

**NASA
Technical
Paper
3298**

March 1993

IN-52
150339
P.14

Effect of Aerobic Capacity on Lower Body Negative Pressure (LBNP) Tolerance in Females

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(NASA-TP-3298) EFFECT OF AEROBIC
CAPACITY ON LOWER BODY NEGATIVE
PRESSURE (LBNP) TOLERANCE IN
FEMALES (NASA) 14 p

N93-20318

Unclas

H1/52 0150339

NASA



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INTRODUCTION

The relationship between aerobic capacity and responses to an orthostatic challenge remains equivocal. Several research groups have concluded that aerobic conditioning or high aerobic capacity is associated with decreased orthostatic function [1-6]. These findings have led to the suggestion [1] that astronauts should minimize or avoid aerobic training to prevent orthostatically induced symptoms from occurring during the entry, landing, and egress phases of spaceflight. The results of other investigative teams, however, have led to the conclusion that orthostatic function is not influenced by aerobic capacity [7-14]. The results from these studies indicate that aerobic conditioning may cause either a beneficial effect [9] or no effect [14] on orthostatic tolerance. The majority of the investigations regarding aerobic capacity and orthostatic function have used male subjects. Results of two studies, in which female subjects were used, have demonstrated no association between aerobic capacity and orthostatic function [15,16].

Bed rest has been used extensively as a physiological analogue to spaceflight to investigate the effects of prolonged "microgravity" exposure in human subjects. The cardiovascular responses to standing do not differ between subjects exposed to a bed-rest period of similar duration [17]. NASA is primarily interested in orthostatic function on the landing day of a mission; therefore, the relationship between aerobic capacity and orthostatic tolerance, measured after a bed-rest period, may be a more relevant relationship to examine than the simple relationship between aerobic capacity and orthostatic tolerance. No study has been conducted examining the effect of initial aerobic capacity on the orthostatic function of females following a bed-rest deconditioning period.

This investigation was conducted to determine whether a relationship exists in female subjects between: (1) aerobic capacity and orthostatic tolerance, measured using Lower Body Negative Pressure (LBNP), and (2) initial

aerobic capacity and change in LBNP tolerance induced by bed-rest deconditioning.

METHODS

Nine females served as subjects for the experiment (Table 1). Prior to the 13-day 6° head-down-tilt, bed-rest period, body composition was determined using hydrostatic weighing, and percentage body fat was calculated using the formula of Brozek et al. [18]. Subjects also performed an exercise to determine aerobic capacity. Subjects were prepared for 12-lead electrocardiography and auscultatory blood pressure determinations. These measures were taken in the supine and standing positions prior to each graded exercise test and during the last 30 secs of each stage of the Bruce treadmill exercise protocol. ECG was continually monitored on an oscilloscope. A customized Quinton QPLEX metabolic gas analysis system was used to collect metabolic data continuously during the test. This system consists of QPLEX software modified to collect and calculate ventilatory (pneumotach) and gas exchange (Marquette Mass Spectrometer) data. The gas analysis system was calibrated before and after each exercise test. Prior to and following the bed-rest period, an LBNP test was performed. At least 48 hours elapsed between the graded exercise test and the LBNP test performed prior to bed rest. The LBNP test protocol and the termination criteria for the test are presented in Fig. 1 and in Table 2, respectively. LBNP tolerance was quantified as: (1) the absolute level of negative pressure (NP) the subjects tolerated for ≥ 60 sec, and (2) Luft's Cumulative Stress Index (CSI), which is the sum of the product of time and pressure for each stage. Plasma volume of the subjects was measured before and during the last day of bed rest using ^{125}I -human serum albumin.

TABLE 1. *Subject characteristics (Mean ± SD)*

Age (yr)	34	± 6
Height (cm)	163.1	± 6.0
Weight (kg)	60.1	± 6.8
Fat (%)	24.8	± 9.4
$\dot{V}O_{2\text{peak}}$ (mL/kg/min)	33.3	± 4.9

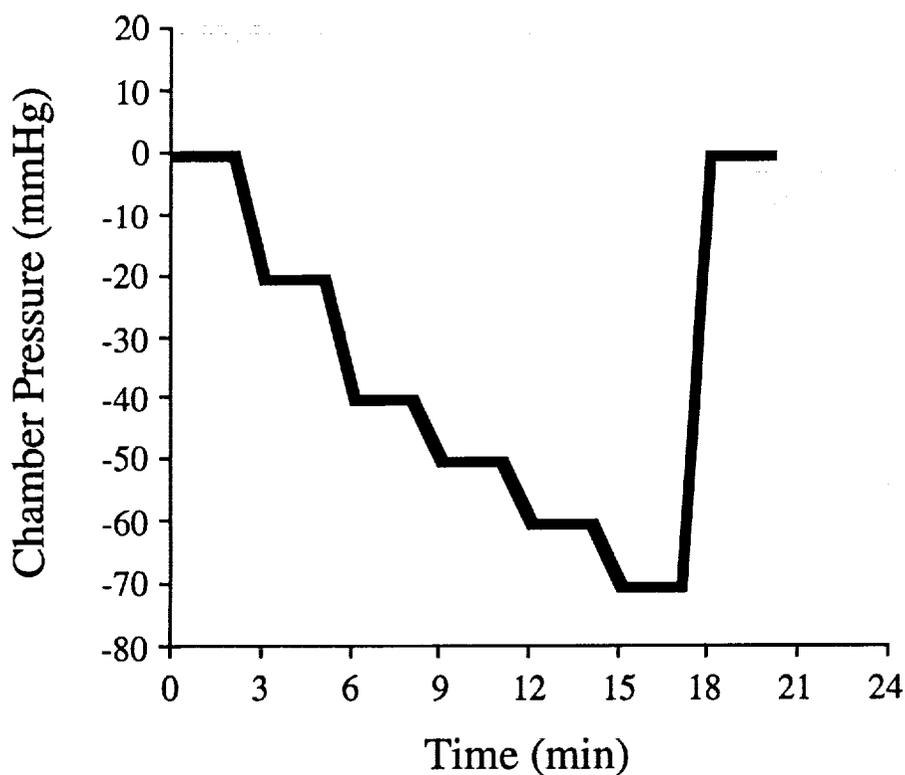


FIG. 1. LBNP protocol

LBNP data, collected prior to and following bed-rest deconditioning, were compared using a repeated measures analysis of variance. Pearson product-moment correlation was used to determine the relationship between negative pressure tolerance and aerobic capacity prior to bed rest and to determine the relationship between

aerobic capacity and the pre- to post-bed-rest change in negative pressure tolerance.

RESULTS

The 13-day bed-rest period was associated with a decrease in LBNP tolerance when the

TABLE 2. *LBNP termination criteria*

1. Sudden drop in blood pressure
Decrease in systolic blood pressure < 3.33 kPa/min (25 mmHg/min) or decrease in diastolic blood pressure of > 2 kPa/min (15 mmHg/min)
2. Sudden drop in heart rate
Decrease in heart rate of < 15 beats/min
3. Signs or symptoms of intolerance
Extreme subject nausea, clammy skin, profuse sweating, pallor of the skin
4. Subject request
5. Systolic blood pressure < 9.33 kPa (70 mmHg)
6. Significant cardiac dysrhythmias
Bradycardias (heart rate < 40 for individuals whose resting heart rate is < 50)
Tachycardia (ventricular or supraventricular)
Second- or third-degree heart block
Six or greater premature ventricular complexes (PVCs) per minute
R-on-T PVCs
Closely coupled PVCs (QR/QT < 0.85 sec)
Ventricular couplets

data were examined as either raw negative pressure values at test termination (Fig. 2) or as Luft's CSI values (Fig. 3). The data were suggestive of a weak negative relationship between LBNP tolerance and aerobic capacity before bed rest; however, the correlation between either of the two indices of LBNP tolerance and aerobic capacity did not differ significantly from zero (Figs. 4 and 5). No apparent relationship existed between the change in LBNP tolerance induced by the bed-rest period and initial aerobic capacity (Figs. 6 and 7). The mean change in plasma volume was -11.0%.

DISCUSSION

The decline in LBNP tolerance exhibited by the subjects following bed rest is consistent with observations made in previous studies [19]. This decline has been correlated with a decrease in plasma volume that occurs during the bed-rest period. Plasma volume loss (-11.0%) in the

subjects compares favorably with that found in the literature. Decline in plasma volume, measured during a bed-rest period of 10 days, was approximately the same for male (-10.0%) and female (-11.3%) subjects [20].

The finding of no significant correlation between pre-bed-rest aerobic capacity and LBNP responses is similar to the data reported in several studies [12,15,16]. In the study conducted by Frey and colleagues [16], it was reported that of the 45 female subjects, only 6 exhibited presyncopal symptoms during an LBNP test to -6.67 kPa (-50 mmHg). The $\dot{V}O_{2max}$ of these six subjects did not differ significantly from those who tolerated -6.67 kPa (-50 mmHg) for 5 minutes without symptoms. Convertino and co-workers [12] studied 18 male subjects and found no significant relationship between LBNP tolerance and aerobic capacity ($r = 0.05$, $p = 0.85$).

Other investigative groups have concluded that high levels of aerobic fitness are associated

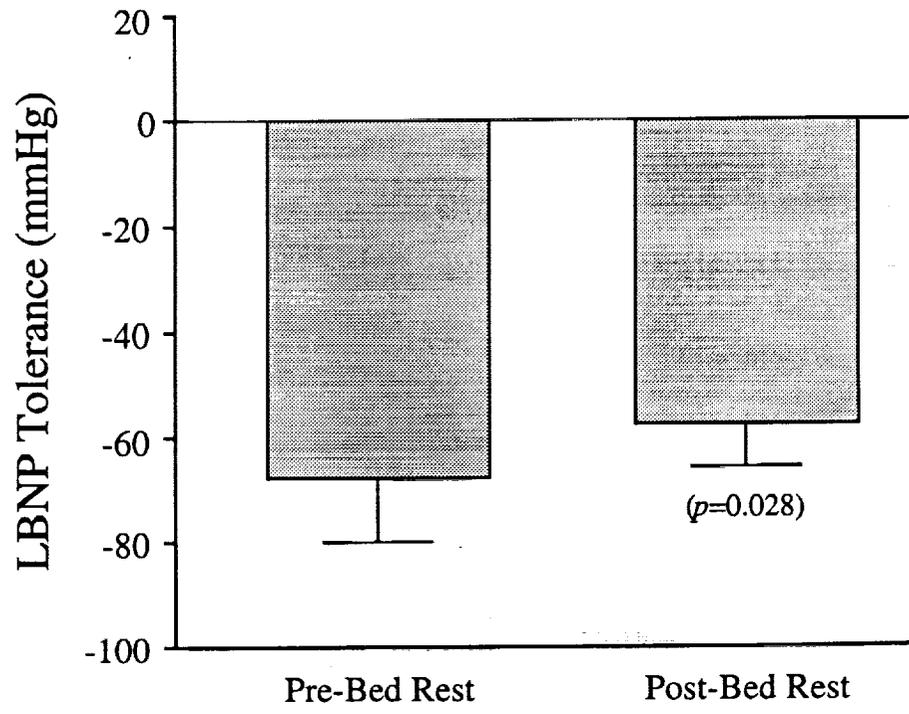


FIG. 2. LBNP tolerance (mmHg)

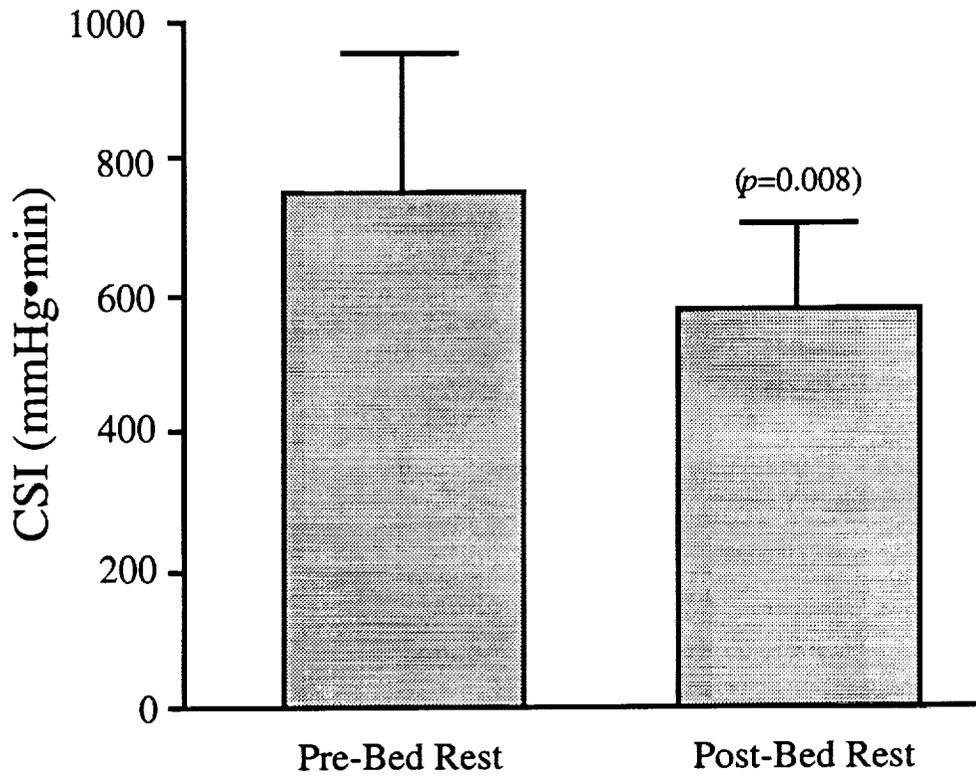


FIG. 3. LBNP tolerance (CSI)

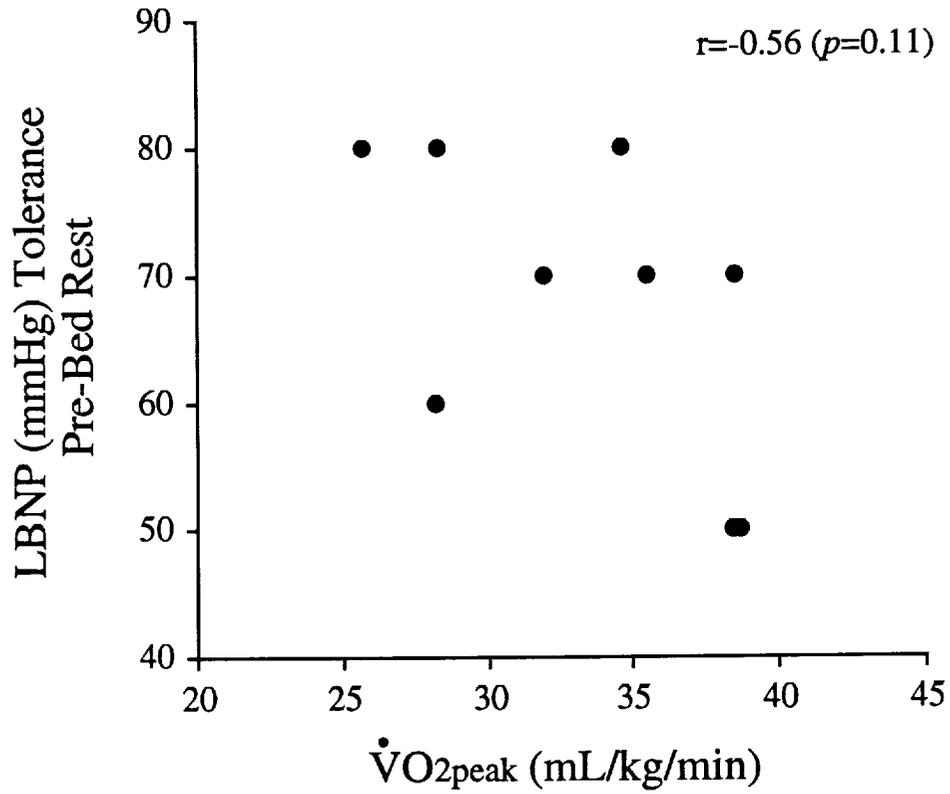


FIG. 4. LBNP tolerance (mmHg) versus aerobic capacity

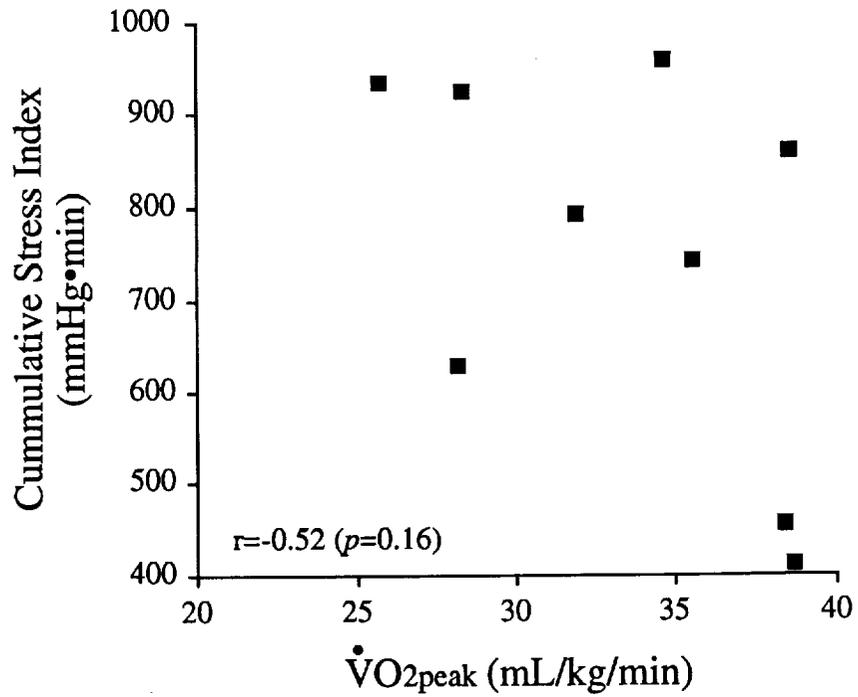


FIG. 5. LBNP tolerance (mmHg · min) versus aerobic capacity

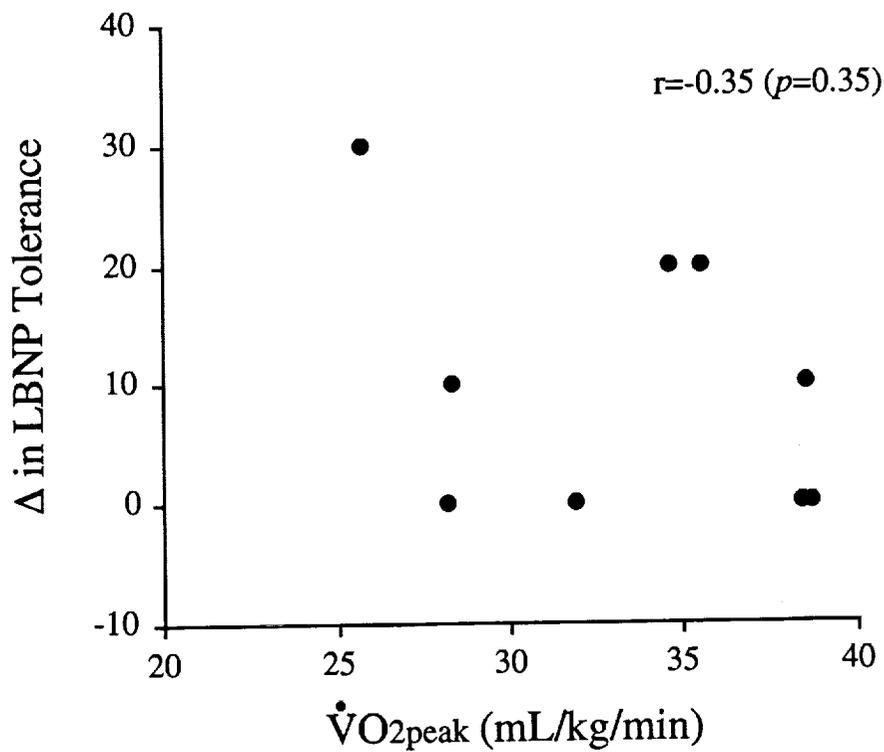


FIG. 6. Change in LBNP tolerance (mmHg) versus aerobic capacity

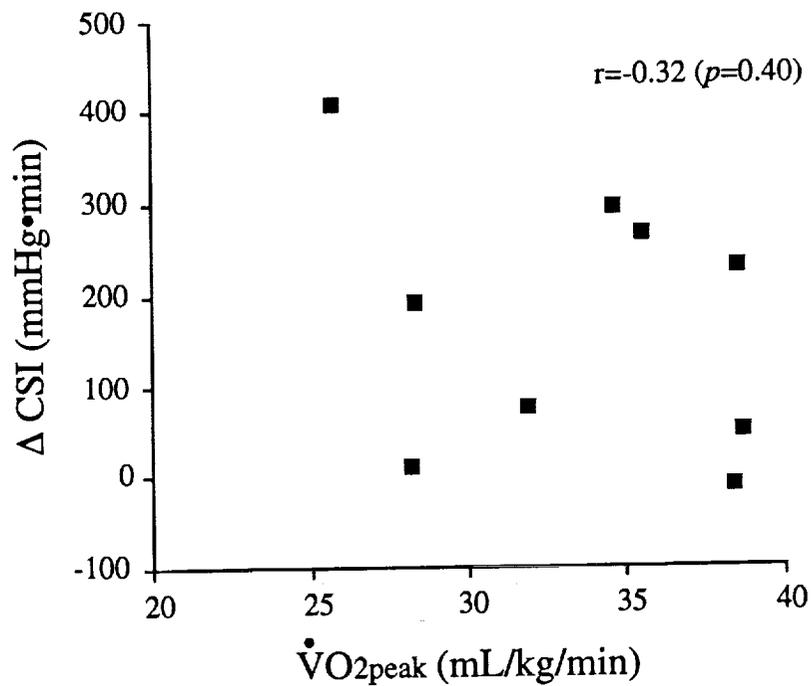


FIG. 7. Change in LBNP tolerance (mmHg·min) versus aerobic capacity

with poor orthostatic tolerance, leading to such statements as ". . . aerobic training prior to and during flight should be minimized and de-emphasized." [21] In an often-cited study that associated high aerobic capacity with attenuated orthostatic function, Klein and co-authors [22] analyzed cross-sectional data collected and originally reported by Luft and colleagues [3]. Luft reported an increased rate of syncope in five runners when compared to five sedentary subjects during LBNP testing. The analysis of Klein and co-authors revealed a significant relationship ($r = -0.60, p < 0.01$) between $\dot{V}O_{2\max}$ and LBNP tolerance for the 47 subjects. Of these, 13 subjects were endurance runners (mean $\dot{V}O_{2\max} = 51$ mL/kg/min). The LBNP tolerance of the runners was less than that of the nonrunners (mean $\dot{V}O_{2\max} = 36$ mL/kg/min). The authors proposed that increased cardiac vagal tone and an increased venous compliance of the runners were factors that limited LBNP tolerance; however, the authors presented no data to support or refute these hypotheses.

The discrepancies between studies may be due to differences in research design. In a review of the interaction between aerobic fitness, endurance training, and orthostatic intolerance, Convertino [23] noted that the data, which support a negative effect of aerobic capacity on orthostatic function, are based on a few cross-sectional studies in which syncope occurred in 22 highly trained competitive runners. The majority of published research studies, which are longitudinal and have used nearly 300 subjects of varying fitness and training levels, have not supported a negative relationship between orthostatic function and aerobic capacity [24].

The finding here of no relationship between pre-bed-rest aerobic capacity and change in LBNP tolerance does not match that found in the

literature. A study conducted at the NASA/Ames Research Center (ARC) [25] examined the effect of 10 days of bed-rest deconditioning on aerobic capacity and LBNP tolerance. Higher aerobic fitness prior to bed rest was associated with a greater loss in LBNP tolerance ($r = -0.87, p < 0.01$). The discrepancy between these results and those of the ARC study may be due to the differing definitions of LBNP tolerance used by the investigators. In this study, LBNP tolerance is defined as the lowest pressure attained by the subjects for at least 60 secs; however, the ARC study defined LBNP tolerance as the amount of time the subject tolerated -6.67 kPa (-50 mmHg). In addition, the ARC study used 12 male subjects whose $\dot{V}O_{2\max}$ ranged from 24-43 mL/kg/min and who were from 45-55 years old. The nine female subjects were younger (27-47 years); however, the range of $\dot{V}O_{2\max}$ (26-39 mL/kg/min) of the subjects was similar to that observed in the ARC study. This difference in subject characteristics may suggest an age or gender effect. The 3-day difference in bed-rest durations would not be anticipated to influence the results [19].

The results of this current study should be interpreted within the framework of its limitations, as only nine females have been examined. Although the subjects ranged from the 25th to 92nd percentile in $\dot{V}O_{2\max}$ for individuals of their age and gender [26], none of the subjects could be considered highly trained.

In conclusion, for this group of subjects, a significant relationship between aerobic capacity and orthostatic function does not exist. In addition, aerobic capacity did not significantly influence the change in LBNP tolerance induced by bed-rest deconditioning.

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REPORT DOCUMENTATION PAGE

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Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 1993		3. REPORT TYPE AND DATES COVERED Technical Paper	
4. TITLE AND SUBTITLE Effect of Aerobic Capacity on Lower Body Negative Pressure (LBNP) Tolerance in Females.				5. FUNDING NUMBERS	
6. AUTHOR(S) Alan D. Moore, Jr., Suzanne M. Fortney, and Steven F. Siconolfi					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Medical Sciences Division Space Biomedical Research Institute National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, TX 77058				8. PERFORMING ORGANIZATION REPORT NUMBER S-695	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING / MONITORING AGENCY REPORT NUMBER NASA TP-3298	
11. SUPPLEMENTARY NOTES Moore: KRUG Life Sciences, Houston, TX; Fortney and Siconolfi: Lyndon B. Johnson Space Center, Houston, TX.					
12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category 52				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This investigation determined whether a relationship exists in females between (1) aerobic capacity and Lower Body Negative Pressure (LBNP) and (2) aerobic capacity and change in LBNP tolerance induced by bed rest. Nine females, age 27-47 [34.6 ± 6.0 (Mean \pm SD)], completed a treadmill-graded exercise test to establish aerobic capacity. A presyncopal-limited LBNP test was performed prior to and after 13 days of bed rest at a 6° head-down tilt. LBNP tolerance was quantified as (1) the absolute level of negative pressure (NP) tolerated for ≥ 60 sec and (2) Luft's Cumulative Stress Index (CSI). Aerobic capacity was 33.3 ± 5.0 mL/kg/min and ranged from 25.7 to 38.7. Bed rest was associated with a decrease in NP tolerance [-9.04 ± 1.6 kPa (-67.8 ± 12.0 mmHg) versus -7.7 ± 1.1 kPa (-57.8 ± 8.33 mmHg); $p = 0.028$] and in CSI (99.4 ± 27.4 kPa-min [745.7 ± 205.4 mmHg-min] versus 77.0 ± 16.9 kPa-min [577.3 ± 126.8 mmHg-min]; $p = 0.008$). The correlation between aerobic capacity and absolute NP or CSI pre-bed rest did not differ significantly from zero ($r = -0.56$, $p = 0.11$ for NP; and $r = -0.52$, $p = 0.16$ for CSI). Also, no significant correlation was observed between aerobic capacity and pre- to post-bed-rest change for absolute NP tolerance ($r = -0.35$, $p = 0.35$) or CSI ($r = -0.32$, $p = 0.40$). Therefore, a significant relationship does not exist between aerobic capacity and orthostatic function or change in orthostatic function induced by bed rest.					
14. SUBJECT TERMS pressure, lower body negative (LBNP); pressure, negative (NP); physiological effects, aerobic capacity; physiological effects, Luft's Cumulative Stress Index (CSI); bed rest				15. NUMBER OF PAGES 16	
				16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL		