mission. Thus, in this individual we had the same measurements for short and long flights, with the only difference being that a stand test was used before and after the short flight and a tilt test was used before and after the long flight.

Biochemical Analyses

Plasma norepinephrine and epinephrine levels were determined with a radioenzymatic assay (9). Plasma volumes and red cell volumes were measured using a standard carbon monoxide rebreathing method (10–12).

Statistical Analyses

All data are presented as mean ± SEM. The following variables were compared for the last minute supine and the last standing measurement: arterial pressure, stroke volume, cardiac output (stroke volume × heart rate), and total peripheral resistance (mean arterial pressure/cardiac output). Data from the short-duration flight stand tests and the long-duration flight tilt tests were compared in the six subjects who had both experiences. For this analysis, only arterial pressure and heart rate were compared because no other data were available for the short flights. In addition, tilt test data from long- ($N = 6$) and short-duration flights ($N = 20$) were compared. Astronauts were grouped into long-duration presyncopal, long-duration nonpresyncopal, short-duration presyncopal, and short-duration nonpresyncopal subjects to test for intergroup differences. A repeated-measures multiple analysis of variance was used. Student's t tests were performed to document differences in variables when there was a significant main effect. The incidence of presyncope between short and long flights was compared using a χ^2 test.

RESULTS

Figure 1 compares the incidence of presyncope during stand and tilt tests after short flights and during tilt tests after long flights. The incidence during tilt tests after long flights was significantly greater than it was during either stand tests or tilt tests after the short flights. During stand tests after short flights, only one of the six crew members (17%) had become presyncopal. During tilt tests after short flights, slightly more (25%) became presyncopal. During tilt tests after the long flights, five of the six astronauts (83%) became presyncopal. No subject became presyncopal during preflight testing or during testing 2 to 4 days after landing. All of the presyncopal incidents after the short flights were preceded by a steady decline in systolic and diastolic pressures until the hypotension could not be tolerated, similar to the pattern shown in Figure 3, and similar to our previous report (7). However, the pattern of presyncope after the long flights was not uniform. Of the five events, two were preceded by the steady declines in pressure similar to that seen after the short flights. However, three maintained

TABLE 1. Subjects and Testing Schedules

	Subjects 1–6[a]		Subjects 7–26[b]
Type of test	Stand test	Tilt test	Tilt test
Mission duration	Short (8–16 d)	Long (129–190 d)	Short (8–16 d)
Testing schedule	1. Preflight 2. Landing day 3. 2–4 d postlanding	1. Preflight 2. Landing day 3. 2–4 d postlanding	1. Preflight 2. Landing day

[a] Flew short and long missions.
[b] Flew only short missions.

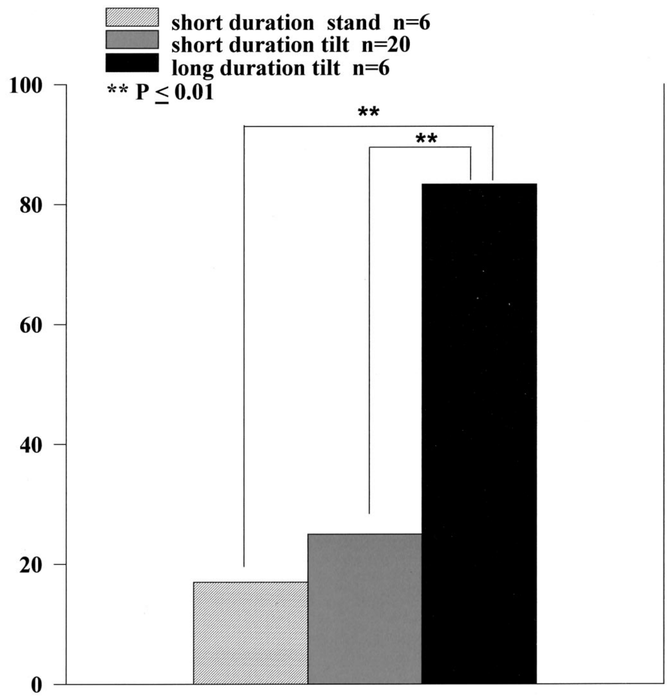

Fig. 1. Incidence of presyncope during stand and tilt testing after short- and long-duration flights. Presyncope is defined as the failure to complete 10 minutes of 80° upright tilt without symptoms.

upright pressure well until they experienced sudden vasodepressor presyncope.

Table 2 presents data (last minute supine, last standing measurement, and standing − supine) for all tilt tests before flight. Subjects are grouped according to whether they did or did not become presyncopal during their tilt tests on landing day. The groups are as follows: long-duration presyncopal (N = 5), short-duration presyncopal (N = 5), long-duration nonpresyncopal (N = 1), and short-duration nonpresyncopal (N = 15). There were no intergroup differences in preflight measurements. Table 3 presents the same information for tilt tests performed on landing day. Comparison of presyncopal and nonpresyncopal subjects confirmed previous findings: the presyncopal subjects had lower standing systolic and diastolic pressures and total peripheral resistance. However, new findings were seen when short-flight presyncopal subjects and long-flight presyncopal subjects were compared. Heart rate responses to upright posture were not different between groups. However, as a group, long-flight presyncopal subjects had significantly greater upright peripheral vascular resistance, and lower stroke volumes and cardiac outputs, than the short-flight presyncopal subjects. These findings may relate to the differences in the arterial pressure patterns that preceded presyncope, which were mentioned above.

Figures 2 and 3 show data from two long-duration flight subjects who experienced different patterns of presyncope on landing day. Figure 2 depicts beat-to-beat arterial pressure and heart rate for subject A after a short (*top*) and a long (*bottom*) flight. After the short flight, subject A maintained stable arterial pressure from the time of upright posture (*horizontal arrow*) throughout the test, with the heart rate stabilizing at about 60 bpm. After the long flight, upright arterial pressure was maintained for only about 2 minutes (*horizontal bar*), with a heart rate about 100 bpm. At

TABLE 2. Preflight Measurements[a]

	Long-Duration Subjects			Short-Duration Subjects		
	Supine	Standing	Standing − Supine	Supine	Standing	Standing − Supine
Presyncopal subjects[b]						
Systolic pressure, mm Hg	119.8 ± 4.4	115.8 ± 7.8	−4.0 ± 6.2	129.0 ± 3.1	123.3 ± 0.4	−5.8 ± 5.7
Diastolic pressure, mm Hg	74.8 ± 6.4	79.2 ± 6.3	4.4 ± 2.8	77.3 ± 7.5	79.5 ± 5.7	1.8 ± 5.3
Heart rate, bpm	62.2 ± 2.3	83.8 ± 2.5	20.0 ± 4.4	64.0 ± 6.7	82.3 ± 7.8	18.3 ± 3.7
Stroke volume, ml	77.3 ± 15.6	35.8 ± 7.5	−41.5 ± 20.8	84.1 ± 9.7	39.0 ± 6.3	−41.0 ± 9.9
Cardiac output, l/min	4.7 ± 0.2	3.0 ± 0.6	−1.7 ± 0.2	4.5 ± 0.6	3.1 ± 0.4	−1.1 ± 0.8
Peripheral vascular resistance, mm Hg · 1^{-1} · min	17.3 ± 0.9	30.5 ± 5.6	13.2 ± 5.6	18.6 ± 2.3	27.9 ± 1.5	9.2 ± 2.3
Nonpresyncopal subjects[c]						
Systolic pressure, mm Hg	116.0	120.0	4.0	115.4 ± 3.1	113.9 ± 3.4	−1.5 ± 1.9
Diastolic pressure, mm Hg	58.0	64.0	6.0	68.9 ± 2.3	73.4 ± 2.0	4.2 ± 1.0
Heart rate, bpm	62.0	74.0	12.0	60.9 ± 2.3	82.1 ± 3.1	20.6 ± 1.7
Stroke volume, ml	110.0	59.4	−50.5	73.0 ± 4.7	32.8 ± 2.1	−40.2 ± 3.6
Cardiac output, l/min	7.0	4.5	−2.5	4.3 ± 0.2	2.6 ± 0.2	−1.7 ± 0.2
Peripheral vascular resistance, mm Hg · 1^{-1} · min	11.1	18.4	7.3	20.7 ± 1.5	34.3 ± 2.5	13.6 ± 1.9

[a] Values are mean ± SE. Supine, standing, and standing minus supine difference measurements for all variables between groups.
[b] Long-duration presyncopal subjects, N = 5; short-duration presyncopal subjects, N = 5.
[c] Long-duration nonpresyncopal subjects, N = 1; short-duration nonpresyncopal subjects, N = 15.

TABLE 3. Landing Day Measurements[a]

	Long-Duration Subjects			Short-Duration Subjects		
	Supine	Standing	Standing − Supine	Supine	Standing	Standing − Supine
Presyncopal subjects[b]						
Systolic pressure, mm Hg	132.8 ± 5.2	90.6 ± 8.1[d]	−42.2 ± 10.6[d]	131.0 ± 6.9	86.3 ± 10.2[f]	−44.8 ± 11.6[f]
Diastolic pressure, mm Hg	77.6 ± 1.9	55.8 ± 2.6[d]	−21.8 ± 2.2[d]	79.0 ± 4.7	54.8 ± 5.2[f]	−24.2 ± 8.5[f]
Heart rate, bpm	65.4 ± 5.5	89.0 ± 5.0	27.2 ± 5.6	68.3 ± 10.0	91.8 ± 11.6	23.5 ± 1.8
Stroke volume, ml	59.8 ± 4.1	26.1 ± 2.6	−38.7 ± 6.8	68.9 ± 9.0	34.1 ± 4.5	−33.9 ± 12.3
Cardiac output, l/min	3.7 ± 0.2[e]	2.3 ± 0.3[e]	−1.4 ± 0.2	4.4 ± 0.2[e]	3.2 ± 0.3[e]	−1.2 ± 0.4
Peripheral vascular resistance, mm Hg · 1^{-1} · min	26.7 ± 3.0	39.1 ± 3.3[e]	12.5 ± 3.7	20.6 ± 1.6	24.2 ± 3.4[e]	6.3 ± 5.0[e]
Nonpresyncopal subjects[c]						
Systolic pressure, mm Hg	120.0	115.0	−5.0	122.1 ± 3.8	119.7 ± 3.0[d,f]	−11.3 ± 5.2[d,f]
Diastolic pressure, mm Hg	74.0	68.0	−6.0	75.1 ± 1.6	77.5 ± 2.3[d,f]	4.5 ± 3.0[d,f]
Heart rate, bpm	64.0	109.0	45.0	66.1 ± 3.2	95.1 ± 5.4	27.8 ± 2.7
Stroke volume, ml	86.6	22.9	−63.7	71.1 ± 4.0	32.7 ± 2.9	−37.5 ± 7.3
Cardiac output, l/min	6.6	2.7	−6.6	4.5 ± 0.2	3.0 ± 0.2	−1.5 ± 0.2
Peripheral vascular resistance, mm Hg · 1^{-1} · min	13.9	33.6	19.7	21.0 ± 1.5	32.4 ± 2.3	11.4 ± 2.1

[a] Values are mean ± SE. Supine, standing, and standing minus supine difference measurements for all variables between groups.
[b] Long-duration presyncopal subjects, $N = 5$; short-duration presyncopal subjects, $N = 5$.
[c] Long-duration nonpresyncopal subjects, $N = 1$; short-duration presyncopal subjects, $N = 15$.
[d] $p \leq .05$ long-duration presyncopal vs. short-duration nonpresyncopal.
[e] $p \leq .05$ long-duration presyncopal vs. short-duration presyncopal.
[f] $p \leq .05$ short-duration presyncopal vs. short-duration nonpresyncopal.

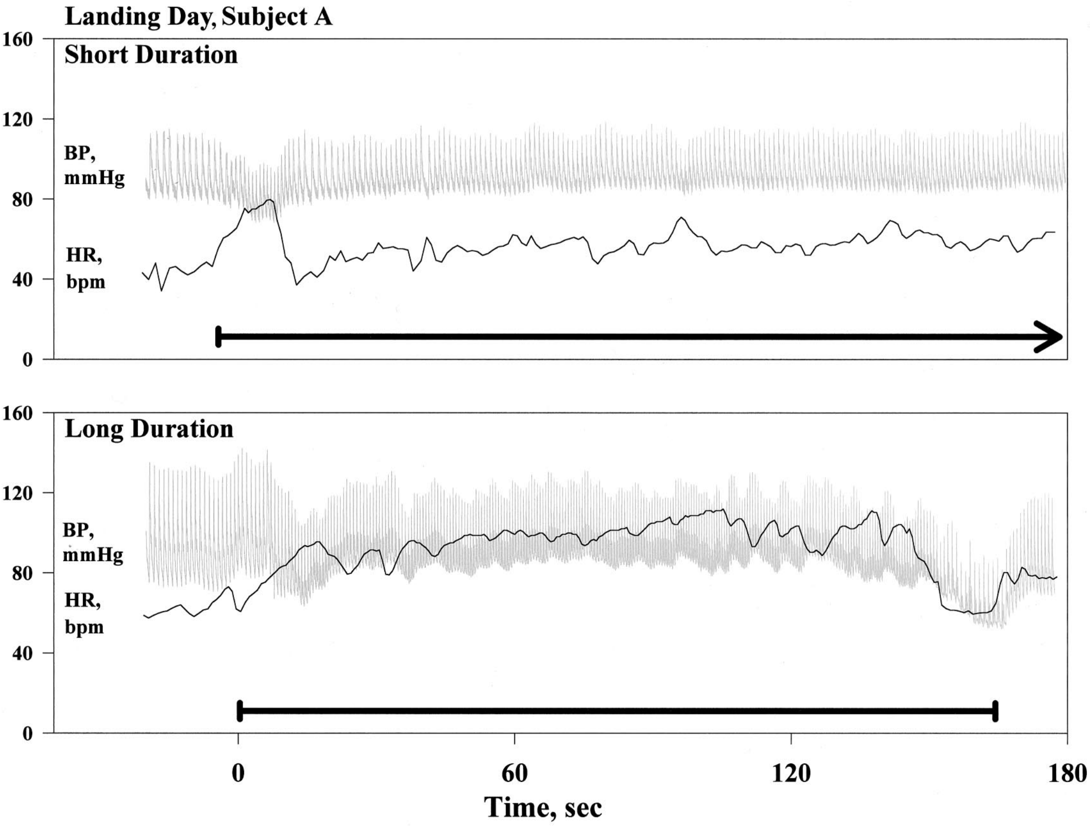

Fig. 2. Beat-to-beat arterial pressure and heart rate during a stand test after a short flight (*top*) and a tilt test after a long flight (*bottom*) in one subject. In the top panel the horizontal arrow indicates that the entire 10 minutes of upright posture was maintained without presyncopal symptoms or hemodynamic instability. Note that after an initial rise and recovery, heart rate varied around 50 to 60 bpm during upright posture. In contrast, after the long flight (*bottom*), the interrupted horizontal line indicates that presyncopal symptoms occurred, associated with a sudden drop in both pressure and heart rate. (No blood work was available on this subject.)

that time the subject became nauseated and asked to be returned to the supine position. Both pressure and heart rate began to decrease rapidly. No blood work was available on this subject. Figure 3 presents similar data for subject B. However, in this subject, measurements of plasma volume and plasma catecholamine levels also were obtained for both the short and long flights. After the short flight (*top*), subject B maintained arterial pressure throughout the period of upright posture (*horizontal arrow*), with a heart rate about 100 bpm, without symptoms. After the long-duration flight (*bottom*), pressure fell immediately from the time of upright posture and continued to fall until presyncope occurred after about 2 minutes (*horizontal bar*). Upright heart rate was about 110 bpm. This subject did not become nauseated but did experience symptoms of lightheadedness, and the test was terminated because of hypotension. Figure 4 shows supine and standing plasma norepinephrine and epinephrine levels from subject B taken during the tests presented in Figure 3. After the short flight (*top, left*), the norepinephrine level with standing increased by 1308 pg/ml. After the long flight (*bottom, left*), the increase was only 13 pg/ml. On the other hand, the epinephrine response to standing was about five times greater after the long flight (*top and bottom, right*). This subject's plasma volume losses were virtually identical (about 9%) after both the short and long flights.

Figure 5 presents a comparison between short-duration flight stand tests (*left*) and long-duration flight tilt tests (*right*) in the six individuals who participated in both. There was a markedly greater fall of arterial pressure after the long flights than after the short ones, but no difference in the heart rate response. Only one of the six crew members (17%) became presyncopal on landing day after the short flights; five of the same six (83%) became presyncopal after the long flights (a five-fold increase). No subject became presyncopal during either the preflight tests or 2 to 4 days after landing.

Blood Volume Measurements

Red blood cell and plasma volume changes are presented in Figure 6. They are compared with those of 29

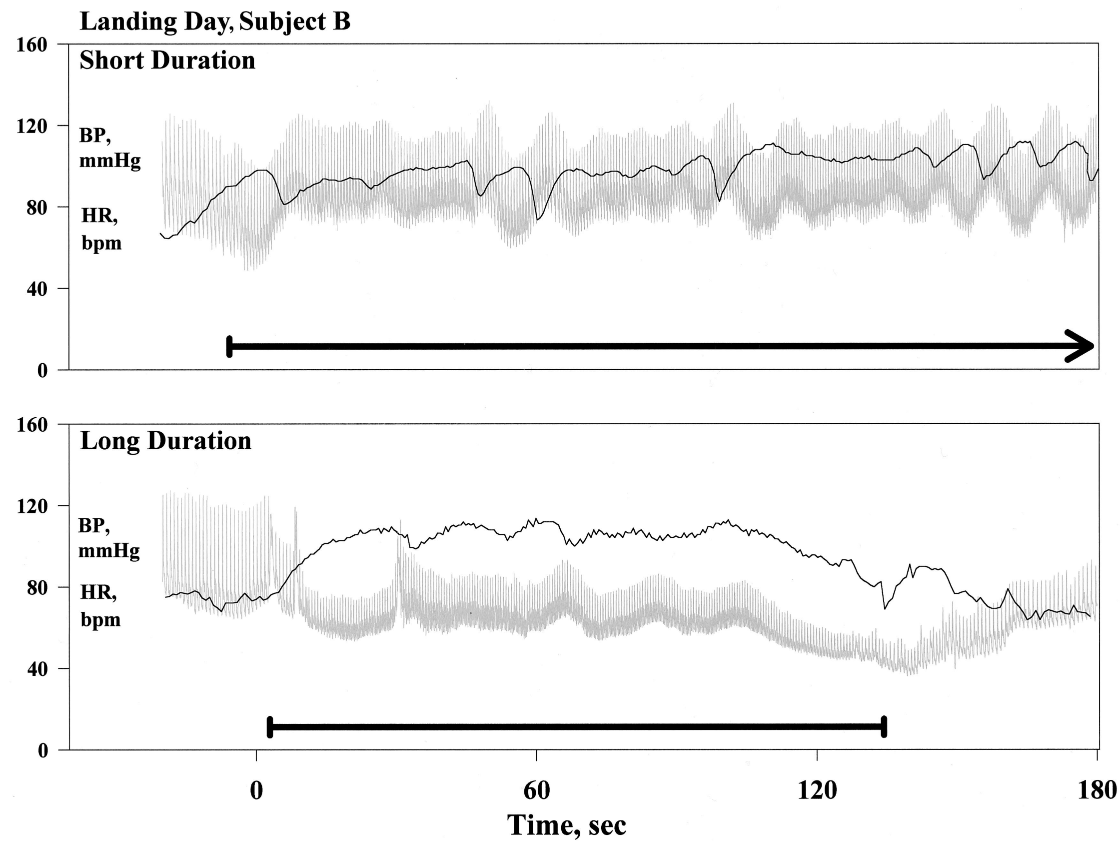

Fig. 3. Beat-to-beat arterial pressure and heart rate during upright posture after a short (*top*) and long (*bottom*) flight in a different subject from that in Figure 2. In the top panel the horizontal arrow indicates that upright posture was maintained for the entire 10-minute test. Upright heart rate was about 100 bpm. In contrast, after the long flight (*bottom*), the interrupted horizontal bar indicates that the subject was able to maintain upright posture for only about 2 minutes before presyncopal symptoms occurred. Unlike the subject in Figure 2, arterial pressure fell immediately on assumption of upright posture and continued to fall steadily and rapidly until presyncopal symptoms occurred. As with the subject in Figure 2, a simultaneous fall in heart rate and arterial pressure preceded presyncope.

short-duration subjects, which were reported earlier (7). Plasma volume and red cell volume losses were not different between short- and long-duration missions.

DISCUSSION

This study is the first of which we are aware to perform any tests of orthostatic tolerance on landing day after spaceflights of 4 to 6 months. It thus fills an important gap in the knowledge base regarding orthostatic hypotension after long-duration spaceflight. The key finding of this study is that the incidence of orthostatic intolerance is significantly greater after long-duration than after short-duration spaceflight, whether assessed by stand vs. tilt tests in the same subjects (17% vs. 83%) or by tilt vs. tilt tests in different subjects (25% vs. 83%), as shown in Figure 1. There was a slightly greater incidence with tilt than with stand after short-duration flights, probably because tilt testing is more provocative. However, it is most unlikely that the five-fold increase in presyncope after the longer flights is due simply to the use of the tilt table. The overall incidence of presyncope after short flights was comparable to that in our previous reports (7), though less than Buckey et al. reported in a smaller group (8).

The data for the subject from whom we obtained a complete set of measurements, including blood work, before and after both short and long flights (Figures 3 and 4) are striking. This subject had no trouble maintaining upright arterial pressure after the short flight but was entirely unable to maintain upright pressure after the long flight. Loss of plasma volume was the same in this subject after both flights and thus does not offer an explanation for this difference in tolerance. However, autonomic responses seem to be different. The very large norepinephrine response after the short flight indicates an intact sympathetic response, and the small epinephrine response does not suggest a stress response. In contrast, after the long flight, this

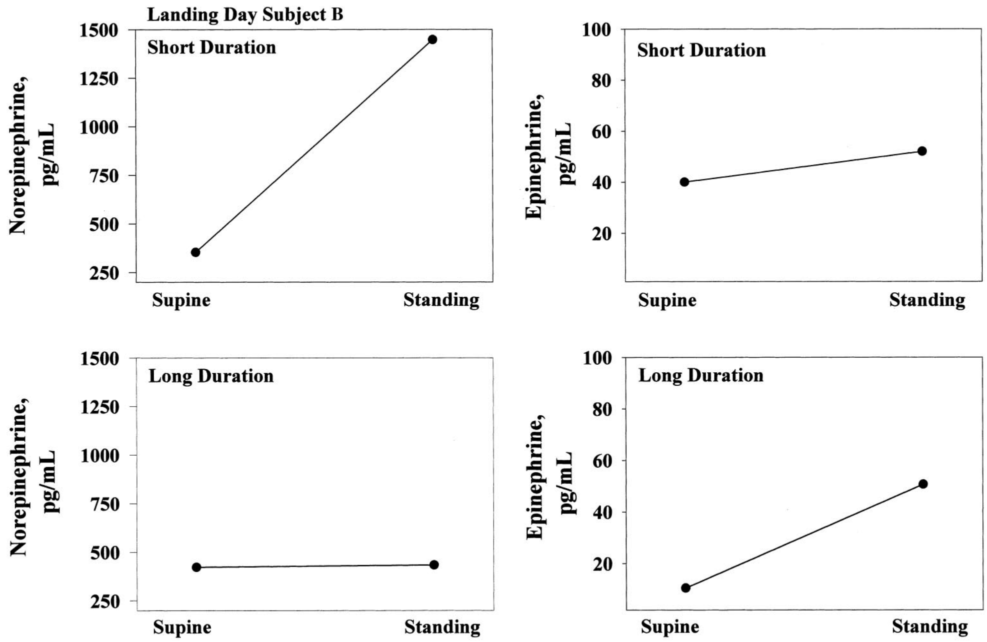

Fig. 4. Supine and standing plasma norepinephrine (*left*) and epinephrine levels (*right*) in the subject presented in Figure 3. Measurements were taken on landing day after this subject's short (*top*) and long (*bottom*) flights.

subject exhibited virtually no increase in norepinephrine with upright posture, but the epinephrine release was five times greater than after the short flight, indicating more of a stress response on that occasion. Although it is possible that the low norepinephrine level could have been due to the fact that the test was terminated early because of presyncopal symptoms, we suggest that is unlikely. Previous reports have shown that 2 minutes of upright posture is long enough to elicit measurable increases in plasma norepinephrine levels (7, 13). In addition, the greater increase in epinephrine after the longer flight further suggests that the catecholamine measurements are not erroneously low. Thus, these data illustrate that a single subject can have a normal adrenergic response to standing after short-duration flight but present with a hypoadrenergic response to standing (ie, decreased norepinephrine release from sympathetic nerve endings), with presyncope, after long-duration flight. These data must be confirmed by additional studies.

The hypoadrenergic pattern displayed by subject B is the most common pattern of postflight orthostatic intolerance after short-duration flights. Both in our previous report (7) as well as in the present study, every presyncopal incident after short flights resembled the hypoadrenergic pattern. In addition, this was the most common pattern of presyncope reported by Buckey et al. (8). However, in the present study, only two of five presyncopal incidents after long-duration flights showed this pattern. The other three incidents were more similar to that presented in Figure 2 (*bottom*). In those cases, arterial pressure recovered, at least partially, during standing, until the subjects experienced a vasodepressor response. Thus, we suggest that the factors that precipitate presyncope during upright posture after long-duration spaceflight may be more diverse than after short-duration spaceflight. There are several possible explanations for this difference. There may be a greater input by neurovestibular disturbances, which have been noted to be far more profound after long flights (William H. Paloski, personal communication, 2000). It could also indicate a greater susceptibility to neurocardiogenic syncope, which is not associated with hypoadrenergic responses (14). This idea is supported by the fact that the long-duration flight presyncopal astronauts had lower standing stroke volumes and cardiac outputs and higher standing total peripheral resistance than the short-duration presyncopal subjects (Table 3), a situation that predisposes to neurocardiogenic syncope. We speculate that the high resistance might be due to a possible upregulation of α-1 adrenergic receptors after long-duration flight. This possibility is supported by a recent report of increased pressor responses to intravenous phenylephrine injections on landing day in presyncopal astronauts (15). Although muscle sympathetic nerve activity has recently been shown to be greater in-flight in nonpresyncopal astronauts, it may in fact be lower in presyncopal astronauts, leading to a receptor upregulation.

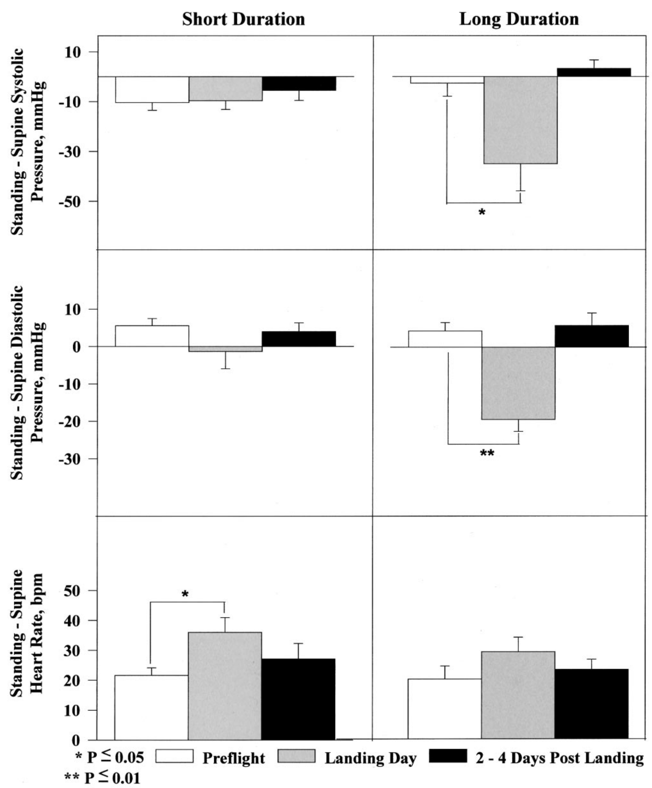

Fig. 5. Systolic and diastolic pressures and heart rates in six subjects before flight, on landing day, and 2 to 4 days after landing for their short- (*left*) and long-duration (*right*) missions. Short-duration data were obtained during stand tests. Long-duration data were obtained during tilt tests.

It has been previously shown that stroke volume is reduced after spaceflight, but this is the first report showing that it is reduced more after long than after short flights. One factor that could contribute to this would be a greater loss of plasma volume with long-duration flight. However, the data we have suggests that plasma volume losses are not greater after the longer flights (Figure 6), although larger sample sizes are needed to confirm that finding. Low stroke volumes also might be a result of increased venous compliance, perhaps secondary to muscle atrophy. This possibility is supported by the data shown in Figure 2, which shows increased pulse pressures after the long vs. the short flight. It is not supported by the data shown in Figure 3, which show decreased pulse pressures after the long vs. the short flight. Another factor that could contribute to lower stroke volumes in the long-duration flight astronauts is a decrease in cardiac contractile function. We recently reported echocardiographic data in four of these six subjects, which showed postflight decreases in stroke volume of 17%, decreases in ejection fraction of 10.5%, and increases in left ventricular end-systolic volume of 39% (16). Similar changes were not seen in the short-duration flight crew members in that report (16) or in a previous report (17). This suggests that cardiac contractile function may be reduced after long- but not short-duration spaceflight. The causes of the low stroke volumes are probably multifactorial and individually specific and are not delineated entirely by the present data.

Limitations

One limitation to this study is the inconsistency in the Mir environment from subject to subject. Although all crew members tried to maintain a regular exercise routine during flight, that was not always possible because of various emergency situations aboard the station. However, all of the long-duration subjects spent at least 7 days aboard the American Shuttle before landing, during which exercise, diet, and hydration status were less variable. Another limitation is that stand tests were used during the years that the long-duration astronauts were flying their Shuttle missions. Therefore, short-duration vs. long-duration flight comparisons in the same individuals required stand vs. tilt comparisons. Because of this limitation, we also compared the six long-duration flight subjects' tilt test responses with tilt responses of the astronauts

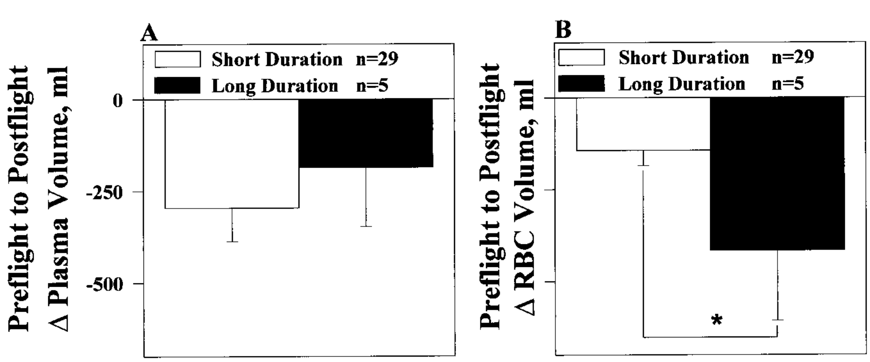

Fig. 6. Pre- to postflight changes in plasma volume (*A*) and red blood cell (RBC) volume (*B*) associated with short- and long-duration flights. Short-duration plasma volumes are reproduced with permission (6).

who flew on the Shuttle missions that carried these six to and from the Mir. We observed a comparable increase in presyncope after long-duration flight with both comparisons. Other study limitations relate to the small sample size and the fact that plasma volumes and catecholamines could not be obtained in all subjects.

SUMMARY

These studies comprise the only data available to compare the differential effects of short-duration and long-duration spaceflight on orthostatic tolerance in the same individuals. The results show that subjects returning from long-duration spaceflight have markedly reduced tolerance to upright posture. Five of six long-duration flight subjects could not complete 10 minutes of upright posture during tilt testing. One subject showed a subnormal sympathetic response after a long flight that was not present after a short flight. More studies are needed to clearly delineate the causes of these effects and their possible countermeasures.

We are indebted to the subjects who participated in these studies and to Joyce Leakey for excellent technical assistance. Supported by NAS9-97005 and National Institutes of Health Grant M01 RR00827.

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