Effect of Minimal Dehydration on Orthostatic Tolerance Following Short-Term Bed Rest

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THE TENDENCY toward orthostatic hypotension demonstrated by Astronauts Schirra[1] and Cooper[2] has restirred interest in the responses of the cardiovascular system to subgravity, and data from early water immersion studies[3-6] are now being supplemented by studies of bed rest.

Most of these studies, including those conducted at this laboratory[7,8] have been concerned primarily with long-term bed rest. Data are scarce on the effects of a few days to two weeks duration and also on the effects of combined stress, such as short-term rest with minimal dehydration. Nevertheless, because weightlessness cannot be produced on earth, legitimate concern exists that any earth-laboratory study of the physiological effects of "hypodynamic environments" can only have limited value to space application. Two points, however, should be made: (1) it is possible that the hypotension experienced by the last two American astronauts may have resulted from a host of environmental factors, of which "weightlessness" may or may not have been prominent, and (2) within the limitations of a one-G environment, earth-laboratory studies might increase their potential operational usefulness if they were to include, in a well-controlled manner, realistic, multiple stresses. Toward that end, a preliminary study was performed in which one subject was exposed to short-term bed rest with minimal dehydration.

METHODS

The subject was a 20 year old Caucasian male college senior. Past medical history, family history, review of systems, and physical examination were normal. An admitting chest X-ray with barium swallow, EKG, complete blood count, urinalysis, and routine blood and urine chemistries were also normal. He participated actively in athletics and was in excellent physical condition. He was 187 cms tall, weighed 73.1 kgms on admission, and was characterized as an ectomorphic mesomorph by a fat: muscular: linear Parnell index of 3.5:5:4.5, respectively.[9]

The subject was admitted to the Research Ward on 7 July 1963 and discharged on 29 August 1963. During this time, he served as a subject for this study only. Diet consisted of 2523 Calories (77 gm protein, 74 gm fat, 385 gm carbohydrate, and 1.724 gm calcium).[7] It was divided into three daily meals and three in-between meal feedings of liquid formula. Water was allowed *ad lib*, except as will be noted. Control measurements consisted of daily fluid intake and output, 24 hour urine specific gravity, nude morning weight, hematocrit, and hemoglobin. Vital signs were taken every eight hours.

The subject underwent five bed rest periods, as shown in Table I. (The 700 cc intake includes fluid content of food.) Freedom of movement in bed was allowed, provided the horizontal position was maintained at all times. The subject read much of the time, and he also watched television with the aid of biprism glasses.

TABLE I. EXPERIMENTAL PROFILE

Period No.	Intended Duration	Room Temp	Relative Humidity	Fluid Intake Per Day
I	48 hrs	70°F	20-40%	ad lib
II	48 hrs	70°F	20-40%	700 cc
III	48 hrs	95°F	20%	ad lib
IV	48 hrs	95°F	20%	700 cc
V	48 hrs	70°F	20-40%	ad lib

Bed rest period measurements included daily intake and output, urine specific gravity of each voided sample, hematocrit and hemoglobin (every eight hours during periods II, III and IV), and vital signs every two hours while awake during periods I and V, and every hour while awake during II, III and IV. An indwelling rectal thermocouple allowed hourly monitoring of the subject's temperature during periods III and IV. The subject was not weighed during the rest periods.

The heat exposures (periods III and IV) were accomplished in a carefully controlled environmental chamber.

Tilt table testing was performed each Monday morning before the subject arose from bed, and Monday afternoon after approximately seven hours of ambulation. These two tilts served as additional controls immediately preceding each bed rest period. At the end of each period (Thursday morning), the subject was again tilted.

Tilts were performed in a 70°, feet down position. They lasted a maximum of ten minutes but were terminated upon the appearance of definite presyncopal signs and symptoms. Five minute pre- and post-tilt stabilization periods accompanied each tilt. Heart rate and blood pressure were recorded each minute. Because of the frequency of tilting, intra-arterial catheters were impractical, and blood pressure was measured by auscultation. All blood pressure readings on the tilt table were taken by the same investigator, and the same sphygmomanometer was used for the entire study.

The subject spent the rest of each week in the Re-

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search Ward, where he read, studied, played cards, etc. He was allowed to go outside during the day, provided his diet could be followed and intake and output records maintained.

RESULTS

Table II presents the subject's base-line physiological profile while living on the ward during the control periods. These values were within normal limits for a healthy, young male, and they were fairly constant from day to day.

In Table III are shown these same values during each day of the five bed rest periods. During periods I and V, the values did not significantly differ from the non-bed rest periods, and weight loss was 0.5 per cent or less. In period II, urine specific gravity rose during the second day to 1.023. This was higher than control values. The day after this period ended, urine specific gravity rose further to 1.033, then fell to 1.017 by the following day. Weight loss was 1.9 kgm, or 2.6 per cent of body weight at beginning of period II.

During period III, body temperature rose to 98.8° F. Blood pressure, heart rate, and respiratory rate remained within control limits. Fluid intake was large, and output was relatively diminished. Urine specific gravity reached a high of 1.023. The intake-output balance and the lowered hematocrit indicate that large amounts of fluid were used to maintain a normothermic status. Weight loss was 0.9 kgm, or 1.2 per cent of weight at the beginning of period III.

During period IV, both temperature and heart rate were elevated, but not markedly. Blood pressure remained stable. Because of a back ache, the subject requested that the rest period be terminated at the end of the twenty-sixth hour. This period, therefore, lasted 26 hours and was followed immediately by the tilt test. During this 26 hour period, urinary output totaled 550 cc, with specific gravity of 1.022. After removal from the climatic chamber, the subject voided 640 cc, with specific gravity of 1.033. The following day specific gravity dropped to 1.028, and it further fell to 1.012 by the next day. During this bed rest period, weight loss was 3.8 per cent.

Despite the prolonged periods in bed, he experienced no difficulty in receiving approximately eight hours of sleep per night.

Figure I illustrates the responses to tilt. Plotted are

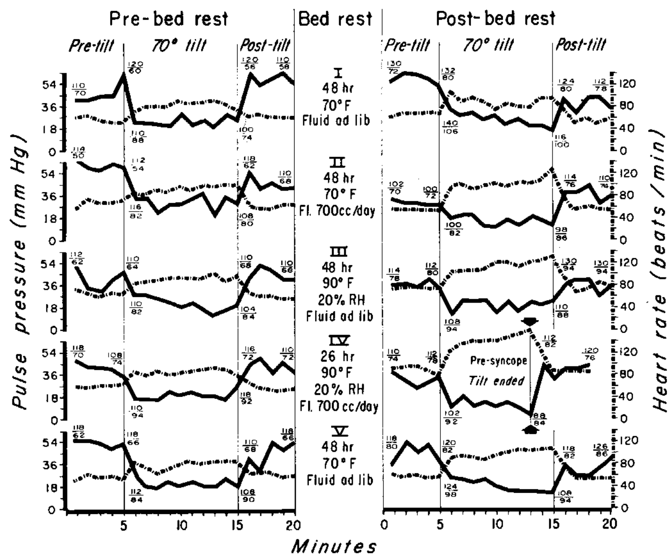

Fig. 1. Responses to 70° tilt before and after five bed rest periods.

TABLE II. NON-BED REST PERIODS

	Temp. (°F.)	Blood Pressure (mm Hg)	Pulse Pressure (mm Hg)	Heart Rate (beats/min)	Resp. Rate (per min)	Hemo-globin (gms %)	Hemato-crit (%)	Weight (kgm)	Fluid Intake (cc)	Fluid Output (cc)	Urine Specific Gravity
Average	97.7	106/63	44	63	17	15.5	46	72.381	2449	1991	1.012
Range	97.0-98.4	96-120 / 50 75	30-58	56-80	16-20	14.2-16.3	42-47	71.283 to 73.113	2380 to 3010	1360 to 2755	1.010 to 1.017

TABLE III. BED REST PERIODS

	Temp. (°F)	Blood Pressure (mm Hg)	Pulse Pressure (mm Hg)	Heart Rate (beats/min)	Resp. Rate (per min)	Hemo-globin (gms %)	Hemato-crit (%)	Beginning Weight (kgm)	Ending Weight (kgm)	Weight Change	Weight Change (%)	Fluid Intake (cc)	Fluid Output (cc)	Urine Specific Gravity
I. Day 1	98.2	112/54	58	76	16	15 9	46	72.813	--	--	--	2380	1605	1.011
Day 2	97.8	114/54	60	60	16	15.9	48	--	72.468	-0.345	-0.5%	2380	2455	1.014
II. Day 1	97.4	102/72	30	54	16	15.3	45	72.713	--	--	--	700	1066	1.016
Day 2	98.0	106/65	41	57	17	15.8	45	--	70.823	-1.890	-2.6%	700	901	1.023
III. Day 1	98.5	106/68	38	62	16	14.4	42	72.463	--	--	--	4380	1288	1.011
Day 2	98.8	109/72	37	66	16	15.1	42	--	71.570	-0.893	-1.2%	4370	808	1.023
IV. Day 1	99.4	109/75	34	78	17	14.4	42	72.182	--	--	--	700	550	1.022
Day 2	100.2	110/72	38	83	20	14.6	43	--	69.445	-2.737	-3.8%	<215	0	--
(end of 26th hour)														
V. Day 1	97.4	104/60	44	58	16	15.0	45	71.418	--	--	--	2380	1850	1.014
Day 2	97.6	107/68	39	68	16	15.2	45	--	71.375	-0.043	-0.1%	2380	2199	1.014

pulse pressure and heart rate each minute during the five minute pre-tilt period while the subject was recumbent on the table, the ten minutes of tilt, and the five minutes of post-tilt recumbency. Also shown are the systolic and diastolic (fifth phase) readings obtained at the beginning and ending of the pre-tilt, tilt, and post-tilt periods. Examination of data from the Monday morning and afternoon tilts showed no significant differences; therefore, the morning tilts were graphed as the pre-bed rest tilts on the left. On the right are the post-rest tilts.

Seventy degree tilt for ten minutes was tolerated without major signs or symptoms following all bed rest periods except the fourth period. Here, progressive nausea developed around the fourth minute of tilt and blurring of peripheral vision at the seventh minute. Because of progressive clinical deterioration, the tilt was terminated at the end of the eighth minute, prior to the onset of frank syncope. At this time, blood pressure was 88/84, and pulse rate was 156. Recovery was rapid, and he was returned to the ward where he sat, walked, and drank fluid *ad lib.* He was re-tilted four hours later without incident.

No problems developed during any other tilt, although moderate reductions in pulse pressures were noted during the tilts following the third and, particularly, second rest periods.

DISCUSSION

In this study minimal dehydration was produced through heat, restricted fluid, and a combination of these two stresses. The maximum water deficit, measured as weight loss, occurred during period IV and was 5.9 pounds, or 3.8 per cent of weight at the beginning of the period. Following only this period did pre-syncope develop which necessitated premature termination of tilt. Because of these results, one of the authors (C. DiG.) repeated the conditions of this rest period, serving as the subject. The study was terminated at the end of the twenty-sixth hour, and the response to 70° head-up body tilt determined. Although this individual has served as a bed rest subject before and has a well established tolerance to 48 hour bed rest under normal circumstances, presyncope developed (marked nausea, blood pressure: 92/80; heart rate: 174) at the end of five minutes and ten seconds of 70° tilt. At this time the tilt was terminated. Weight loss was 3.2 per cent of initial weight during the experimental period in this subject, quite similar to the result in the experimental subject.

These data are similar to those of Adolph et al,[10] who showed that 45° tilt in non-bed rest subjects dehydrated 4 per cent of initial weight produced syncope in six minutes, and 3 per cent water deficit resulted in syncope at eight minutes.

Post-flight medical data from Schirra's MA-8 flight[1] showed rectal temperature of 100.1°F., blood pressure of 118/78, pulse rate of 92 beats per minute, and weight loss of 4.5 pounds or 2.5 per cent of pre-flight weight. Specific gravity of recovered flight urine was 1.010, and its highest value, reached 12 hours after recovery, was 1.021. These and other data from the flight indicate "inconsequential", or, at most, minimal dehydration.

On the basis of Adolph's work and this currently reported study, it appears that even minimal dehydration, when produced by the proper combination of factors, can result in orthostatic intolerance. It is conceivable that the lower extremity venous pooling and heart rate lability experienced by Schirra at the end of his flight were due as much to minimal dehydration as to weightlessness.

The deficiency of this study is that it was performed only once, and in one subject. It should be repeated. The results, however, demonstrate that orthostatic intolerance was produced in one subject by a combination of factors but not to any one alone. The same concept applies to bioastronautic research efforts, particularly current programs in subgravity research: many important stresses act in concert upon the astronaut during flight, and his physiological profile represents his response to all of them.

SUMMARY

A healthy subject was exposed to 48 hour bed rest periods under conditions of comfortable temperature and fluid *ad lib*, comfortable temperature and restricted fluid, heat and fluid *ad lib*, and a 26 hour period of heat combined with restriction of fluid. Minimal dehydration was achieved. Seventy degree tilt was tolerated for ten minutes following all bed rest periods, except the 26 hour period of combined heat and dehydration at the end of which pre-syncope developed by the eighth minute of tilt. This study suggests the need for well-controlled, multiple stress studies to maximize potential application to manned space flight.

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REFERENCES

1. Berry, C. A., Minners, H. A., McCutcheon, E. P., and Pollard, R. A.: Aeromedical Analysis. *In* Results of the Third U. S. Manned Orbital Space Flight. Manned Spacecraft Center, N.A.S.A., Houston, Texas, October 3, 1962.
2. Interview with Walter C. Williams, Associate Director of NASA's Manned Spacecraft Center, as reported in *Aviation Week and Space Technology*, 79:74, July 1, 1963.
3. Graybiel, A., and Clark, B.: Symptoms Resutling From Prolonged Immersion in Water: The Problem of Zero G Asthenia. School of Aviation Medicine, Pensacola, Florida. USN-SAM Project MR 005. 15-2001, Subtask 1, Report No. 4, July 1960.
4. Graveline, D. E., and Balke, B.: The Physiologic Effects of Hypodynamics Induced Water Immersion. School of Aviation Medicine, Brooks Air Force Base, Texas. Report No. 60-88, 1960.
5. Benson, V. G., Beckman, E. L., Coburn, K. R., and Chambers, R. M.: Effects of Weightlessness as Simulated by Total Body Immersion Upon Human Response to Positive Acceleration. Aviation Medical Acceleration Laboratory, Johnsville, Penna. Report No. NADC-MA-6132, June 1961.
6. Beckman, E. L., Coburn, K. R., Chambers, R. M.,

DeForest, R. E., Augerson, W. S., and Benson, V. G.: Physiologic changes observed in human subjects during zero G simulation by immersion in water up to neck level. *Aerospace Med.,* 32:1031, 1961.

7. Birkhead, N. C., Blizzard, J. J., Daly, J. W., Haupt, G. J., Issekutz, B., Myers, R. N., and Rodahl, K.: Cardiodynamic and Metabolic Effects of Prolonged Bed Rest. Aerospace Medical Research Laboratory, Wright-Patterson A.F.B., Ohio. Report No. AMRL-TDR-63-37, May, 1963.

8. Birkhead, N. C., Haupt, G J., Blizzard, J. J., Lachance, P. A., and Rodahl, K.: Effects of supine and sitting exercise on circulatory and metabolic alterations in prolonged bed rest. *Physiologist,* 6:140, Aug. 1963.

9. Parnell, R. W.: Behaviour and Physique: an Introduction to Practical and Applied Somatometry. London: Edward Arnold, Ltd., 1958.

10. Adolph, E. F., and Associates. Physiology of Man in the Desert, pp. 192-194. New York: Interscience Publishers, Inc., 1947.