APOLLO CARDIOVASCULAR EVALUATION

Well documented changes in cardiovascular homeostasis occur as a result of relative inactivity or reduced stress input, such as the confinement and weightlessness of spaceflight. Potential problems of cardiovascular deconditioning were anticipated and studied by various earth-based simulations (e. g., bedrest) even before man's first space flight. America's Mercury and Gemini programs demonstrated that, though consistently present, cardiovascular deconditioning posed no serious problems for earth orbital flights to 14 days' duration. However, Apollo brought a considerably different spacecraft and the mission of lunar landing. Further data on cardiovascular alterations and their effect on lunar surface activity became a requisite for the mission. Pre- and postflight cardiovascular evaluations were performed on all crewmembers of Apollo manned flights, together with control subjects, to assess one prime aspect of cardiovascular function, orthostatic tolerance.

VISUAL AID I lists objectives of these cardiovascular evaluations.

VISUAL AID II shows test methods used for assessing orthostatic tolerance. Physiological measurements taken were: heart rate, blood pressure, and change in leg size (as an indicator of pooled blood in the lower body). Other variables interacting with these cardiovascular elements were considered (e. g., body weight, blood volume, exercise capacity, vasoactive hormones).

VISUAL AIDS III and IV show typical LBNP and 90° Stand test data.

VISUAL AID V summarizes heart rate responses for all five missions Of the several physiological measurements, heart rate is the most sensitive indicator of change.

It should be pointed out that only 60% of the 15 Apollo astronauts showed significant postflight elevations of their resting supine heart rate, while 77% of those stressed by LBNP and 100% of those stressed by simply standing had significantly elevated heart rates. Provocation by a cardiovascular stressor reveals changes which would not otherwise be detected.

Thus far nearly all subjects have returned to their preflight ranges by about 30 to 50+ hours after splashdown. This corresponds well with recovery times noted in Gemini flights.

An shown in VISUAL AID VI, postflight decreases in calf circumferences have been observed in all crewmen, this being significant ($p < 0.05$) in 10 of fifteen (67%) subjects. This has not been observed among control subjects.

The nine crewmen of Apollos 7 - 9 were tested with LBNP. Only two showed significantly increased calf size postflight during LBNP, while three measured significantly less increase in calf size. This rather implies that heart rate response postflight is disproportionately greater than the amount of blood pooled in the lower extremities.

Even with this apparent paradox, however, the correlation of heart rate response with change in leg volume has shown a very high correlation for all subjects tested. This has allowed use of regression correlation parameters as indicators of cardiovascular response. VISUAL AID VII shows graphically the results of these regressions for the Apollo 8 crew. Preflight consistency is remarkable within a given subject. Immediate postflight alterations are obvious and subsequent following through recovery is qualitatively and quantitatively possible.

VISUAL AID VIII summarizes results of regression slopes and intercepts for heart rate response with change in leg volume. V: Signif elevat p-fl

Blood pressure should theoretically follow more closely a gravity simulation stress on the cardiovascular system. VISUAL AIDS IX and X show some typical LBNP and 90° Stand blood pressure curves. But results (VISUAL AID XI) from neither LBNP nor 90° Stand tests for Apollo flights have shown consistency of any quantitative patterns in either systolic or diastolic blood pressures. Even pulse pressure does not correlate well with other measurements, but its resting supine value is generally decreased postflight (13 of fifteen). Only four of

15 are statistically significant decreases (p 0.05), however. In all cases during LBNP pulse pressure is decreased from preflight values (5 significant) and three episodes of postflight presyncope occurred. Seven of 9 showed decreased pulse pressure during the 90° Stand test (3 significant). It is obvious that more accuracy and better resolution of blood pressure measurements are needed. Contributory to this high variability, however, is the typically observed tendency toward hyper-reactivity and lability of blood pressure during the recovery period one to three days after splashdown.

Weight loss accurred in all 15 Apollo astronauts (VISUAL AID XII). This averaged 5.6 pounds with a range of 1.25 to 10 pounds over the 8 to 11 day flights. Most of this is probably due to alterations is body fluids.

Blood volume changes are surely involved in the overall cardio-vascular responses and some preliminary reports indicate highly significant postflight changes in vasoactive and fluid control hormones.

Finally, preflight data from the 90° Stand test were used predictively in following Apollo 11 CDR and LMP during lunar EVA. From VISUAL AID XIII it is evident that the hydrostatic stress of 1/6 g is less than that of 1 g, but some high peaks of heart rates during activity must indicate decreased work capacity, partially contributed to by decreased orthostatic tolerance.

SUMMARY

Some degree of cardiovascular deconditioning, as measured by orthostatic tolerance testing, has been a consistent reality throughout the relatively short (8 - 11 days) duration Apollo flights.

Heart rate response is the best currently available indicator of the presence and magnitude of this cardiovascular deconditioning.

Whether longer duration flights will incur additive and/or irreversible effects or whether man will readily adapt can be determined only by continuing space related investigations.

VISUAL AID XIV presents several recommendations for the future course of cardiovascular space medicine.

1. Continued studies over longer duration flights.
2. More extensive measurements of cardiovascular and related functions, such as the electromechanical events of the cardiac cycle and the interrelationships of renal, hormonal and hematological systems.
3. Development of more reliable, automated, and inflight operational measurements, as body mass, blood pressure resolution, cardiac output, and urinalyses.
4. Correlation of interrelated systems changes.
5. Evaluation of the time course of changes through space-based and inflight test capabilities.
6. Determination of etiological factors for application of therapeutic and/or preventive measures.

GWHoffler

G. W. Hoffler, M. D.

7 September, 1969

APOLLO CARDIOVASCULAR EVALUATION

OBJECTIVES

A. Measure and document alterations in cardiovascular orthostatic tolerance consequent to space flight.

B. Determine impact of these changes upon Apollo mission activities.

C. Aid inflight monitoring of crewmen for their safety and optimal functional effectiveness.

D. Extend baseline data of cardiovascular adaptations to space flight.

METHODS FOR EVALUATING ORTHOSTATIC TOLERANCE

A. PROVOCATIVE TESTS OF THE ANTI-GRAVITY RESPONSES OF THE CARDIOVASCULAR SYSTEM

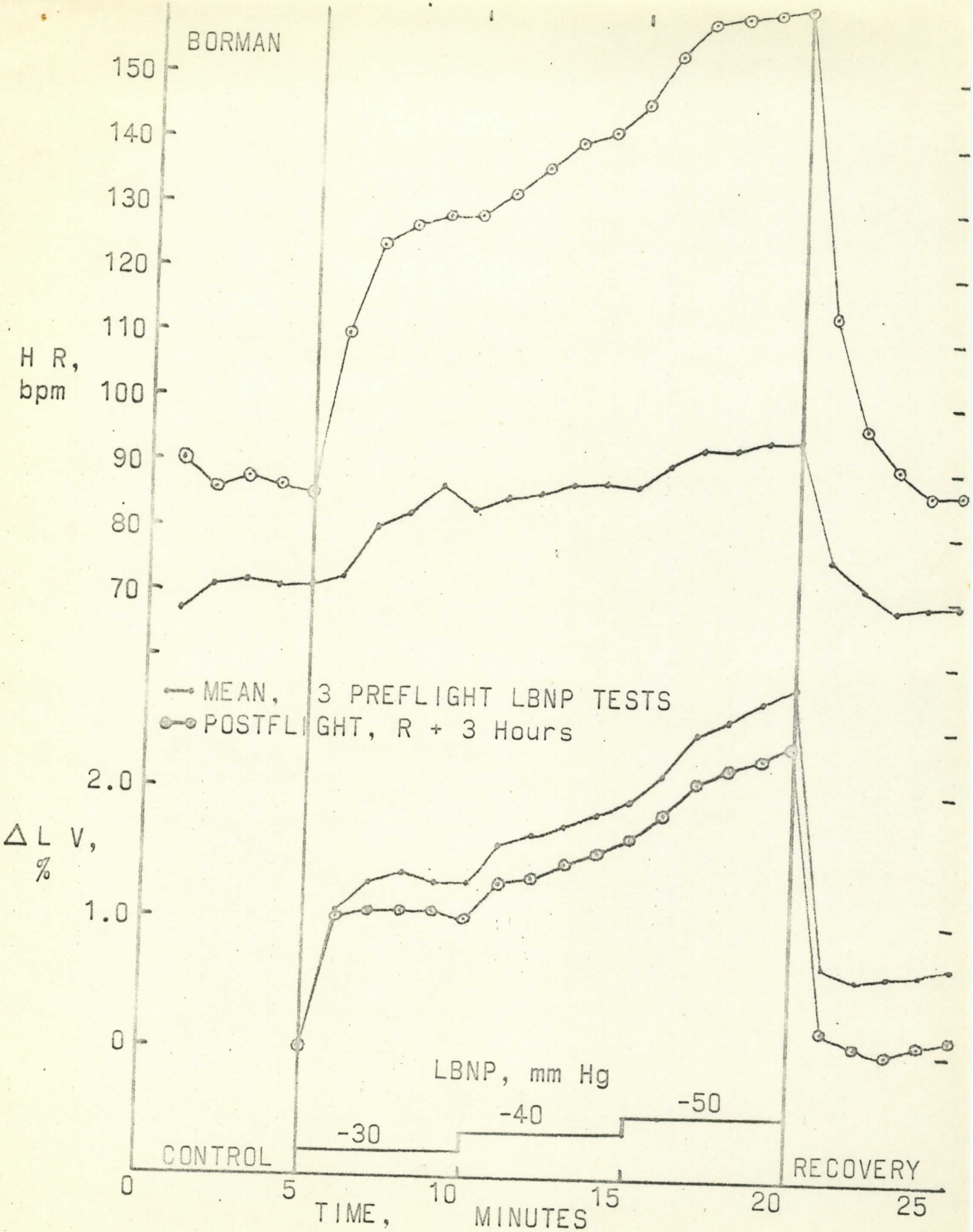
1. LOWER BODY NEGATIVE PRESSURE (LBNP) BY INCREMENTAL DIFFERENTIAL PRESSURE ____ 7, 8, & 9
2. 90° PASSIVE STAND ____ 9, 10, & 11

Both preceeded by 5 minutes of supine control data and LBNP followed by 5 minutes of recovery data.

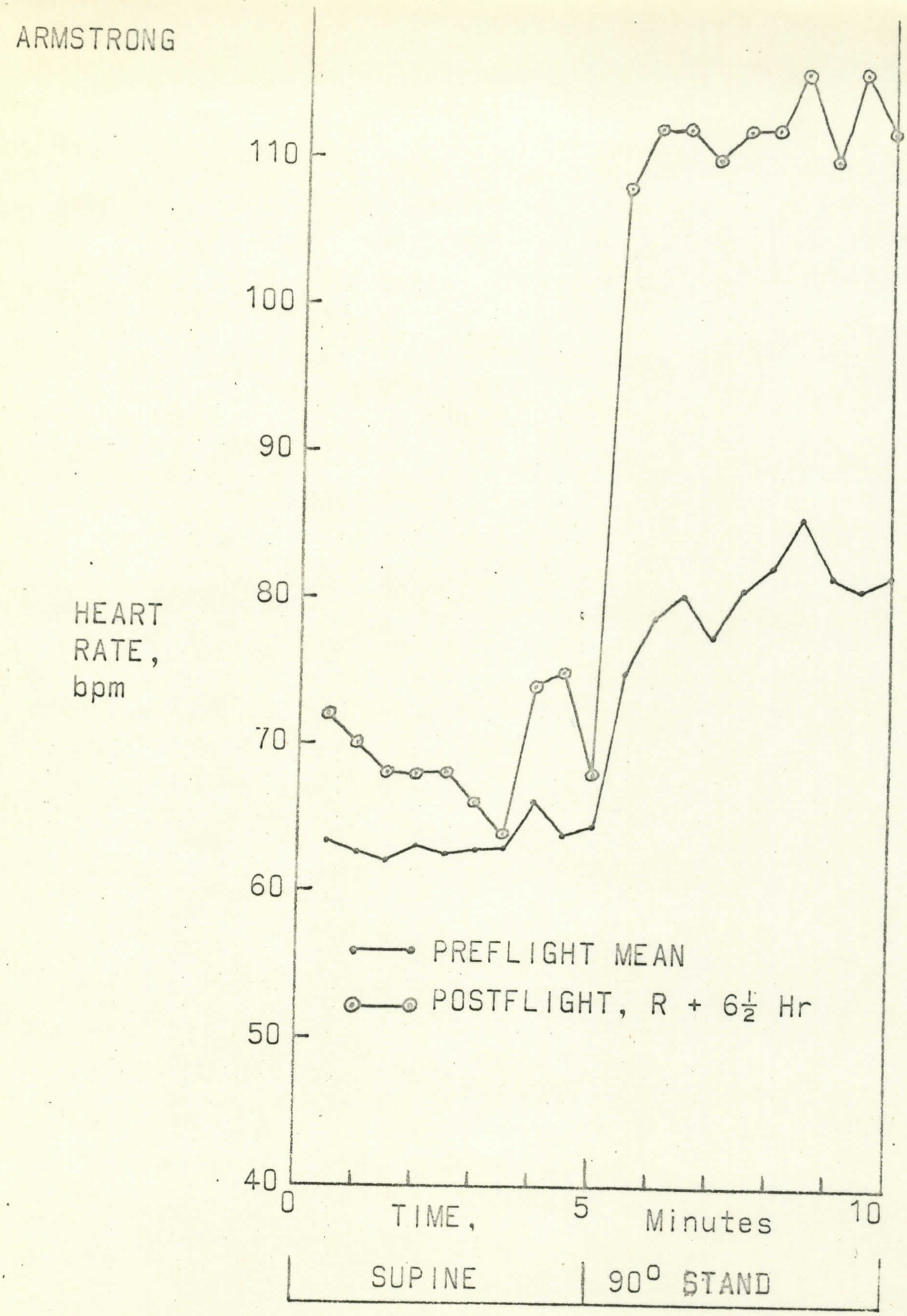
B. PRE- and POSTFLIGHT COLLECTION OF TIMED PHYSIOLOGIC MEASUREMENTS

1. HEART RATE	HR
2. BLOOD PRESSURE	SBP, DBP, PP, MBP
3. CHANGE IN LEG VOLUME	ΔLV
4. OTHER RELATED DATA	

Weight, Blood volume, Vasoactive hormones, Exercise Capacity



BORMAN
H R, bpm
150
140
130
120
110
100
90
80
70
MEAN, 3 PREFLIGHT LBNP TESTS
POSTFLIGHT, R + 3 Hours
Δ L V, %
2.0
1.0
0
LBNP, mm Hg
-30
-40
-50
CONTROL
RECOVERY
0
5
10
15
20
25
TIME, MINUTES



ARMSTRONG
HEART RATE, bpm
110
100
90
80
70
60
50
40
0
5
10
TIME, Minutes
PREFLIGHT MEAN
POSTFLIGHT, R + 6½ Hr
SUPINE
90° STAND

SUMMARY OF HEART RATE RESPONSES FOR APOLLO 7 - 11 FLIGHTS

Indicated postflight values VERSUS mean of 3 preflight values

	TEST DAY	TEST MODE	No. SUBJ.	No. SUBJ./CATEGORY ↑2 SD	±	↓2 SD	RANGE Δ BPM
APOLLO CREWMEMBERS	R+0	REST SUPINE	15	9	4	2	-7 to +22
		LBNP	9	7	2	-	+13 to +66
		90^o STAND	9	9	-	-	+13 to +47
	R+1	REST SUPINE	15	5	9	1	-7 to +9
		LBNP	9	5	4	-	-3 to +38
		90^o STAND	9	6	3	-	+1 to +35
	R+2	REST SUPINE	6	2	3	1	-7 to +10
		LBNP	6	1	5	-	-11 to +19
		90^o STAND	3	1	2	-	-4 to +18

Recovery to preflight values generally by R+30 to +50 hours

	TEST DAY	TEST MODE	No. SUBJ.	↑2 SD	±	↓2 SD	RANGE Δ BPM
CONTROLS	R-1	REST SUPINE	13	2	11	-	-8 to +11
		LBNP	7	1	5	1	-15 to +9
		90^o STAND	7	1	6	-	-2 to +11

SUMMARY OF CALF CIRCUMFERENCE DATA FOR APOLLO 7 - 11 FLIGHTS

Postflight value VERSUS mean of 3 preflight measurements

TEST MODE	No. SUBJECTS	STATUS	SIGNIFICANCE
REST SUPINE	15 of 15	Decreased	
	10 of 15	Decreased	$p < 0.05$
LBNP STRESSED (APOLLO 7, 8, and 9 only)	2 of 9	Increased	$p < 0.05$
	3 of 9	Decreased	$p < 0.05$
	4 of 9	Variable	NS

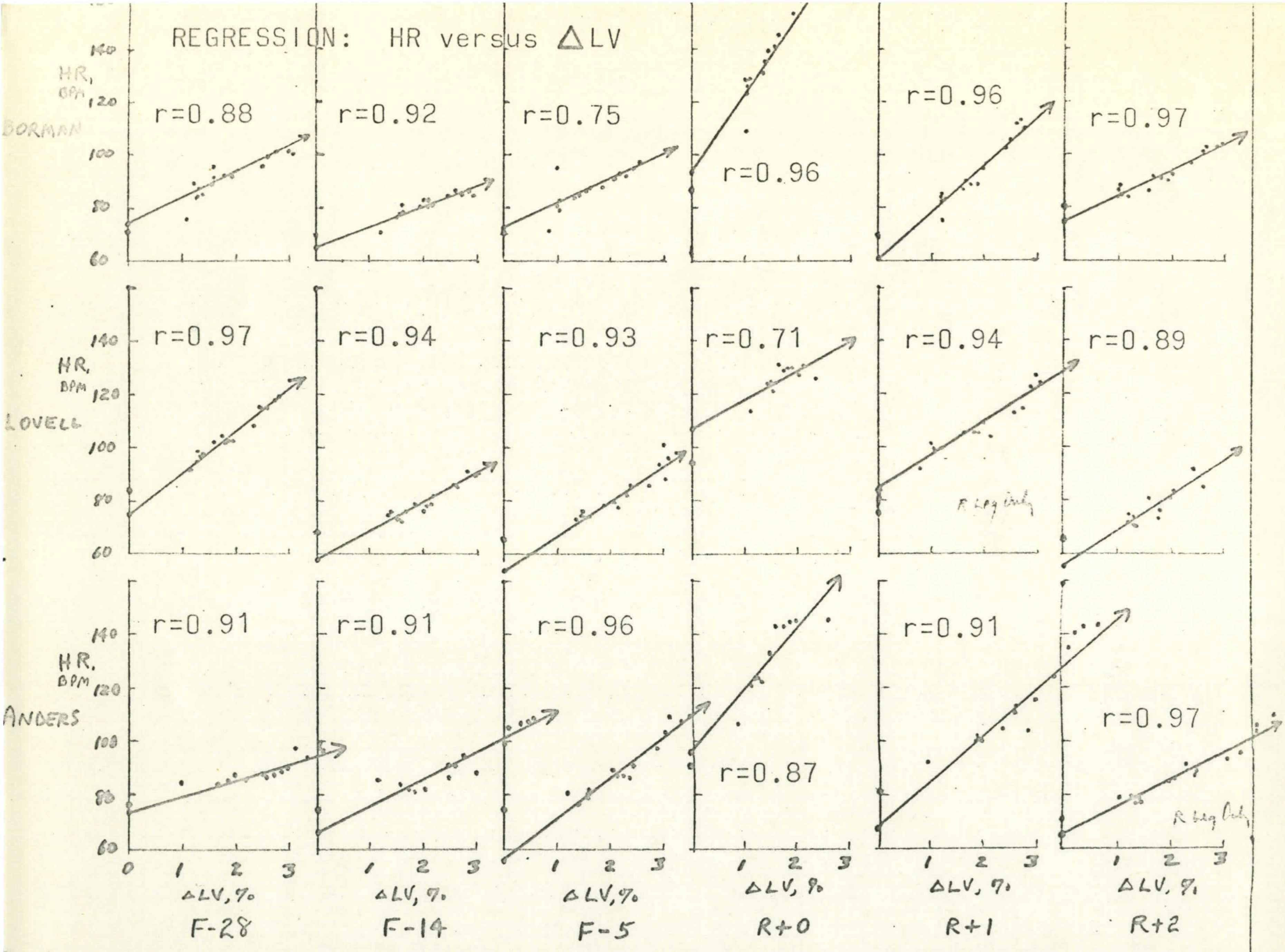


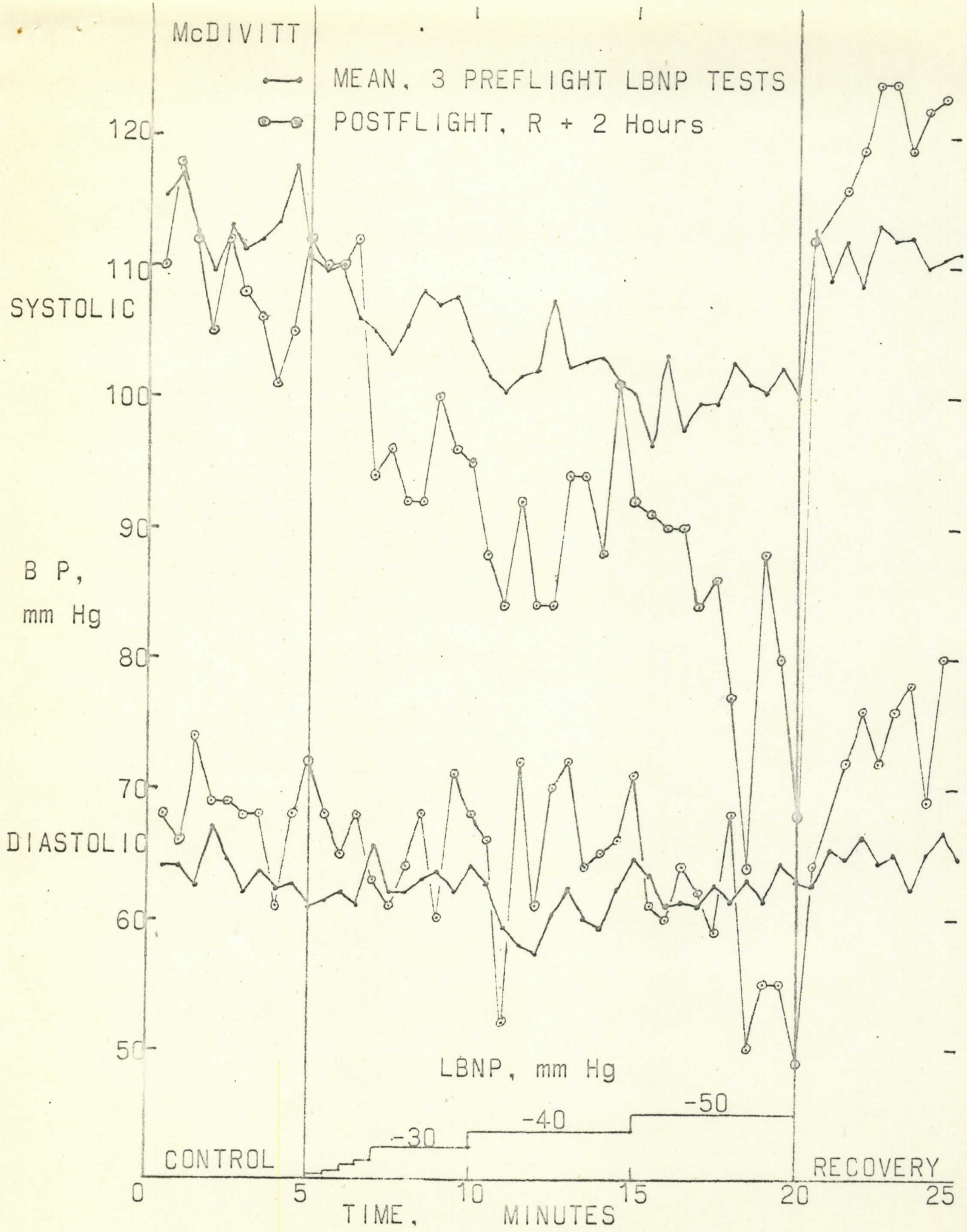
TABLE III - SUPPLEMENT TO REGRESSION DATA FOR HEART RATE VS. Δ LEG VOLUME

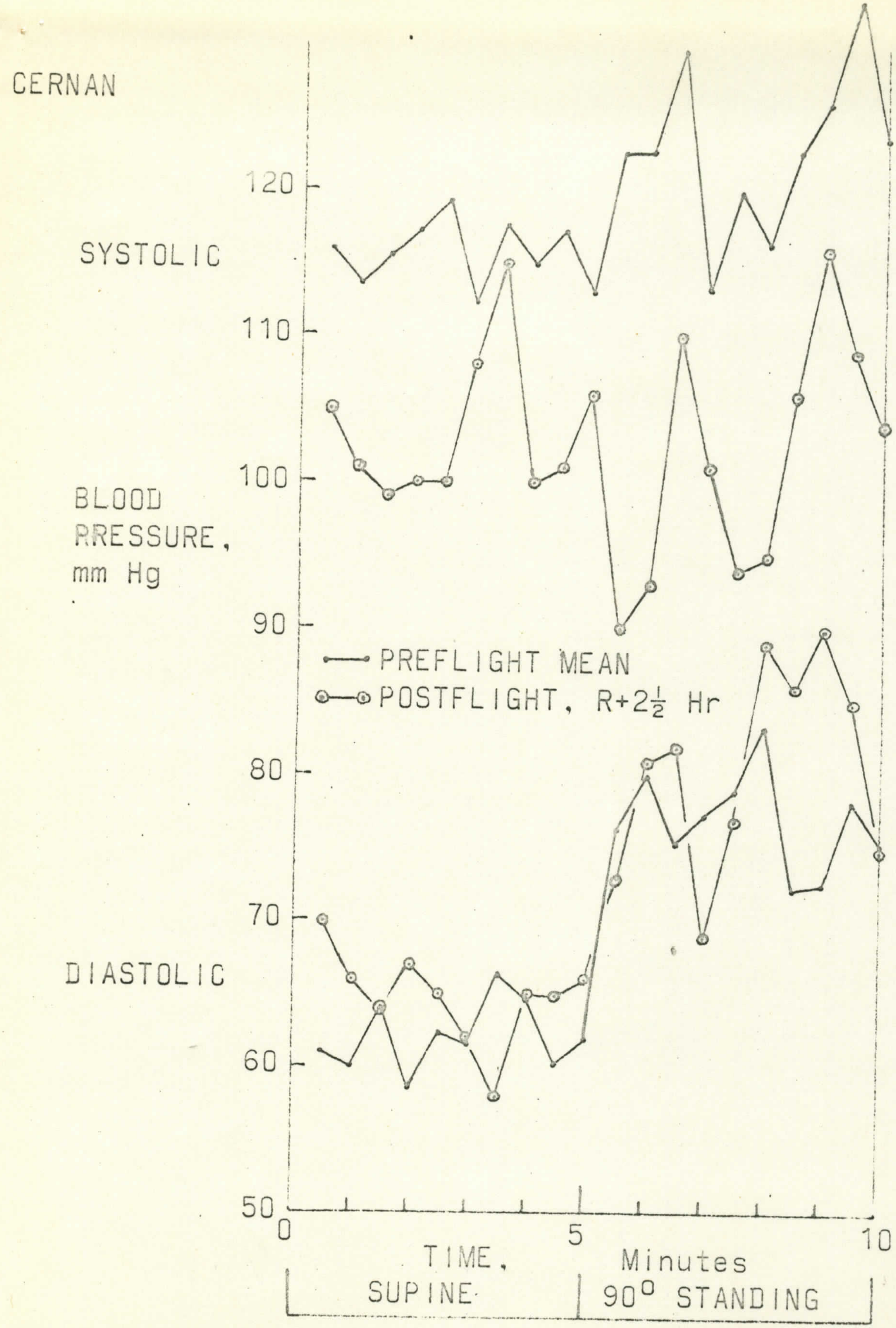
APOLLO 7 - 9 REGRESSION DATA

FOR HEART RATE ON CHANGE IN LEG VOLUME

Elevation of Immediate Postflight OVER Mean of 3 Preflight Values

FLIGHT	CREWMAN	SLOPE	INTERCEPT
	SCHIRRA	–	X
7	EISELE	X	X
	CUNNINGHAM	X	X
	BORMAN	X	X
8	LOVELL	-	X
	ANDERS	X	X
	McDIVITT	X	-
9	SCOTT	-	-
	SCHWEICKART	X	-


McDIVITT
MEAN, 3 PREFLIGHT LBNP TESTS
POSTFLIGHT, R + 2 Hours
120
110
SYSTOLIC
100
90
B P,
mm Hg
80
70
DIASTOLIC
60
50
LBNP, mm Hg
-30
-40
-50
CONTROL
RECOVERY
0
5
10
15
20
25
TIME, MINUTES


CERNAN
SYSTOLIC
BLOOD
PRESSURE,
mm Hg
DIASTOLIC
120
110
100
90
80
70
60
50
PREFLIGHT MEAN
POSTFLIGHT, R+2½ Hr
0
5
10
TIME, Minutes
SUPINE
90° STANDING

PULSE PRESSURE RESULTS FROM APOLLO 7 - 11 FLIGHTS

Postflight Values VERSUS Mean of 3 Preflight Values

TEST MODE	No. SUBJECTS	STATUS	SIGNIFICANCE
REST SUPINE	13 of 15	Decreased	
	4 of 15	Decreased	$p < 0.05$
LBNP	9 of 9	Decreased	
(APOLLO 7, 8, & 9 only)	5 of 9	Decreased	$p < 0.05$

Three experienced presyncopal episodes during immediate postflight LBNP.

TEST MODE	No. SUBJECTS	STATUS	SIGNIFICANCE
90^{0} STAND	7 of 9	Decreased	
(APOLLO 9, 10, & 11 only)	3 of 9	Decreased	$p < 0.05$

APOLLO CREWMEMBER WEIGHTS

FLIGHT	CREWMEMBER	LAUNCH DAY	RECOVERY DAY	DIFFERENCE
APOLLO 7	SCHIRRA	194.3	188.0	- 6.3
11 Days	EISELE	157.0	147.0	-10.0
	CUNNINGHAM	156.0	148.0	- 8.0
APOLLO 8	BORMAN	169.25	160.5	- 8.75
8 Days	LOVELL	171.8	164.0	- 7.8
	ANDERS	142.0	138.0	- 4.0
APOLLO 9	McDIVITT	158.75	153.5	- 5.25
10 Days	SCOTT	178.25	172.5	- 5.75
	SCHWEICKART	159.12	153.0	- 6.12
APOLLO 10	STAFFORD	170.5	168.5	- 2.0
8 Days	YOUNG	165.25	159.5	- 5.75
	CERNAN	172.5	163.0	- 9.5
APOLLO 11	ARMSTRONG	171.5	164	- 7.5
8 Days	COLLINS	166.0	159	- 6.0
	ALDRIN	167.25	166	- 1.25

Average Loss = -5.6 Pounds   Range = -1.25 to -10.0

SELECTED APOLLO 11 HEART RATES

AWAKE, ROUTINE ACTIVITY

	Preflight 1 g Stand	0 g	1/6 g	Lunar EVA	1/6 g	0 g	Postflight 1 g Stand
CDR ARMSTRONG	85	72	70	95	75	70	112
LMP ALDRIN	76	69	60	75	70	68	88

SPECIAL EVENTS

	0 g Average	Descent Peak	EVA Average	EVA Peak	Lunar Surface Average	Ascent Peak	0 g Average
CDR	70	150	110	156	92	120	66
LMP	67	-	88	110	77	-	68

RECOMMENDATIONS FOR FUTURE COURSE OF CARDIOVASCULAR SPACE MEDICINE

1. Continued studies over longer duration flights.
2. More extensive measurements of cardiovascular and related functions.
3. Development of more reliable, automated, and inflight operational measurements (e.g., body mass, blood pressure resolution, cardiac output, urinalysis).
4. Correlation of interrelated systems changes.
5. Evaluation of the time course of changes through space-based and inflight test capabilities.
6. Determination of etiological factors for application of therapeutic or preventive measures.