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Metabolic Rate Measurements Comparing Supine with Upright Upper-Body Exercises

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Abbrevations and Acronyms

ATSP	ambient temperature, pressure, saturated with water
BSA	body surface area
Btu	British thermal unit
CO_2	carbon dioxide
DCS	decompression sickness
EVA	extravehicular activity
ft	foot
h	hour
in-lb	inch-pound
kcal	kilocalorie
kp	kilopond
kPa	kilopascal
kpm	kilopond meter
L	liter
lb	pound
m	meter
N	newton
N_2	nitrogen
N•m	newton meter
O_2	oxygen
psi	pounds per square inch
RQ	respiratory quotient
SE	standard error
STPD	standard temperature, pressure, and dry

INTRODUCTION

A number of ground-based studies have been conducted in an altitude chamber at the NASA Johnson Space Center to verify operational protocols for extravehicular activities (EVAs) that reduce the risk of decompression sickness (DCS) [9, 2]. During these studies, test subjects exercised using their upper-body limbs to simulate different EVA tasks at a level of 200 kcal/h. This level approximated the average energy expended during EVA on previous space flights [2].

To study the possible effect of microgravity on the incidence of DCS, a provocative investigation of DCS was conducted with subjects who were bed rested for 3 days prior to exercising their upper-body limbs supine in bed at a simulated altitude. The development of DCS symptoms during supine exercise by the bed-rest subjects was compared to that of control subjects during upright exercises [8]. During the study, it was essential that the work activities conducted at reduced pressure were comparable in both the supine and upright exercise groups.

The aim of this study was to measure the metabolic rates during both supine and upright exercise as previously documented [3]. Increases in metabolic rates during exercise and decreases in mechanical efficiency of the treadmill in space flights have been reported [1]. The purpose of this NASA Contractor Report is to document the ground-based study that tested the hypothesis that metabolic rates during supine and upright exercise are similar.

MATERIALS AND METHODS

Subjects

Six subjects (three males and three females) were tested. Each subject had a screening examination similar to an Air Force Class III physical examination, signed the NASA Human Research Consent Form, and completed a maximal exercise stress test prior to participating in the study.

Exercises

Three exercise stations, a hand-cycle ergometer (Model 194 EM Monark Cycle Ergometer, MacLevy Products Corp., Elmhurst, NY), a rope-pull device (Mini-Gym Model 180X Isokinetic Exerciser, Misanron Health and Fitness Systems, Inc., Independence, MO), and a torque wrench [3], were designed for two groups of identical subjects, those who were supine in bed and those who exercised upright (seated or standing) by the station. Each subject performed the supine or upright exercise at 4-minute intervals (assigned randomly) for a total of 60 minutes for each group. A minimum rest period of 1 hour was established between the supine and upright exercises. Two subjects did not complete the upright exercise portion of the study.

The protocol schedule (Table 1) allowed for a rotation every 4 minutes of each exercise station for two cycles (24 minutes) and two 4-minute rest periods (8 minutes). The hand-cycle ergometer was operated at a rate of 3 revolutions of the hand crank every 5 seconds for each hand (clockwise for the right hand and counterclockwise for the left hand), followed by a 5-second rest against a resistance of 0.5 kp (288 kpm) for both the upright and supine stations. While seated or supine, the rope-pull device was operated with hands together at a rate of two pulls to the waist every 5 seconds for a period of 4 minutes against a resistance of 11 kp (25 lb) for a distance of approximately 0.7 m (758 kpm). During the second cycle, the rope was pulled twice with alternating hands every 5 seconds. The torque wrench was operated by holding the wrench in the right hand on each of four studs alternately pushing and pulling each holding for 5 seconds, repeating the movements for a 4-minute period at a work load of 35 Nm (3.6 kpm).* The left hand was used during the second cycle. Flashing cadence lights indicated 5-second intervals. The subjects were monitored with an electrocardiograph (Mingograf, Siemans Medical, Stafford, TX) during exercise as a safety precaution.

Expired Gas Collection

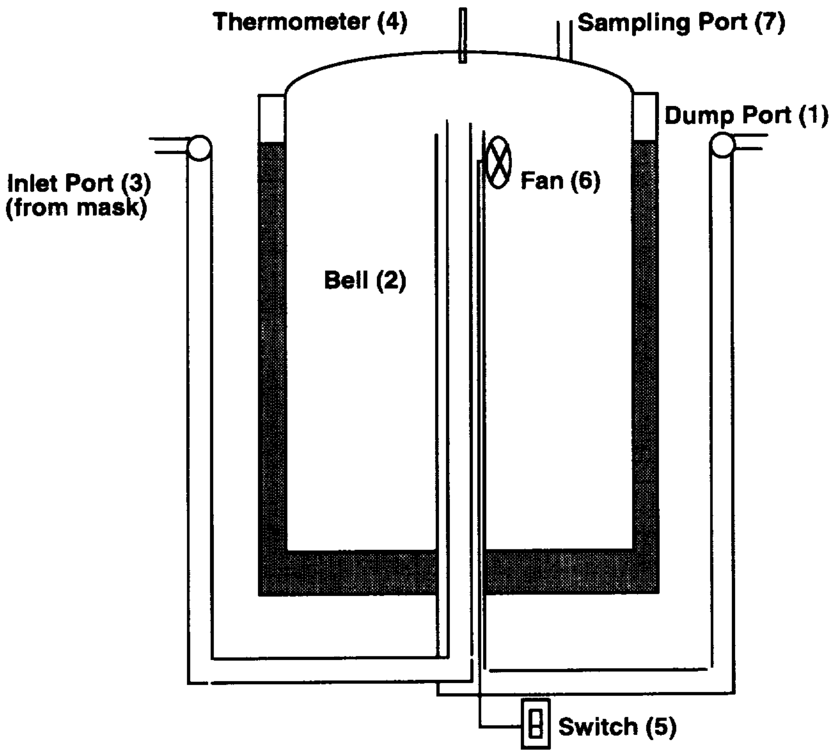
After a baseline measurement of the metabolic rate at rest and one rotation of the three exercise stations (for warm-up), the metabolic rate was measured twice at each exercise station during six 4-minute gas collection periods (24 minutes, Table 1).

Table 1. *Rotation protocol for the exercise stations and gas collection*

Time	Station/(Code #)	Procedure
-0:04	Baseline	Expired Gas Collection
0:00	Hand-cycle ergometer (1)	
0:04	Right-hand torque (2A)	
0:08	Right-hand rope pull (3A)	
0:12	Hand-cycle ergometer (1)	Expired Gas Collection
0:16	Left-hand torque (2B)	
0:20	Left-hand rope pull (3B)	Expired Gas Collection
0:24	Rest	
0:28	Hand-cycle ergometer (1)	
0:32	Right-hand torque (2A)	Expired Gas Collection
0:36	Right-hand rope pull (3A)	
0:40	Hand-cycle ergometer (1)	Expired Gas Collection
0:44	Left-hand torque (2B)	
0:48	Left-hand rope pull (3B)	Expired Gas Collection
0:52	Rest	
0:56	Hand-cycle ergometer (1)	
1:00	Right-hand torque (2A)	Expired Gas Collection

The subjects breathed through a mouthpiece and two-way valve (Hans-Rudolph Co., Kansas City, MO) connected to a 120-liter gasometer (Collins, Inc., Boston, MA) for 3 to 4 minutes. The gasometer and the procedure are illustrated in Figure 1.

*The resistances for the original exercise stations resulting in mean metabolic rates of 177 kcal/h ±21(SD) (702 Btu/h±82[SD]) were 0.5 kp (4.6 N) for the hand ergometer, 11 kp or 108 N (25 lb) for the rope-pull, and 34 N•m (300 in-lb) for the torque station (J. Waligora, 1983, personal communications; see Appendix A).



Steps to collect expired gas

1. Turn knob (1) open and slowly lower the bell (2) to dump gas
2. Close knob (1)
3. Connect mouth-piece to the test subject
4. Turn knob (3) to open breathing tube to the gasometer inlet port
5. Fill the bell (2) of gasometer partially with subject's air
6. Switch on (5) the fan (6) for 10 seconds
7. Close inlet knob (3)
8. Turn open knob (1) and slowly lower the gasometer bell (2) to dump gas
9. Close knob (2)
10. Note initial volume from the scale (not shown) on data sheet
11. Turn knob (3) to open breathing tube to the gasometer inlet port
12. Start stop-watch
13. Observe that the bell rises and collects gas for exactly 4 minutes
14. Close inlet knob (3)
15. Remove mouthpiece from test subject
16. Note final volume from the scale and temperature (4) on data sheet
17. Switch on (5) the fan (6) for 10 seconds
18. Attach mass spectrometer line to the gas outlet (7)
19. Note percentage of N_2, O_2, and CO_2 on the data sheet
20. Dump remaining gas as in step 1

Figure 1. *Gasometer and procedure for collecting expired gas in a 120-liter gasometer*

The exact time was recorded. The volume of expired gas was calculated by subtracting the initial reading from the final reading on the gasometer scale that corresponded to the distance that the bell was displaced in the water at ambient temperature and pressure. A fan in the gasometer was engaged for 10 seconds to mix the expired gas. The samples were analyzed directly for the percentage of oxygen, nitrogen, and carbon dioxide in the inspired and expired gas with a mass spectrometer (Model 1100, Perkin Elmer, Inc., Pomona, CA). The data record sheet is illustrated in Figure 2.

Name:________________________ Sex:______ Date:______________

Age:______ Height:________ Weight:_______ Body Surface Area:________

Gasometer Factor=1.332 Atmospheric Pressure:__________mmHg

TIME (min)	GASOMETER READINGS (APTS)				% EXPIRED GAS		
*Code#/ Total Time	Initial	Final	Volume	°C	O_2	N_2	CO_2
Group							
Group							
*Code number for the exercise station							

Figure 2. *Data sheet for metabolic rate measurement*

The temperature of the gasometer was recorded for each measurement, and barometric pressure was recorded at the start of the experiment. The inspired air was sampled at the subject's mouthpiece, and the expired air was sampled from the gasometer through a small outlet valve. Before measurements were taken and in between subjects, any air remaining in the gasometer was purged by partially filling up the bell with the subject's air and discarding it.

Data Analysis [6]

All raw data were collected and stored in a data base; the following formulas were used to calculate each measurement, using Microsoft Exel Software (Microsoft Corp., Redmond, WA).

- Expired gas volume (L) at ambient temperature, pressure, saturated with water (ATPS)=[(final reading-initial reading)x1.332].

- Gas volume/min (ATPS)=(liters ATPS/duration of gas collection).

- Gas volume/min at standard temperature, pressure, and dry (STPD)=[(L/min ATPS)(273 °C/(273 °C ±°C of the gas))][(barometric pressure mmHg-wet vapor pressure mmHg)/760 mmHg]. The value for the vapor pressure of wet gas is listed in a Table 2 [6].

Table 2. *Vapor pressure (PH_2O) of wet gas at laboratory temperatures (°C)*

°C	PH_2O	°C	PH_2O
20	17.5	26	25.2
21	18.7	27	26.7
22	19.8	28	28.4
23	21.1	29	30.0
24	22.4	30	31.8
25	23.8	31	33.7

- Volume O_2 consumption (L/min)=[L/min STPD][(%N_2 expired/%N_2 inspired)(%O_2 inspired)-%O_2 expired)/100)].

- Volume CO_2 production was calculated by [L/min STPD][(%CO_2 expired-%CO_2 inspired)/100].

- Respiratory quotient (RQ)=(L/min CO_2 produced/L/min O_2 consumed).

- The metabolic rate in kcal/L O_2 consumed came from Table 3 [6] using the RQ.

- The metabolic rate in kcal/h=[(L/min O_2 consumed)(kcal/L O_2 consumed)][60 min].

- The body surface area (BSA) of each subject was calculated from the weight and height using sliding scales [6].

- Input of energy (kpm/h)=(mean metabolic rate in kcal/h)(426.4 kpm/kcal)

- Mechanical work output (kpm/h)=(mechanical work output/4 min)(60 min/h)

- Percentage of mechanical efficiency=(mechanical work output)/(input of energy)

- Net energy expended (kcal/h)=(energy expended during exercise)-(baseline energy expenditure)

- Energy expended during exercise due to standing/sitting=(energy expended during upright exercise)-(energy expended during supine exercise)

The metabolic rates (kcal/h), RQ values, mechanical efficiency, and net energy input from each exercise station for supine and upright-control subjects were compared statistically using one-factor analysis of variance and post hoc F-tests with Statview II Software (Abacus Concept, Inc., Berkeley, CA). A value of $p<0.05$ was chosen to indicate a significant difference between the groups and rejection of the null hypothesis. CA-Cricket Graph III (Computer Associates International, Inc., San Jose, CA) and MacDraw II (Claris Corp., Santa Clara, CA) were used to illustrate the figures.

Table 3. *Nonprotein respiratory quotient (RQ) relative to oxygen consumed (kcal/L)*

RQ	Oxygen Consumed	RQ	Oxygen Consumed
0.707	4.686	0.86	4.875
0.71	4.690	0.87	4.887
0.72	4.702	0.88	4.899
0.73	4.714	0.89	4.911
0.74	4.727	0.90	4.924
0.75	4.739	0.91	4.936
0.76	4.751	0.92	4.948
0.77	4.764	0.93	4.961
0.78	4.776	0.94	4.973
0.79	4.788	0.95	4.985
0.80	4.801	0.96	4.998
0.81	4.813	0.97	5.010
0.82	4.825	0.98	5.022
0.83	4.838	0.99	5.035
0.84	4.850	1.00	5.047
0.85	4.862		

RESULTS

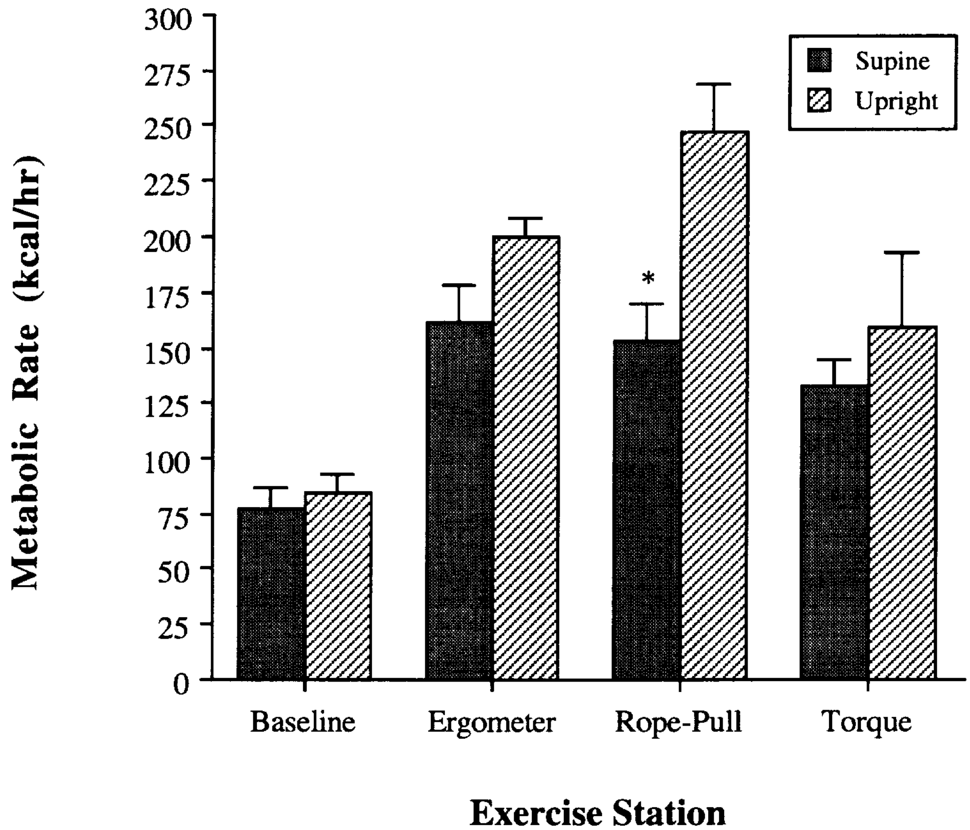
All the data were collected, recorded, and averaged for each exercise station. The baseline and average values each combined for the supine exercises and for the upright-control exercise stations were calculated for each subject and these data are listed in Appendix B.

The mean metabolic rates (kcal/h) during supine (n=6) and upright-control (n=4) exercise stations are listed in Table 4 and illustrated in Figure 3.

Table 4. *Comparison of metabolic rates (kcal/h) between supine and upright-control exercise groups (Mean ±SE)*

	Baseline	Ergometer	Rope-Pull	Torque
Supine	76.9 ±10.3	161.6 ±16.8	153.5 ±16.6*	132.3 ±11.8
Upright	83.8 ±9.3	200.4 ±8.4	247.0 ±21.7	158.6 ±34.2

*$p<0.05$ comparing supine to upright group



*$p<0.05$

Figure 3. *Comparison between mean metabolic rates (kcal/h) during supine (n=6) and upright (n=4) exercising, before exercise (baseline) and for each exercise station*

Although the means of the metabolic rates during supine exercise were consistently lower, only those during the rope-pull exercise were statistically significant.

The RQ means for all groups were not significantly different (Table 5).

Table 5. *Comparison of RQ values between supine and upright-control exercise groups (Mean ±SE)*

	Baseline	Ergometer	Rope-Pull	Torque
Supine	0.861 ±0.049	0.861 ±0.035	0.877 ±0.036	0.881 ±0.032
Upright	0.901 ±0.065	0.876 ±0.037	0.839 ±0.101	0.851 ±0.026

The relationship between the body surface area of the subjects and the metabolic rate was examined by simple regression (Figure 4). Although a positive trend was observed, it was not statistically significant nor was there a difference between the two groups, $r^2=0.391$ for supine and $r^2=0.365$ for upright control).

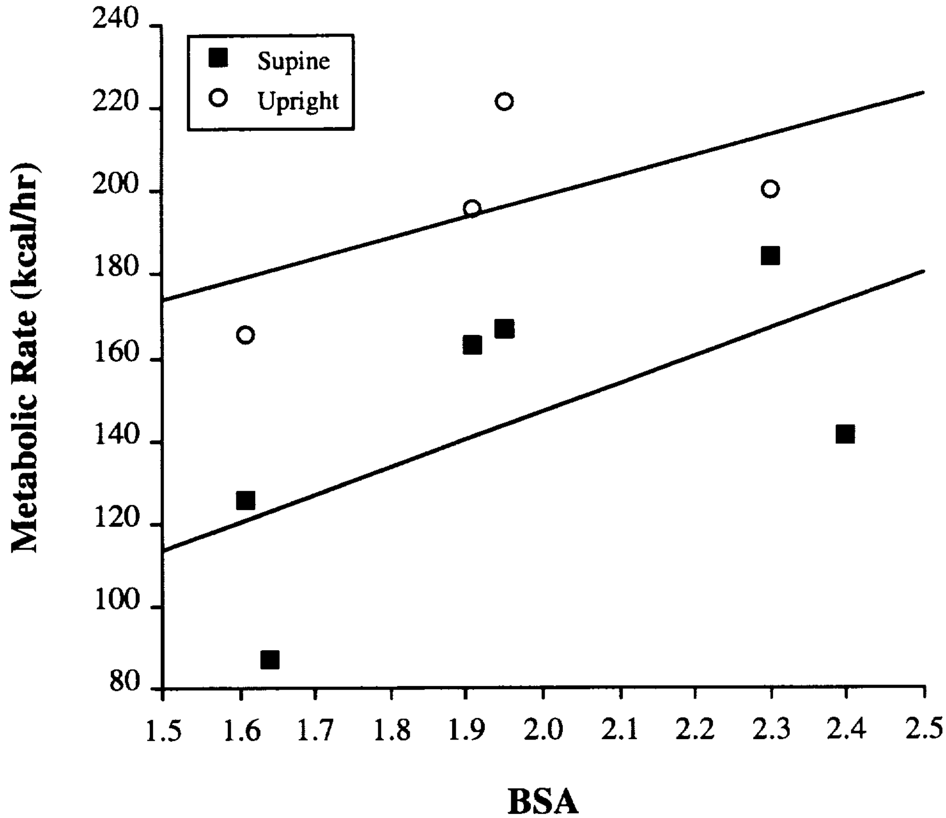


Figure 4. *The relationship between body surface area (BSA) and metabolic rate during supine and upright exercise*

The total work output (kpm/h) and total energy input (kpm/h) were calculated for the upright and supine exercise stations (Appendix B). The percentage of mechanical efficiency for each exercise station is listed in Table 6. The mechanical efficiency of the supine rope-pull exercise group was significantly higher than that of the upright rope-pull exercise group.

Table 6. *Comparison of percentage of mechanical efficiency between supine and upright-control exercise groups of each exercise stations (Mean ±SE)*

	Ergometer	Rope-pull	Torque
Supine	6.0 ±0.7	15.0 ±0.7*	4.8
Upright	5.0 ±0	11.0 ±1.08	3.8

*$p<0.05$ comparing supine to upright group (n=4 for each group)

The net energy expenditures comparing supine to the upright exercise stations are listed in Table 7. Although the net energy input was lower in the supine exercise groups, only the difference for the rope-pull station was statistically significant. Therefore, an additional mean energy expenditure of 112 kcal/h was required for the upright rope-pull exercise station.

Table 7. *Comparison of net energy input (kcal/h) between supine and upright-control exercise groups (Mean ±SE)*

	Ergometer	Rope-pull	Torque
Supine	89 ±14	64 ±18*	67 ±25
Upright	129 ±9.4	176 ±20	91 ±35

*$p<0.05$ comparing supine to upright group

DISCUSSION

The prevention of DCS is a major concern for the NASA's Space Flight Medical Program during EVA in Space Transportation System flights and Space Station Freedom missions. DCS is due to the formation of a free gas phase in tissues during decompression and may be exhibited in subjects as joint pain (bends) or neurological impairment and other symptoms. This concern is based on marked changes in pressure from the Shuttle cabin pressure at 101.3 kPa (14.7 psi) to that of the EVA suit at 29.64 kPa (4.3 psi). DCS risk is reduced by washing nitrogen from the tissues with breathing oxygen and by staged cabin and airlock decompression to 29.6 kPa (4.3 psi) prior to EVA [9, 2].

It is known that exercise at altitude increases the risk of DCS [4, 5], but little is known about the combined effect of in-flight exercise and EVA on the risk of DCS. A preliminary ground-based study indicated that subjects who performed 30 minutes of exercise daily for 3 days prior to a chamber flight that included simulated-EVA exercises did not have an increased risk of DCS [4]. Another study was designed for bed-rest subjects exercising at a simulated altitude (6400 m [21,000 ft]). A reduction in the incidence of venous gas-phase formation and DCS was observed in individuals of the bed-rest exercise group as compared to those of the upright-control exercise group [8].

Although the work activities were similar in the altitude exposures with and without simulated microgravity, this study was designed to determine whether the metabolic rates during both the bed-rest and ambulatory-control exercises were approximately 200 kcal/h. Significant differences in metabolic rates for the supine group as compared to upright-control group for the rope-pull device were demonstrated. Although the differences were small, the finding did not support the hypothesis (the null hypothesis stated that there is no significant difference in metabolic rates when exercising in either position, supine and upright). This indicated that exercising while supine may require different energy expenditures than upright exercising. Eliminating the data of two subjects who did not complete the upright-exercise portion of the study did not alter the statistical results, except for comparing the mechanical efficiencies between the supine and upright rope-pull groups. The numeric values of the mechanical efficiencies were much smaller than those of the metabolic rates, probably skewed by large variations within the small group of subjects.

Components that affect the daily energy expenditures of a subject depend on the resting metabolic rate (60 to 70 percent), the thermic effect of eating (approximately 10 percent), and the thermic effect of physical exercise (15 to 30 percent) [6]. The resting metabolic rate of an individual is related proportionately to the body surface area and dependent on the age and gender. Although the number of subjects was small, these variables did not affect the results of this study. The mean RQ values and the r^2 value for the correlation between metabolic rate and BSA did not vary significantly between the supine and upright-control groups. These RQ values indicated no differences between the groups in the caloric transformation of the subjects' diets. Since the same subjects participated in the supine and upright-control groups, these findings were expected and are now verified.

The mechanical efficiencies were calculated for each station, and a significant difference between the supine and upright rope-pull stations was observed. This may contribute, in part, to the differences in the metabolic rates. Since the net energy expenditure for the upright exercise stations was greater compared to that for the supine exercise stations, a small amount of additional energy may be required to exercise while standing or sitting as compared to that supine.

Factors that are postulated to result in reduced metabolic rates during supine exercises are as follows:

- The supine rope-pull exercise station may be mechanically more efficient than the upright-control rope-pull exercise station.

- Exercising upright may require additional energy that is not required while supine and is reflected in a decreased metabolic rate for supine exercises.

If critical, an increase in the mechanical work loads of the supine exercise stations may be necessary to maintain the required metabolic rate of 200 kcal/h.

Bed rest is an accepted model for microgravity [7]. Further studies on the effects of bed rest prior to supine exercise and exercise during microgravity are necessary to determine the factor(s) that may affect metabolic activity and to develop methods of compensating or accounting for gain or loss, if necessary. The relationship between supine exercising, metabolic rates, and the incidence of DCS during EVA also should be examined to determine the true risk of DCS in space flight.

REFERENCES

[1] CONVERTINO, V. A. Physiological adaptations to weightlessness: effects on exercise and work performance. *Exer. Sport Sci. Rev.* 18:119-166, 1990.

[2] HORRIGAN, J. D. J., J. M. WALIGORA, AND J. H. BREDT. Extravehicular activities. In: NICOGOSSIAN, A., C. L. HUNTOON, AND S. L. POOL (eds.). *Space Physiology and Medicine*. Philadelphia: Lea & Febiger, 1989, pp. 121-135.

[3] JAUCHEM, J. R., J. M. WALIGORA, J. CONKIN, J. D. J. HORRIGAN, AND P. C. JOHNSON. Blood biochemical factors in humans resistant and susceptible to formation of venous gas emboli during decompression. *Eur. J. Appl. Physiol.* 55:68-73, 1986.

[4] KUMAR, K. V., J. M. WALIGORA, AND J. H. GILBERT. The influence of prior exercise at anaerobic threshold on decompression sickness. *Aviat. Space Environ. Med.* 63:899-904, 1992.

[5] MALCONIAN, M. K., P. ROCK, J. DEVINE, A. CYMERMAN, J. R. SUTTON, AND C. S. HOUSTON. Operation Everest II: Altitude decompression sickness during repeated altitude exposure. *Aviat Space Environ Med.* 58:679-682, 1987.

[6] MCARDLE, W. D., F. I. KATCH, AND V. L. KATCH. *Exercise Physiology.* Philadelphia, PA: Lea & Febiger; 1991.

[7] NICOGOSSIAN AE, DIETLEIN LF. Microgravity: Simulations and analogs. Nicogossian A, Editor. In: *Space Physiology and Medicine*. Second Edition, Huntoon CL, Pool SL, Associate Editors. Philadelphia: Lea & Febiger; 1989, p. 240-248.

[8] POWELL, M. R., J. M. WALIGORA, AND W. NORFLEET. Decompression in simulated microgravity; bedrest and its influence on stress-assisted nucleation. *Undersea Biomed. Res.* 1992; 19(S):54, 1992.

[9] WALIGORA, J. M., J. D. J. HORRIGAN, J. CONKIN, AND I. A. T. HADLEY. Verification of an altitude decompression sickness prevention protocol for shuttle operations utilizing a 10.2-psi pressure stage. *NASA Technical Memorandum 58259*, 1984.

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Appendix A. Bends III Exercise Protocol for New Subjects and Metabolic Rate (BTU/hr)

Subject Number	Weight (kg)	Exercise Type	Standing Rest (Btu/h)	All exercise (Btu/h)	All exercise rest (Btu/h)	Lying Rest (Btu/h)	Exercise Corrected to 75 kg (Btu/h)	Exercise & Rest Corrected to 75 kg (Btu/h)	Mini Gym Exercise 1 (Btu/h)	Crank Station Exercise 2 (Btu/h)	Torque Station Exercise 3 (Btu/h)
1	78										
2	80	A	580	707	648	470	663	607	628	715	780
3	75										
4	98	B	520	902	838	648	690	641	943	784	979
5	67										
6	95	B	516	733	671	489	578	529	722	667	809
7	66	B	321	686	653	554	782	744	681	641	737
8	79	B	489	770	711	593	731	675	818	722	
9	78	A	448	721	665	496	693	639	672	734	758
10	85	A	420	743	668	446	655	590	648	775	806
11	101	B	465	692	685	663	513	508	638	708	732
12	75	B	312	633	592	470	633	592	585	535	780
13	68	B	408	577	580	590	637	640	528	585	619
14	66	A	460	634	597	487	720	679	631	748	487
15	95										
16	77	A	468	586	568	516	570	553	468	609	681
17	72	A	468	733	673	492	767	701	615	765	821
18	70	B	450	714	671	540	765	718	734	724	686
19	64										
20	80										
21	80										
22	95										
23	79										
Mean	80		451	702	658	532	671	629	665	693	744
±SD	11		71	82	67	68	80	70	117	75	116
±SE	2		19	22	18	18	21	19	31	20	31

Exercise 1: A type, right and left hand pull to 25 lb alternating every 5 sec. B type, both hands pull twice in 5 sec.

Exercise 2: A type, right hand crank 3 times in 5 sec. B type, left hand crank 3 times in 5 sec. with 5 sec. rest between cranks. Resistance set 1/2 kp.

Exercise 3: A type, right hand torque to 300 in•lb for 5 sec. B type, left hand torque to 300 in•lb for 5 sec. Ratchet ball also used.

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

I.D.#	Activity Level	Exercise	Age	Sex	Wt (lb)	Wt (kg)	Ht (in)	Ht (m)	Body Surface Area (BSA) (m2)	Average BMR* (kcal/m2/h)	Estimated Resting Energy Output kcal/h	Initial Volume Trial 1	Final Volume (ATPS) Trial 1	Initial Volume Trial 2	Final Volume (ATPS) Trial 2	Gas Volume (L) (ATPS) (calc) Trial 1	Gas Volume (L) (ATPS) (calc) Trial 2
5	Upright	Baseline	25	F	198	90	64	1.63	1.95	36	70	5	18			17.32	
		Ergometer										7.2	62.1	5.9	53.5	73.13	63.40
		Rope-Pull										7.3	77	4.9	62.6	92.84	76.86
		Torque										6.4	38.5	6.7	34.9	42.76	37.56
		Post										5.6	24.9			25.71	
	Upright	Exercise										6.97	59.20	5.83	50.33	69.57	59.27
	Supine	Baseline	25	F	198	90	64	1.63	1.95	36	70	6	21.8			21.05	
		Ergometer										6.3	51.9	6.1	50.3	60.74	58.87
		Rope-Pull										5.9	48.1	5.4	45	56.21	52.75
		Torque										6.5	33.8	5.3		36.36	
		Post										4.9					
	Supine	Exercise										6.23	44.60	5.60	47.65	51.10	55.81
6	Upright	Baseline	35	M	220	100	76	1.93	2.30	37	85	5.1	30.7			34.10	
		Ergometer										6.7	52.4	6.4	64.3	60.87	77.12
		Rope-Pull										6.2	52.7	6.9	48.7	61.94	55.68
		Torque										7	45.9	7.3	60.1	51.81	70.33
		Post										5.4	36.8			41.82	
	Upright	Exercise										6.63	50.33	6.87	57.70	58.21	67.71
	Supine	Baseline	35	M	220	100	76	1.93	2.30	37	85	5.4	30.6			33.57	
		Ergometer										6.4	56.1	7	42.1	66.20	46.75
		Rope-pull										6.3	56.1	7.6	43.2	66.33	47.42
		Torque										5	46.2	6.3	43.5	54.88	49.55
		Post										6	30.2			32.23	
	Supine	Exercise										5.90	52.80	6.97	42.93	62.47	47.91
7	Upright	Baseline	28	M	185	84	72	1.83	2.40	38	91	not done					
	Supine	Baseline	28	M	185	84	72	1.83	2.40	38	91	5	22			22.64	
		Ergometer										5.2	43	6.2	48.5	50.35	56.34
		Rope-Pull										6.2	38.8	5.9	39.5	43.42	44.76
		Torque										6.6	37.6	6.5	35.6	41.29	38.76
		Post										5.1	20			19.85	
	Supine	Exercise										6.00	39.80	6.20	41.20	45.02	46.62
2	Upright	Baseline	33	F	125	57	64	1.63	1.61	36	58	6.3	34.6			37.70	
		Ergometer										6.2	55.3	7	57.3	65.40	67.00
		Rope-pull										5.8	66.5	6.5	64	80.85	76.59
		Torque										6.9	45.4	6.2	44.5	51.28	51.02
		Post										6.6	28			28.50	
	Upright	Exercise										6.30	55.73	6.57	55.27	65.85	64.87
	Supine	Baseline	33	F	125	57	64	1.63	1.61	36	58	6.1	30.8			32.90	
		Ergometer										6	47.2	6.3	44.5	54.88	50.88
		Rope-pull										6.3	62.4	5.8	55.4	74.73	66.07
		Torque										5.8	38.8			43.96	
		Post										7.7	25.7			23.98	
	Supine	Exercise										6.03	49.47	6.05	49.95	57.85	58.47
3	Upright	Baseline	37	F	137	62	64	1.63	1.64	36	59	not done					
	Supine	Baseline	37	F	137	62	64	1.63	1.64	36	59	4.5	16.1			15.45	
		Ergometer										5.5	28.7	5.1	28.3	30.90	30.90
		Rope-pull										5.7	26.3	7	25.9	27.44	25.17
		Torque										5.8	26.4	6.1	27	27.44	27.84
		Post										5.3	20.9			20.78	
	Supine	Exercise										5.67	27.13	6.07	27.07	28.59	27.97
4	Upright	Baseline	28	M	160	73	72	1.83	1.91	38	73	28.5	61.8			44.36	
		Ergometer										28.6	82	27.9	82.2	71.13	72.33
		Rope-pull										28.9	100+	27.2	96.8		92.71
		Torque										28.4	81.9	27.1	84.5	71.26	76.46
		Post										29.1	85.9			75.66	
	Upright	Exercise										28.63	81.95	27.40	87.83	71.20	80.50
	Supine	Baseline	28	M	160	73	72	1.83	1.91	38	73	28.4	54.8			35.16	
		Ergometer										28.2	69.8	27.8	76.7	55.41	65.13
		Rope-pull										27.7	67.8	27.9	86.3	53.41	77.79
		Torque										28	61.8	29.1	60.6	45.02	41.96
		Post										29.7	45.6			21.18	
	Supine	Exercise										27.97	66.47	28.27	74.53	51.28	61.63

*BMR= Basal metabolic rate

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

I.D.#	Activity Level	Exercise	Gas Volume (L) (ATPS) (calc) Average	Temp. C Trial 1	Temp. C Trial 2	Vapor Pressure (mmHg) wet gas (Table) Trial 1	Vapor Pressure (mmHg) wet gas (Table) Trial 2	Time Collect (min)	Vol L/min (ATPS) Trial 1	Vol L/Min (APTS) Trial 1	Baro Pressure mmHg	Vol L/min (STPD) (calc) Trial 1	Vol L/min (STPD) (calc) Trial 2
5	Upright	Baseline		24		22.4		4	4.33		763	3.88	
		Ergometer	68.27	23	24	21.1	22.4	4	18.28	15.8508	763	16.46	14.198011
		Rope-Pull	84.85	24	24	22.4	22.4	3.5	26.53	21.958971	763	23.76	19.669273
		Torque	40.16	24	24	22.4	22.4	4	10.69	9.3906	763	9.57	8.4114265
		Post		25		23.8		4	6.43		763	5.73	
	Upright	Exercise	64.42	23.67	24.00	21.97	22.40	3.83	18.50	15.73	763.00	16.60	14.09
	Supine	Baseline		23		21.1		4	5.26		763	4.74	
		Ergometer	59.81	23	23	21.1	21.1	4	15.18	14.7186	763	13.67	13.251627
		Rope-Pull	54.48	23	23	21.1	21.1	4	14.05	13.1868	763	12.65	11.872499
		Torque		22	23	19.8	21.1	4	9.09		763	8.23	
		Post		22		19.8		4			763		
	Supine	Exercise	53.46	22.67	23.00	20.67	21.10	4.00	12.78	13.95	763.00	11.52	12.56
6	Upright	Baseline		23		21.1		4	8.52		764	7.69	
		Ergometer	69.00	23	23	21.1	21.1	4	15.22	19.2807	764	13.72	17.38243
		Rope-Pull	58.81	22	22	19.8	19.8	3	20.65	18.5592	764	18.71	16.818062
		Torque	61.07	22	23	19.8	21.1	4	12.95	17.5824	764	11.74	15.851336
		Post		23		21.1		4	10.46		764	9.43	
	Upright	Exercise	62.96	22.33	22.67	20.23	20.67	3.67	16.27	18.47	764.00	14.72	16.68
	Supine	Baseline		24		22.4		4	8.39		763	7.52	
		Ergometer	56.48	23	24	21.1	22.4	4	16.55	11.6883	763	14.90	10.469542
		Rope-pull	56.88	23	24	21.1	22.4	4	16.58	11.8548	763	14.93	10.61868
		Torque	52.21	24	23	22.4	21.1	4	13.72	12.3876	763	12.29	11.152953
		Post		23		21.1		4	8.06		763	7.26	
	Supine	Exercise	55.19	23.33	23.67	21.53	21.97	4.00	15.62	11.98	763.00	14.04	10.75
7	Upright	Baseline											
	Supine	Baseline		24		22.4		4	5.66		764	5.08	
		Ergometer	53.35	23	23	21.1	21.1	4	12.59	14.0859	764	11.35	12.699081
		Rope-Pull	44.09	23	23	21.1	21.1	4	10.86	11.1888	764	9.79	10.087214
		Torque	40.03	23	23	21.1	21.1	4	10.32	9.6903	764	9.31	8.7362474
		Post		23		21.1		4	4.96		764	4.47	
	Supine	Exercise	45.82	23.00	23.00	21.10	21.10	4.00	11.26	11.66	764.00	10.15	10.51
2	Upright	Baseline		20		17.5		4	9.42		763	8.61	
		Ergometer	66.20	20	20	17.5	17.5	4	16.35	16.7499	763	14.94	15.308805
		Rope-pull	78.72	21	20	18.7	17.5	4	20.21	19.1475	763	18.38	17.500125
		Torque	51.15	20	20	17.5	17.5	4	12.82	12.7539	763	11.72	11.656605
		Post		20		17.5		4	7.13		763	6.51	
	Upright	Exercise	65.36	20.33	20.00	17.90	17.50	4.00	16.46	16.22	763.00	15.01	14.82
	Supine	Baseline		21		18.7		4	8.23		763	7.48	
		Ergometer	52.88	20	20	17.5	17.5	4	13.72	12.7206	763	12.54	11.62617
		Rope-pull	70.40	20	20	17.5	17.5	4	18.68	16.5168	763	17.07	15.09576
		Torque		20		17.5		4	10.99		763	10.04	
		Post		20		17.5		4	5.99		763	5.48	
	Supine	Exercise	58.16	20.00	20.00	17.50	17.50	4.00	14.46	14.62	763.00	13.22	13.36
3	Upright	Baseline											
	Supine	Baseline		20		17.5		4	3.86		759	3.51	
		Ergometer	30.90	20	20	17.5	17.5	4	7.73	7.7256	759	7.02	7.0230346
		Rope-pull	26.31	20	20	17.5	17.5	4	6.86	6.2937	759	6.24	5.7213515
		Torque	27.64	20	20	17.5	17.5	4	6.86	6.9597	759	6.24	6.3267855
		Post		20		17.5		4	5.19		759	4.72	
	Supine	Exercise	28.28	20.00	20.00	17.50	17.50	4.00	7.15	6.99	759.00	6.50	6.36
4	Upright	Baseline		28		28.4		4	11.09		762	9.71	
		Ergometer	71.73	25	26	23.8	25.2	4	17.78	18.0819	762	15.82	16.005585
		Rope-pull	46.35	26	26	25.2	25.2	3.5		26.487771	762		23.446224
		Torque	73.86	28	26	28.4	25.2	3.15	22.62	24.272	762	19.81	21.484886
		Post		26		25.2		4	18.91		762	16.74	
	Upright	Exercise	75.85	26.33	26.00	25.80	25.20	3.55	20.20	22.95	762.00	17.81	20.31
	Supine	Baseline		27		26.7		4	8.79		762	7.74	
		Ergometer	60.27	27	26	26.7	25.2	4	13.85	16.2837	762	12.20	14.413869
		Rope-pull	65.60	25	25	23.8	23.8	4	13.35	19.4472	762	11.88	17.304694
		Torque	43.49	27	26	26.6	25.2	4	11.26	10.4895	762	9.91	9.2850078
		Post		26		25.2		4	5.29		762	4.69	
	Supine	Exercise	56.45	26.33	25.67	25.70	24.73	4.00	12.82	15.41	762.00	11.33	13.67

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

I.D.#	Activity Level	Exercise	%O2 expire Trial 1	%N expire Trial 1	%CO2 expire Trial 1	%O2 expire Trial 2	%N expire Trial 2	%CO2 expire Trial 2	%O2 inspire Trial 1	%N inspire Trial 1	%CO2 inspire Trial 1	%O2 inspire Trial 2	%N inspire Trial 2	%CO2 inspire Trial 2
5	Upright	Baseline	16	79.5	4.44				21.2	78.7	0.09			
		Ergometer	16.5	78.9	4.62	16	79.2	4.65	21.2	78.7	0.10	21	78.9	0.10
		Rope-Pull	17.1	78.6	4.35	15.7	79.3	5.02	21.1	78.7	0.09	21	78.9	0.10
		Torque	16	79.4	4.49	15.9	79.5	4.5	21.2	78.8	0.10	21.1	78.9	0.10
		Post	16.3	79.4	4.3				21.1	78.9	0.10			
	Upright	Exercise	16.53	78.97	4.49	15.87	79.33	4.72	21.17	78.73	0.10	21.03	78.90	0.10
	Supine	Baseline	15.8	79.4	4.72				21	78.8	0.10			
		Ergometer	16	79.2	4.77	15.8	79.5	4.57	21	78.8	0.10	21	78.8	0.10
		Rope-Pull	16.3	79.1	4.55	15.9	79.4	4.54	21	78.8	0.10	21	78.8	0.10
		Torque	16.6	79	4.43	16.2	79.1	4.48	21.1	78.8	0.10	21	78.8	0.10
		Post	15.7	79.8	4.42				21	78.8	0.10			
	Supine	Exercise	16.30	79.10	4.58	15.97	79.33	4.53	21.03	78.80	0.10	21.00	78.80	0.10
6	Upright	Baseline	16.8	79.6	3.6				21.1	78.7	0.08			
		Ergometer	16.8	79.4	3.7	17.1	79.3	3.5	21.1	78.7	0.08	21.1	78.7	0.09
		Rope-Pull	16.6	79.3	4.1	16.7	79.1	3.9	21.1	78.7	0.09	21.1	78.7	0.09
		Torque	17.1	79.4	3.4	17	79.3	3.5	21.1	78.7	0.09	21.1	78.7	0.09
		Post	16.9	79.5	3.5				21.1	78.7	0.09			
	Upright	Exercise	16.83	79.37	3.73	16.93	79.23	3.63	21.10	78.70	0.09	21.10	78.70	0.09
	Supine	Baseline	16.6	79.4	3.71				21.1	78.7	0.10			
		Ergometer	16	79.5	4.3	16	79.7	4.27	21.2	78.7	0.08	21.2	78.8	0.09
		Rope-pull	16.3	79.5	4.13	16.2	79.6	4.11	21.1	78.8	0.10	21.2	78.8	0.09
		Torque	16.6	79.3	4.02	16.2	79.6	4.17	21.2	78.8	0.09	21.2	78.8	0.09
		Post	16.3	79.6	3.97				21.2	78.8	0.09			
	Supine	Exercise	16.30	79.43	4.15	16.13	79.63	4.18	21.17	78.77	0.09	21.20	78.80	0.09
7	Upright	Baseline												
	Supine	Baseline	15.8	80.2	3.97				21.1	78.7	0.10			
		Ergometer	16.3	79.6	3.95	16.6	79.4	3.88	21.1	78.7	0.10	21.1	78.8	0.09
		Rope-Pull	16.4	79.6	4	16.8	79.3	3.75	21.1	78.7	0.10	21.1	78.8	0.10
		Torque	16.4	79.5	4.14	16.8	79.3	3.75	21.1	78.8	0.11	21.1	78.8	0.10
		Post	16	80	3.8				21.1	78.8	0.10			
	Supine	Exercise	16.37	79.57	4.03	16.73	79.33	3.79	21.10	78.73	0.10	21.10	78.80	0.10
2	Upright	Baseline	18.3	78.8	3.04				21.2	78.6	0.07			
		Ergometer	17.3	79.3	3.54	17.1	79.5	3.45	21.2	78.6	0.07	21.2	78.6	0.08
		Rope-pull	17.7	78.8	3.62	17.6	79	3.5	21.2	78.6	0.07	21.2	78.6	0.08
		Torque	17.9	79	3.1	18	79.1	3.02	21.2	78.6	0.07	21.2	78.6	0.08
		Post	17.8	79.2	2.98				21.2	78.6	0.08			
	Upright	Exercise	17.63	79.03	3.42	17.57	79.20	3.32	21.20	78.60	0.07	21.20	78.60	0.08
	Supine	Baseline	18.1	78.8	3.23				21.2	78.8	0.07			
		Ergometer	17.7	78.9	3.45	17.5	79.2	3.4	21.2	78.8	0.07	21.2	78.8	0.07
		Rope-pull	18.2	78.7	3.23	17.9	79	3.22	21.2	78.8	0.07	21.2	78.8	0.07
		Torque	18.1	78.8	3.14				21.2	78.8	0.07			
		Post	17.9	79.2	3.03				21.2	78.8	0.07			
	Supine	Exercise	18.00	78.80	3.27	17.70	79.10	3.31	21.20	78.80	0.07	21.20	78.80	0.07
3	Upright	Baseline												
	Supine	Baseline	16.8	79.3	3.88				20.9	79.1	0.10			
		Ergometer	16.4	79.6	4	16.2	79.8	4.01	20.9	79.1	0.10	20.9	79.1	0.10
		Rope-pull	16.4	79.7	3.95	16.3	79.8	3.98	20.9	79.1	0.10	20.9	79.1	0.09
		Torque	16.6	79.7	3.8	16.5	79.7	3.75	20.9	79.1	0.10	20.9	79.1	0.09
		Post	16.6	79.7	3.77				20.8	79.1	0.08			
	Supine	Exercise	16.47	79.67	3.92	16.33	79.77	3.91	20.90	79.10	0.10	20.90	79.10	0.09
4	Upright	Baseline	18	78.7	3.26				21.1	78.7	0.10			
		Ergometer	16.8	78.9	4.24	17.1	78.9	3.99	21.1	78.7	0.10	21.1	78.7	0.10
		Rope-pull	17.3	78.4	4.3	17.7	78.5	3.78	21.1	78.7	0.10	21.1	78.7	0.10
		Torque	16.9	79.1	4.04	17	79.1	3.87	21.1	78.7	0.10	21.1	78.7	0.10
		Post	18.4	78.4	3.18				21.1	78.7	0.10			
	Upright	Exercise	17.00	78.80	4.19	17.27	78.83	3.88	21.10	78.70	0.10	21.10	78.70	0.10
	Supine	Baseline	17	79	3.98				21.1	78.7	0.10			
		Ergometer	17.2	78.6	4.1	16.8	78.9	4.28	21.1	78.7	0.10	21.1	78.7	0.10
		Rope-pull	17	78.9	4.02	16.9	78.9	4.23	21.1	78.7	0.10	21.1	78.7	0.10
		Torque	16.3	79.1	4.4	16.6	79	4.29	21.1	78.7	0.10	21.1	78.7	0.10
		Post	17.2	78.8	3.9				21.1	78.7	0.10			
	Supine	Exercise	16.83	78.87	4.17	16.77	78.93	4.27	21.10	78.70	0.10	21.10	78.70	0.10

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

I.D.#	Activity Level	Exercise	Volume O2 Cons. (L/min) (calc) Trial 1	Volume O2 Cons. (L/min) Trial 2	Volume CO2 (L/min) Product (calc) Trial 1	Volume CO2 (L/min) Product (calc) Trial 2	RQ (calc) Trial 1	RQ (calc) Trial 2	Mean RQ (calc)	O2 Cons. (kcal/L) Trial 1	O2 Cons. (kcal/L) Trial 2
5	Upright	Baseline	0.209991933		0.168675947		0.803249648			4.801	
		Ergometer	0.782468917	0.72123735	0.743973947	0.646009487	0.950803197	0.895696108	0.923249652	4.985	4.924
		Rope-Pull	0.944027253	1.063412137	1.012173286	0.967728229	1.072186511	0.910021802	0.991104156	5.047	4.936
		Torque	0.513340484	0.45089084	0.420329721	0.370102767	0.818812725	0.820825649	0.819819187	4.825	4.825
		Post	0.282533678		0.240516891		0.85128574			4.875	
	Upright	Exercise	0.75	0.75	0.73	0.66	0.95	0.88	0.91	4.95	4.90
	Supine	Baseline	0.253898771		0.218849728		0.861956625			4.875	
		Ergometer	0.698141646	0.713805303	0.638452617	0.592347747	0.914502982	0.82984498	0.872173981	4.936	4.838
		Rope-Pull	0.604759478	0.624481383	0.56301428	0.527138947	0.93097223	0.844122756	0.887547493	4.961	4.85
		Torque	0.374619211		0.35622756		0.950905747			4.985	
		Post									
	Supine	Exercise	0.56	0.67	0.52	0.56	0.93	0.84	0.88	4.96	4.84
6	Upright	Baseline	0.349021127		0.270529459		0.775109121			4.776	
		Ergometer	0.615700499	0.723259296	0.496657166	0.592740877	0.806653831	0.819541318	0.813097574	4.813	4.825
		Rope-Pull	0.872005174	0.758030883	0.750234446	0.640768173	0.860355497	0.845306157	0.852830827	4.875	4.862
		Torque	0.491567859	0.675403854	0.388542503	0.540530541	0.790414783	0.80030716	0.795360972	4.788	4.801
		Post	0.416142112		0.321451874		0.772456969			4.764	
	Upright	Exercise	0.66	0.72	0.55	0.59	0.82	0.82	0.82	4.83	4.83
	Supine	Baseline	0.352353472		0.27134904		0.77010463			4.764	
		Ergometer	0.806941498	0.569766267	0.628804713	0.437626835	0.779244486	0.768081336	0.773662911	4.776	4.764
		Rope-pull	0.744652539	0.553788432	0.601701837	0.426870947	0.80803033	0.770819544	0.789424937	4.813	4.764
		Torque	0.581826521	0.581651997	0.482959055	0.455040499	0.830073979	0.782324314	0.806199146	4.838	4.776
		Post	0.371131098		0.281510138		0.758519401			4.751	
	Supine	Exercise	0.71	0.57	0.57	0.44	0.81	0.77	0.79	4.81	4.77
7	Upright	Baseline									
	Supine	Baseline	0.289530879		0.196501761		0.678690168				
		Ergometer	0.572092084	0.591860989	0.436902435	0.481295181	0.763692502	0.813189566	0.788441034	4.751	4.813
		Rope-Pull	0.483604587	0.44725527	0.381692954	0.368183293	0.789266612	0.823206159	0.806236386	4.788	4.825
		Torque	0.454856873	0.38735501	0.375058209	0.31887303	0.824563135	0.823206159	0.823884647	4.825	4.825
		Post	0.242506414		0.165508357		0.682490637				
	Supine	Exercise	0.50	0.48	0.40	0.39	0.79	0.82	0.81	4.79	4.82
2	Upright	Baseline	0.254426306		0.255809224		1.005435438			5.047	
		Ergometer	0.611013925	0.664822852	0.518542411	0.51590674	0.848658908	0.776006328	0.812332618	4.862	4.776
		Rope-pull	0.653270806	0.648885056	0.652545833	0.598504288	0.998890241	0.922357947	0.960624094	5.047	4.948
		Torque	0.399318438	0.388731472	0.3550395	0.342704195	0.889113716	0.881596215	0.885354966	4.911	4.899
		Post	0.231985333		0.188879614		0.814187741			4.813	
	Upright	Exercise	0.55	0.57	0.51	0.49	0.91	0.86	0.89	4.94	4.87
	Supine	Baseline	0.231874304		0.236362194		1.019354839			5.047	
		Ergometer	0.442246206	0.442679711	0.423825645	0.38715147	0.958347726	0.874563392	0.916455559	4.998	4.887
		Rope-pull	0.507627539	0.506282683	0.539539518	0.475516451	1.062864948	0.939231119	1.001048033	5.047	4.973
		Torque	0.311350057		0.308336992		0.990322581			5.035	
		Post	0.186679334		0.162157684		0.868642932			4.887	
	Supine	Exercise	0.42	0.47	0.42	0.43	1.00	0.91	0.96	5.03	4.93
3	Upright	Baseline									
	Supine	Baseline	0.145827853		0.132735354		0.910219489			4.936	
		Ergometer	0.325314776	0.343072133	0.273898349	0.274600653	0.84194869	0.800416667	0.821182678	4.85	4.801
		Rope-pull	0.290504769	0.273764136	0.24008486	0.222560572	0.826440338	0.812964675	0.819702507	4.838	4.813
		Torque	0.278032829	0.288408636	0.230730904	0.231560349	0.829869283	0.802889789	0.816379536	4.838	4.801
		Post	0.205790926		0.174256019		0.846762402			4.862	
	Supine	Exercise	0.30	0.30	0.25	0.24	0.83	0.81	0.82	4.84	4.81
4	Upright	Baseline	0.300948403		0.306773211		1.019354839			5.407	
		Ergometer	0.688879048	0.648805802	0.65507747	0.622617249	0.950932493	0.95963576	0.955284126	4.985	4.998
		Rope-pull		0.784599424		0.862821031		1.099696233	0.549848117		5.407
		Torque	0.853077874	0.903921283	0.780343032	0.80998019	0.914738333	0.896073812	0.905406072	4.936	4.924
		Post	0.438580912		0.515668697		1.175766395			5.407	
	Upright	Exercise	0.77	0.78	0.72	0.77	0.93	0.99	0.80	4.96	5.11
	Supine	Baseline	0.323565115		0.3003117		0.928133739			4.961	
		Ergometer	0.472387782	0.627525286	0.487854058	0.602499732	1.032740634	0.960120246	0.99643044	5.407	4.998
		Rope-pull	0.493539981	0.736076138	0.465780717	0.714683843	0.94375478	0.970937388	0.957346084	4.973	5.01
		Torque	0.486351093	0.425293468	0.426167979	0.389041825	0.876255826	0.914760874	0.89550835	4.899	4.936
		Post	0.184038551		0.178095292		0.967706446			5.01	
	Supine	Exercise	0.48	0.60	0.46	0.57	0.95	0.95	0.95	5.09	4.98

Appendix B. Data Base to Calculate Body Surface Area, Average Metabolic Rates, Mechanical Efficiency, and Energy Input of Control Subjects Exercising at Site Level

I.D.#	Activity Level	Exercise	Metabolic Rate (kcal/h) (calc) Trial 1	Metabolic Rate (kcal/h) (calc) Trial 2	Mean Metabolic Rate (kcal/h) (calc)	Enery Input kpm/hr (kg m/h)	Energy Output (kpm/4 min)	Energy Output (kpm/h)	% Mech. Efficiency	Net Energy Expen-diture kcal/h	Energy - sitting or standing upright kcal/h	Mean energy - sitting or standing upright kcal/h
5	Upright	Baseline	60.49		60	25793						
		Ergometer	234.04	213.08	224	95326				154	17	24
		Rope-Pull	285.87	314.94	300	128093				230	120	71
		Torque	148.61	130.53	140	59514	171.4	2571	4	70	28	44
		Post	82.64		83	35238						
	Upright	Exercise	222.84	219.52	221	94311						
	Supine	Baseline	74.27		74	31667						
		Ergometer	206.76	207.20	207	88257				137		
		Rope-Pull	180.01	181.72	181	77122				111		
		Torque	112.05		112	47778	171.4	2571	5	42		
		Post										
	Supine	Exercise	166.27	194.46	167							
6	Upright	Baseline	100.02		100	42647						
		Ergometer	177.80	209.38	194	82548				108	-3	
		Rope-Pull	255.06	221.13	238	101525				153	51	
		Torque	141.22	194.56	168	71587	171.4	2571	4	83	0	
		Post	118.95		119	50720						
	Upright	Exercise	191.36	208.36	200							
	Supine	Baseline	100.72		101	42946						
		Ergometer	231.24	162.86	197	84022				112		
		Rope-pull	215.04	158.29	187	79595				102		
		Torque	168.89	166.68	168	71544	171.4	2571	4	83		
		Post	105.79		106	45111						
	Supine	Exercise	205.06	162.61	184							
7	Upright	Baseline										
	Supine	Baseline										
		Ergometer	163.08	170.92	167	71208				76		
		Rope-Pull	138.93	129.48	134	57225				43		
		Torque	131.68	112.14	122	51982	171.4	2571	5	31		
		Post										
	Supine	Exercise	144.56	137.51	141							
2	Upright	Baseline	77.05		77	32852						
		Ergometer	178.24	190.51	184	78619				127	53	
		Rope-pull	197.82	192.64	195	83247				137	43	
		Torque	117.66	114.26	116	49447	171.4	2571	5	58	22	
		Post	66.99		67	28566						
	Upright	Exercise	164.58	165.81	165							
	Supine	Baseline	70.22		70	29940						
		Ergometer	132.62	129.80	131	55949				73		
		Rope-pull	153.72	151.06	152	64980				95		
		Torque	94.06		94	40107	171.4	2571	6	36		
		Post	54.74		55	23340						
	Supine	Exercise	126.80	140.43	126							
3	Upright	Baseline										
	Supine	Baseline	43.19		43	18416						
		Ergometer	94.67	98.83	97	41252				38		
		Rope-pull	84.33	79.06	82	34834				23		
		Torque	80.71	83.08	82	34919	171.4	2571	7	23		
		Post	60.03		60							
	Supine	Exercise	86.57	86.99	87							
4	Upright	Baseline	97.63		98	41631						
		Ergometer	206.04	194.56	200	85410				128	30	
		Rope-pull		254.54	255	108536				182	70	
		Torque	252.65	267.05	260	110800	171.4	2571	2	187	125	
		Post	142.28		142							
	Upright	Exercise	152.90	238.72	238							
	Supine	Baseline	96.31		96	41068						
		Ergometer	153.25	188.18	171	72794				98		
		Rope-pull	147.26	221.26	184	78570				112		
		Torque	142.96	125.95	134	57332	171.4	2571	4	62		
		Post	55.32		55							
	Supine	Exercise	147.82	178.47	163							

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13. ABSTRACT (*Maximum 200 words*)
This contractor report documents the ground-based study that tested the hypothesis that metabolic rates during supine and upright upper-body exercises are similar (mean value of 200 kcal/h). Six subjects each performed supine or upright exercise at three exercise stations, a hand-cycle ergometer, a rope-pull device, and a torque wrench. After a baseline measurement of the metabolic rate at rest, the metabolic rate was measured twice at each exercise station. The mean metabolic rates (kcal/h) during supine (n=6) and upright control (n=4) exercise stations were not significantly different except for the rope-pull station, 153.5 ± 16.6 (supine) as compared to 247.0 ±21.7 (upright), p<0.05. This difference may be due in part to an increased mechanical efficiency of supine exercises (15.0 ± 0.7%) as compared to that of upright exercises (11.0 ± 1.08%), p<0.05. The net energy input was significantly smaller for the supine rope-pull exercise (64 ± 18) as compared to upright (176 ± 20). The relationship between best-rest exercises, metabolic rates, and the incidence of decompression sickness (DCS) should be examined to determine the true risk of DCS in spaceflight extravehicular activities.

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