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THE EFFECTS OF UPRIGHT LOWER BODY NEGATIVE PRESSURE CYCLE ERGOMETRY TRAINING ON VO_{2max} AND ENDURANCE

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ABSTRACT

Travel to and residence at Mars may require the use of a Lower Body Negative Pressure (LBNP) training device to maintain fitness. The LBNP device pulls body fluids into the lower body so as to simulate an earth-like gravity vector. The purpose of this study was to determine if a cycle ergometry training program using LBNP would cause a greater increase in VO_{2max} and endurance, than an identical training program that did not use Lower Body Negative Pressure.

VO_{2max} and endurance were determined on a cycle ergometer and on a treadmill using the Bruce protocol. The subjects were matched according to VO_{2max} and divided into experimental and control groups. The subjects then trained three times per week for 8-weeks at about 70% VO_{2max}. Following the eight weeks, they repeated the pre-test protocol. Eight volunteers began the program, and 5 (3 study/2 control) completed it. The results of the post-testing showed greater increases in VO_{2max} in the study group compared to the controls, although the low number of subjects precluded statistical analysis. The study group showed increases in VO_{2max} of 4.8%, 16.25%, and 7%; while the control group showed increases of 5.9% and 2.4%. The results from the endurance test did not show improvement in either group.

These results suggest that training under LBNP conditions may be useful to enhance fitness in 1 G. Similarly, in 0 G or 1/3 G, training with LBNP may simulate a more earth-like training condition because fluids are shifted to the legs as they are in 1G. The consequence may be an increase in blood and plasma volume – the traditional earth-like training effect. A higher level of aerobic fitness may be possible using the LBNP training device while in and traveling to the Martian environment thus increasing Martian work capacity and facilitating reentry into a 1 G environment.

INTRODUCTION

Traveling, living and working in outer space creates physiological and medical concerns for astronauts. Short stays into space affect the astronauts' fitness levels, and long stays in microgravity leave returning astronauts unable to stand. Lower Body Negative Pressure (LBNP) devices have been used to mimic the influences of gravity on the body for studies using extended

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bed rest to simulate microgravity, in efforts to find ways that would allow astronauts to maintain their fitness levels while in space (Lee et al. 1997; Hargens et al. 1994; Murthy et al. 1994). These studies have shown that supine LBNP exercise simulates upright exercise in maintaining submaximal exercise responses. Furthermore, in 1968, Cooper and Ord observed that upright exercise under LBNP conditions might produce a training effect.

Therefore, the purpose of this study was to determine if an eight-week upright LBNP cycle ergometry training program would produce a training effect on VO_{2max} and endurance and relate these results to long term space flight.

REVIEW OF LITERATURE

This section will examine the literature associated with Lower Body Negative Pressure training, and its effects on VO_{2max} and endurance.

Astronauts returning from spaceflight lasting one to two weeks typically find themselves to be orthostatically intolerant upon returning to Earth (Hargens and Watenpaugh, 1996). In an attempt to maintain, or even improve, the physical conditioning of astronauts exposed to a microgravity (space) environment, researchers have tried to train subjects in a simulated microgravity environment on Earth, due to the difficulty of performing this research in space. The two most common ways that microgravity is simulated are bed rest and Head-Down Tilt (HDT). With these methods, fluid redistribution and cardiovascular deconditioning approximates that found during spaceflight. Subjects undergoing bed rest can be placed supine into a Lower Body Negative Pressure chamber to exercise without returning to a standing position effectively maintaining the simulated effect of microgravity. While supine within the LBNP chamber, fluids and blood pressure gradients are redistributed in the body to approximately that of a 1G (Earth) environment. Exercise in the chamber can be on a vertically mounted treadmill or cycle ergometer. In the case of the treadmill, pulleys are used around the legs to remove the vertical gravity vector, which is not present in space. It has been demonstrated that training responses under supine LBNP conditions closely resemble the training responses of an upright 1G training program.

Hargens et al, (1991) compared footward forces produced in a supine LBNP environment to standing, and found them to be similar, thus showing the effectiveness of supine LBNP to approximate those forces when standing. If supine LBNP forces are similar to normal upright forces, then it may follow that upright LBNP forces will be greater than 1G, and that upright LBNP exercise will place an additional stress on the body.

Murthy and co-workers (1994) found that supine LBNP exercise closely resembles that of upright exercise. They measured footward force, muscular pressure of the soleus and tibialis anterior, calf volume, heart rate and blood pressures in both supine LBNP and upright 1G conditions. They concluded that supine exercise against 100 mm Hg LBNP provides similar muscular stress as the same exercise upright against 1G. Additionally, they found that supine LBNP provides greater cardiovascular stress than upright 1G exercise, evidenced by a significantly higher heart rate (99 $\pm$ 5 to 81 $\pm$ 3 beats per minute). Also, and possibly related to the increased heart rate, the calf volume was significantly increased by 3.3 $\pm$ 0.5% during LBNP exercise, while it did not increase significantly during 1G exercise.

Eiken (1988) also observed significantly higher heart rates during supine LBNP cycling exercise than supine exercise without LBNP, in addition to significantly lower blood lactate levels in the LBNP group. Oxygen uptake was found to be 10% lower in the LBNP group, and it rose at a much lower rate than the control group. Cycling endurance was found to be higher in the LBNP group, but still less than similar upright exercise. He concluded that supine LBNP exercise is a "valid and useful model of upright exercise" (p. 775).

Lee and co-workers (1997) found that supine LBNP exercise is able to maintain the exercise responses as well as upright exercise in subjects undergoing five days of bed rest. Pre- and post-bed rest exercise testing showed significant elevations in heart rate, respiratory exchange ratio and minute ventilation in the control group, who did not exercise, but similar values between the upright exercisers and those who exercised supine with LBNP in all variables tested. While this is useful for the space program, it also suggests that supine LBNP exercise occurs at a simulated 1G.

In comparing supine exercise with and without LBNP, Eiken and Bjurstedt (1985) found that exercise with LBNP did not have a significant influence on heart rate compared to exercise without LBNP during graded exercise on a cycle ergometer at workloads of 0, 50 and 100 watts for four minutes each. Significant decreases were found however, in cardiac output, stroke volume, and mean systolic ejection rate at all workloads. This study also showed that leg exercise aids in returning blood to the heart, as stroke volume with LBNP increased considerably from resting values, and continued to increase during exercise, whereas, during exercise without LBNP, stroke volumes decreased with increasing loads.

Submaximal VO2 and ventilatory thresholds were found to be lower in supine LBNP exercise when compared to upright exercise, however, the difference was not significant (Hughson et al, 1993). Significant decreases were found in VO_{2max} and ventilatory thresholds between supine LBNP and upright exercise. At low or high work rates, heart rates were found to be similar in supine LBNP and upright exercise.

Cooper and Ord, in 1968, compared upright and supine exercise during submaximal exercise with and without LBNP, and found significantly higher heart rates (184 to 173) were attained during the upright LBNP exercise. Cycling without LBNP had slightly higher, but not significant, VO_{2max} and minute ventilation values. These cardiorespiratory changes are similar to those seen in a loss of physical fitness, or deconditioning. This study suggests that upright LBNP exercise can produce a training overload that may accelerate a cardiovascular training response when compared to training without LBNP.

The research presented suggests that supine LBNP exercise is similar in training responses to normal upright exercise. Additionally, cardiovascular responses to supine LBNP are similar to, or even slightly higher than, normal upright exercise, and it was observed that upright LBNP exercise produces higher heart rates and a deconditioning-like effect. The next logical step appears to be to try to ascertain the effects of an aerobic training program under upright LBNP conditions, to see if the LBNP induced deconditioning-like response will lead to an increased training response that can be measured with VO_{2max} and endurance testing. This may lead to an additional method for improving cardiovascular fitness that may be more effective than current methods.

METHODOLOGY

During the first week of the study, all the subjects underwent 3 pre-tests: (1) a cycle ergometry VO_{2max} test, (2) a cycle ergometry endurance test, and (3) a treadmill VO_{2max} test.

The cycle ergometry (Monark mechanically braked cycle ergometer) VO_{2max} test used the Chico cycle (similar to a Bruce treadmill test) protocol, which terminated when the subject was unable to continue or maintain 60 rpm for 15 seconds. During the last thirty seconds of each stage a Rating of Perceived Exertion, from the Borg revised scale (ACSM Guidelines, 1995) was obtained. Heart rate was measured with an EKG, and respiratory gases were measured with the metabolic cart (ParvoMedics TrueMax 2400, Parvo Medics, Inc, Sandy, UT) automatically during the test. Endurance was measured fifteen minutes after completion of the VO_{2max} test. The test began with a 60-second warm-up at 60 rpm and 1 kp, then increased to 90 rpm and 2.5 kp. The test ended when the subject could no longer continue or maintain 90 rpm for 15 seconds. The treadmill test took place two days later and used the Bruce protocol (ACSM Guidelines, 1995). The same procedures were used as during the cycle testing. After all subjects had been tested, they were ranked according to their cycle VO_{2max}, and then divided into experimental and control groups. To distribute them evenly, the subject with the highest VO_{2max} was placed into the experimental group and the subject with the second highest VO_{2max} was placed into the control group. This procedure was continued until all subjects were assigned to a group. The subjects were then contacted and training times were arranged that fit their schedules and preferred times. Times were scheduled that allowed one control and one experimental subject to train together to best utilize the lab time. A researcher was present for all training sessions to ensure compliance with the program and increase safety. The training program was individualized to the subjects, based on 60-70% of their cycle VO_{2max} test. Training protocols were estimated using the leg ergometry calculation from the ACSM handbook (pg. 282).

$$VO_2 \text{ ml/min} = 3.5 \text{ ml/kg/min} \times \text{kg BW} + \text{kgm/min} \times 2$$

Calculating 60, 65, and 70% of the individual's VO_{2max} and using a 60-rpm standard predicted the required workload. The subjects trained thirty minutes a day, three times per week for the next eight weeks starting at 60%, then increasing to 65% in the fourth week and 70% in the seventh week. The vacuum was maintained at 30 ± 5 mm Hg, after it was discovered during the first ride of each study subject that the planned 50 mm Hg vacuum resulted in dyspnea, light-headedness, and dizziness during the exercise period.

Following the eight weeks of training, the subjects repeated the cycle VO_{2max}, cycle endurance, and treadmill VO_{2max} testing, following the same protocols as the pre-test.

RESULTS

Table 1 shows the subjects characteristics and Table 2 shows the results from the pre- and post-tests. 8 subjects began the program, and 5 completed the 8 weeks of training.

Subject Characteristics

Subject	Age	Gender	Height	Weight pounds	Attendance 24 possible
1	38	M	6'	185	16
2	28	F	6'1 _"	165	20
3	25	M	6'6"	150	19
4	23	F	5'4"	145	20
5	22	F	5'3"	140	21
6	18	F	5'5"	157	3
7	22	M	6'7"	250	1
8	38	F	5'4"	220	5

Table 1

Study Results

Study	Pre-VO_{2max}(Cycle)	Post-VO_{2max} (Cycle)	% Change	Pre-Endur	Post-Endur	Pre-VO_{2max} (Tread)	Post-VO_{2max} (Tread)	% Change
1	47.8	50.1	4.8	7:31	4:19	53.8	53.3	-0.9
3	40	46.5	16.25	3:15	3:33	49.9	56.4	13
5	32.8	35.1	7	1:45	1:38	32.6	35.1	7.7
7	29	Did	not	finish				
Control	**Pre-VO_{2max} (Cycle)**	**Post-VO_{2max} (Cycle)**	**% Change**	**Pre-Endur**	**Post-Endur**	**Pre-VO_{2max} (Tread}**	**Post-VO_{2max} (Tread)**	**% Change**
2	42.5	45	5.9	4:04	3:20	45.6	47.4	3.9
4	33.7	34.5	2.4	1:39	1:47	41	38.8	-5.4
6	29.6	Did	not	finish				
8	20.6	Did	not	finish				

Table 2

The number of subjects completing the study was not suitable for a statistical analysis. However, the data imply that training in the LBNP box did have an effect on VO_{2max}. The control group did not achieve improvements in VO_{2max} anywhere close to those in the study group. Subjects 4 and 5 were the most closely matched pair in the group. They also trained at the same time and had similar attendance. Comparing their changes shows a three-fold increase in the study partner compared to the control. Subject 3, the most improved, also has nearly a three-fold increase over the highest improvement from the control group.

The LBNP box did not appear to have an effect on endurance, as only 2 subjects showed any improvement. This may be because the endurance test is more a test of power output, rather than cardiovascular fitness, or that the subjects were more fatigued during the VO_{2max} test because they cycled for a longer time.

Cardiovascular fitness improvements made while training on a cycle ergometer translated into an improved VO_{2max} on the treadmill as well. 3 of the 5 subjects had similar gains in VO_{2max} on the treadmill test as they did on the cycle. This shows a lack of training specificity between the cycle and treadmill, and suggests that either a cycle ergometer or treadmill could be used for training in the LBNP box.

CONCLUSIONS

This study was designed to determine if upright training in a Lower Body Negative Pressure environment could produce an ergogenic effect. Lower Body Negative Pressure training on supine bedrest subjects has been shown to approximate upright training, and that a supine LBNP environment produces similar gravitational-like forces when compared to a normal 1G upright environment. It had also been previously suggested that upright LBNP exercise might produce a cardiovascular training effect.

Eight subjects volunteered to be a part of an 8-week training program. They began with a pre-test to measure their current VO_{2max} and endurance times on a cycle ergometer, followed 2 days later by a Bruce treadmill test. The subjects were then allocated to a study group with LBNP cycle training and a control group with normal cycle training. At the end of the 8-week training program, the subjects repeated the pre-test protocols. Five subjects (3 study/2 control) completed the program. The cycle and treadmill VO_{2max} scores of the study group were higher than those of the control group, however the endurance times did not show any differences between the groups, and were improved in only 2 subjects. The low number of subjects precluded a statistical analysis.

From an observational analysis of the results, it is apparent that statistical significance will require a larger study. The nearly 3-fold difference in the study group suggests that an ergogenic effect did occur while training in the LBNP box. The lack of improvement in endurance times could be accounted for by the increased time the subjects went during the VO_{2max} test, and that if not already fatigued, those times may also be increased. It could also show a difference in training methods needed for aerobic capacity and power, because the endurance test is more a measure of power than aerobic capacity.

These results suggest that training under LBNP conditions may be useful to enhance fitness in 1 G. Similarly, in 0 G or 1/3 G, training with LBNP may simulate a more earth-like training condition because fluids are shifted to the legs as they are in 1G. The consequence may be an increase in blood and plasma volume – the traditional earth-like training effect. A higher level of aerobic fitness may be possible using the LBNP training device while in and traveling to the Martian environment thus increasing Martian work capacity and facilitating reentry into a 1 G environment.

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