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16. Abstract

This study was undertaken to evaluate workloads, oxygen consumption, carbon dioxide production, and respiratory exchange rates for passengers during an emergency aircraft evacuation. This was accomplished in an effort to formulate possible qualification standards for a passenger protective breathing device intended to protect from smoke and fumes.

Recommendations were:

1) Establish a work profile for testing devices of:
   15 minutes at 0.7 watts/kg body weight,*
   2 minutes at 1.2 watts/kg body weight,
   1 minute at 1.5 watts/kg body weight,
   2 minutes at 1.2 watts/kg body weight.

2) The volume of the hood should exceed the volume that encloses the head and neck by 3.0 Liters.

3) The device should provide 3.0 L/min O_2 for 20 minutes.

4) The device should be capable of absorbing 45 L of CO_2.

*The subject population studied should include one or two individuals who meet or exceed the weight of the 95th percentile male.

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List of Abbreviations Used in Text

BP	Blood Pressure
BPM	Beats per Minute
CAA	Civil Aviation Authority
CAMI	Civil Aeromedical Institute
CO_2	Carbon Dioxide
DGAC	Direction Generale de L'Aviation Civile
EKG	Electrocardiogram
FAA	Federal Aviation Administration
HR	Heart Rate
kg	Kilogram(s)
L	Liter(s)
Min	Minute(s)
mL	Milliliter(s)
O_2	Oxygen
PPBE	Passenger Protective Breathing Equipment
PPMHR	Percent of Predicted Maximum Heart Rate
r/min	Revolutions per Minute
s	Second(s)
STPD	Standard Temperature and Pressure, Dry
W	Watt(s)

A STUDY OF PASSENGER WORKLOAD AS RELATED TO PROTECTIVE BREATHING REQUIREMENTS

INTRODUCTION

As a result of the British Airtours B-737 accident at Manchester on August 22, 1985, in which a number of deaths were attributed to smoke and fume inhalation, attention was again focused on the feasibility of providing passenger protective breathing equipment (PPBE). A joint effort to reevaluate the need for PPBE was initiated by the British Civil Aviation Authority (CAA) with participation by the Federal Aviation Administration (FAA), Transport Canada, and the French Direction Generale de L'Aviation Civile (DGAC). The initial meeting was held in England, September 28 - October 2, 1986.

As a result of this meeting, the Civil Aeromedical Institute (CAMI) undertook a study to evaluate workloads, oxygen (O_2) consumption, carbon dioxide (CO_2) production, and respiratory exchange rates for passengers during an emergency evacuation. This study was undertaken to define possible requirements for a protective breathing device. The results of this study were initially presented to the participants in the joint effort at a PPBE Workshop held at CAMI February 3-5, 1987. The following report summarizes all salient CAMI study findings and develops possible work profiles for evaluation of passenger protective breathing devices.

METHODS

It is not possible to measure workload directly without influencing (changing) the workload itself. Therefore, in order to estimate workload, measurements of heart rate (HR) were made on individual subjects and correlated to workload (individual correlation coefficients between HR and workload are reported in Table XIII). The subjects then participated in a mock emergency aircraft evacuation, during which time their HR was continuously monitored. The HR was then used to estimate workload during the evacuation by using the previously determined correlations.

For the workload/HR calibration tests, selected subjects were physically fit and not at risk for the imposed workload. A typical passenger population was not used for this study. Subjects first reported to the CAMI clinic where they were given a thorough physical examination including an electrocardiogram (EKG). Medically qualified subjects reported to the laboratory at a later date for the workload/HR calibration test. Nine males and seven females were selected as test subjects.

On the day of the workload/HR calibration test, subjects received a brief physical examination and filled out a questionnaire to ascertain that no medically significant changes had occurred since the initial physical exam. The EKG and HR electrode skin sites were cleaned with alcohol and mild abrasion; NaCl-pumice-type electrode paste was applied to the skin sites, then disposable electrodes were applied. These electrodes were applied to a neutral ground site, to the manubrium and to V positions -3, -4 and -5. Leads CM-3, CM-4, and CM-5 were simultaneously recorded on a Bosch* Electrocardiograph Model 103A with the selected lead displayed continuously on a Bosch Electrocardioscope Model ESC 502 with pulse rate meter. Blood pressure (BP) was monitored every other minute using the Bosch Electronic Blood Pressure Monitor Model EBM 502 in the manual mode.

Subjects were seated at a Godart Type GM-EM bicycle ergometer and the pedal stroke length adjusted. The electrode leads were then connected to the Bosch recorder and the BP cuff placed on the right arm. They were then fitted with a mouth piece and nose clip for the collection of expired respiratory gases. Inspired room air was provided from a Collins 120-Liter Gasometer. The test was begun by having the subject pedal at 50 r/min, a rate which was maintained throughout the test. The beginning workload was set at 30 watts. Workload was increased by 20-watt increments each 2 min until (a) HR reached 80% of predicted maximum HR for male subjects or 75% for female subjects[1], or (b) until the medical monitor stopped the test due to abnormal EKG recordings or too high HR[2], or (c) the end of the 150-W workload. During the final 30 s of each 2-min workload period, expired respiratory gases were collected by means of a modified Douglas valve connected to a 40-Liter, plastic Douglas-type gas bag. Measurements of the expired air were made using a Perkin Elmer Model 1100 Medical Gas Analyzer (mass spectrometer) for oxygen, carbon dioxide, and nitrogen. During this period recordings were also made of inspired tidal volume, minute volume, and respiratory rate. Heart rate and EKG were monitored continuously, with the final 30 s of each 2-min period used for data collection. Beginning with the first minute, BP was monitored every other minute. At the conclusion of each test, subjects were kept in the laboratory until HR and BP returned to normal.

Table I gives the results of workload vs. HR for the 16 subjects calibrated. Data for each subject were plotted (see appendix A) and best fit linear regression coefficients determined. By using the individual point of intercept and slope, workload could be determined for any given HR.

After all calibration runs were completed, an evacuation test was scheduled in which 12 of the calibrated subjects were instrumented with portable Marquette Series 8500 Holter

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* Brand names are given only to describe the experimental procedure, and are not meant to imply recommendation or endorsement.

HR recorders (only 12 Holter recorders were available for the test). The first 12 calibrated subjects who reported in on the evacuation test day were instrumented. The same type skin preparation was made as described above for disposable Holter stress electrodes. Two EKG electrode placements, CM-5 and a modified V-1, were monitored. The CM-5 is manubrium to V-5. The modified V-1 is below left clavical, just lateral to the mid-clavicular line to V-1. A Burdick Electrocardiograph EK5A was used for calibration. In addition to the 12 instrumented subjects, 29 noninstrumented subjects participated in the evacuation test. The 41 subjects were seated in the CAMI evacuation facility as shown in Figure 1. They were instructed to evacuate the facility through the rear lefthand door using an evacuation slide. A bell-timer signal initiated the actual evacuation. The evacuation was recorded on videotape and evacuation times for each individual and the total evacuation time were measured. At the conclusion of the evacuation test, the Holter monitor tapes for the 12 instrumented and calibrated subjects were played on a Marquette Series 8000 T Holter Playback Analysis System and HR values were determined for the evacuation test period.

RESULTS

TABLE I

Calibration Data from Passenger Workload Study

Workload (Watts)= Subject Number	30	50	70	90	110	130	150
	Heart Rate (beats/min)						
1	106	116	146	-	-	-	-
2	84	94	100	106	120	132	148
3	128	132	144	-	-	-	-
4	104	110	116	128	134	142	152
5*	110	118	130	140	-	-	-
6	94	104	118	124	138	146	-
7	124	132	146	-	-	-	-
8	120	126	132	146	156	-	-
9	110	118	130	150	-	-	-
10	88	96	104	108	122	126	144
11	104	116	130	144	-	-	-
12*	98	106	116	126	134	146	154
13	108	130	142	-	-	-	-
14*	118	122	128	140	148	-	-
16*	90	94	102	108	114	122	132
18	98	108	118	132	142	150	-

* Those not measured during evacuation test.
Odd-numbered subjects are females, even-numbered subjects are males.

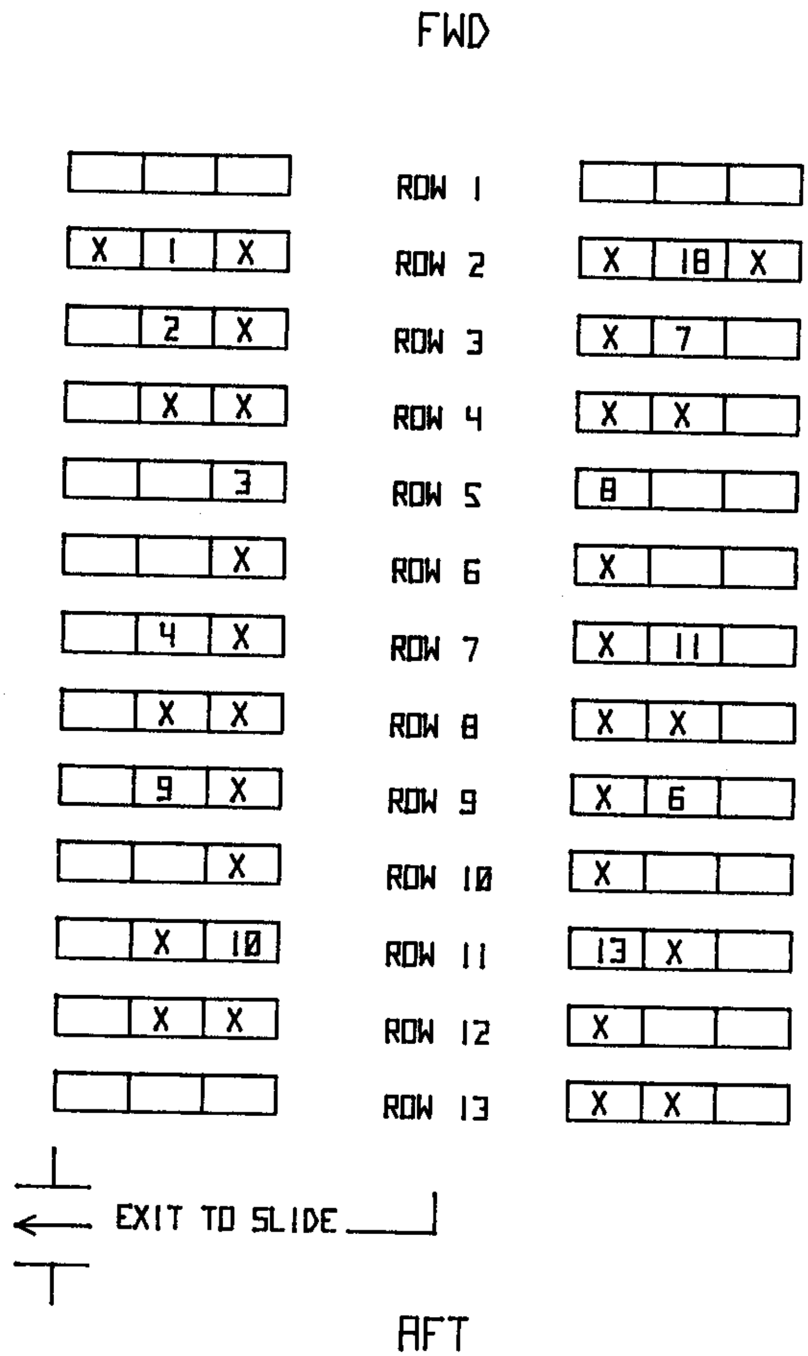

Figure 1. Evacuation simulator seating profile. Numerals identify test subject and seating position at the beginning of the evacuation. "X's" indicate the positions of supernumerary subjects used in the test. Row pitch = 32 in. Evacuation aisle width = 17 in.

The subject population data are presented in Table II. The other parameters determined from the baseline workload calibration tests are presented in Tables III through VII.

TABLE II
Subject Population Data

Subject Number	Sex (M/F)	Age (Yrs)	Weight (kgs)	Height (cm)
1	F	22	61.46	168
2	M	22	75.41	179
3	F	27	53.18	158
4	M	24	66.68	173
5*	F	27	67.36	160
6	M	24	66.34	168
7	F	22	64.30	164
8	M	20	72.57	178
9	F	25	53.64	169
10	M	25	78.02	180
11	F	25	67.70	163
12*	M	32	71.33	168
13	F	29	47.74	164
14*	M	29	99.79	188
16*	M	29	100.70	188
18	M	22	74.16	183

* Those not measured during evacuation test.

TABLE III
Oxygen Consumption (mL/min, STPD)

Workload (Watts) = / Subject Number	30	50	70	90	110	130	150
1	561	829	942	-	-	-	-
2	838	947	1235	1198	1525	1659	1974
3	685	880	958	-	-	-	-
4	781	1004	1237	1449	1635	1819	1981
5*	786	883	1117	1266	-	-	-
6	767	904	1097	1272	1474	1721	-
7	720	862	975	-	-	-	-
8	968	1351	1417	1743	2063	-	-
9	649	724	940	1122	-	-	-
10	736	1015	1271	1405	1594	1677	2004
11	670	758	959	1238	-	-	-
12*	716	973	1265	1291	1471	1823	2250
13	676	865	1020	-	-	-	-
14*	869	1133	1340	1576	1650	-	-
16*	936	985	1157	1492	1724	1923	2056
18	951	1147	1378	1576	1746	1924	-

* Those not measured during evacuation test.

TABLE IV

Oxygen Consumption (mL/min, STPD) per Kg Body Weight

Workload (Watts)= / Subject Number	30	50	70	90	110	130	150
1	9.1	13.5	15.3	-	-	-	-
2	11.1	12.6	16.4	15.9	20.2	22.0	26.2
3	12.9	16.5	18.0	-	-	-	-
4	11.7	15.1	18.6	21.7	24.5	27.3	29.7
5*	11.7	13.1	16.6	18.8	-	-	-
6	11.6	13.6	16.5	19.2	22.2	25.9	-
7	11.2	13.4	15.2	-	-	-	-
8	13.0	18.6	19.5	24.0	28.4	-	-
9	12.1	13.5	17.5	20.9	-	-	-
10	9.4	13.0	16.3	18.0	20.4	21.5	25.7
11	9.9	11.2	14.2	18.3	-	-	-
12*	10.0	13.6	17.7	18.1	20.6	25.6	31.5
13	14.2	18.1	21.4	-	-	-	-
14*	8.7	11.4	13.4	15.8	16.5	-	-
16*	9.3	9.8	11.5	14.8	17.1	19.1	20.4
18	12.8	15.5	18.6	21.3	23.5	25.9	-

* Those not measured during evacuation test.

TABLE V

Expired Carbon Dioxide (mL/min, STPD)

Workload (Watts)= / Subject Number	30	50	70	90	110	130	150
1	672	1160	1360	-	-	-	-
2	448	589	816	822	1125	1382	1683
3	616	898	891	-	-	-	-
4	1161	1225	1386	1536	1949	2439	2575
5*	507	702	933	1233	-	-	-
6	639	773	973	1162	1472	1706	-
7	637	792	984	-	-	-	-
8	689	911	985	1267	1516	-	-
9	605	720	1003	1315	-	-	-
10	534	671	873	1026	1245	1263	1667
11	536	603	835	1112	-	-	-
12*	541	807	1106	1193	1444	1905	2381
13	323	525	704	-	-	-	-
14*	902	953	1062	1285	1461	-	-
16*	763	801	997	1247	1566	1807	2014
18	755	958	1269	1524	1793	2028	-

* Those not measured during evacuation test.

TABLE VI
Expired Carbon Dioxide (mL/min, STPD) per Kg Body Weight

Workload (Watts)= Subject Number	30	50	70	90	110	130	150
1	10.9	18.9	22.1	-	-	-	-
2	5.9	7.8	10.8	10.9	14.9	18.3	22.3
3	11.6	16.9	16.8	-	-	-	-
4	17.4	18.4	20.8	23.0	29.2	36.6	38.6
5*	7.5	10.4	13.9	18.3	-	-	-
6	9.6	11.7	14.7	17.5	22.2	25.7	-
7	9.9	12.3	15.3	-	-	-	-
8	9.5	12.6	13.6	17.5	20.9	-	-
9	11.3	13.4	18.7	24.5	-	-	-
10	6.8	8.6	11.2	13.2	16.0	16.2	21.4
11	7.9	8.9	12.3	16.4	-	-	-
12*	7.6	11.3	15.5	16.7	20.2	26.7	33.4
13	6.8	11.0	14.7	-	-	-	-
14*	9.0	9.6	10.6	12.9	14.6	-	-
16*	7.6	8.0	9.9	12.4	15.6	17.9	20.0
18	10.2	12.9	17.1	20.6	24.2	27.3	-

* Those not measured during evacuation test.

TABLE VII
Maximum Minute Volumes and Tidal Volumes Measured During Workload Calibration Tests

Subject Number	Maximum Minute Volume (Liters/min)	Maximum Tidal Volume (Liters)
1	17.643	1.203
2	36.289	1.814
3	28.371	0.946
4	31.768	2.647
5*	30.723	1.536
6	31.172	1.417
7	20.755	1.297
8	41.889	1.762
9	30.217	1.170
10	40.386	2.524
11	28.885	1.204
12*	55.169	1.970
13	21.933	1.257
14*	34.361	2.402
16*	44.287	1.582
18	46.035	1.644

* Those not measured during evacuation test.

Tables VIII through XI are for data obtained during the evacuation test for those 12 subjects wearing HR recorders.

TABLE VIII

Evacuation Test Recorded Heart Rate and Workloads Calculated from Heart Rate Data

Subject Number	Time to Evacuate (in sec)	Heart Rate (BPM) in 0.5 min Intervals from Start of Test			
		0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0
1	52	126	138	112	102
2	42	94	104	116	110
3	34	130	146	124	-
4	29	106	120	108	104
6	21	124	130	128	132
7	56	-	-	126	112
8	36	122	120	124	114
9	20	120	142	116	114
10	11	114	104	110	100
11	31	120	126	96	-
13	9	156	112	90	94
18	58	118	114	156	154

Subject Number	Time to Evacuate (in sec)	Calculated Workload (Watts) in 0.5 min Intervals from Start of Test			
		0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0
1	52	49	61	35	25
2	42	55	74	98	86
3	34	38	78	23	-
4	29	39	74	44	34
6	21	86	98	94	102
7	56	-	-	35	10
8	36	40	35	44	22
9	20	49	83	43	40
10	11	93	71	84	61
11	31	55	64	19	-
13	9	79	33	10	14
18	58	68	60	138	135

- Indicates that these data points were not reported due to loss of recording because of artifacts or other technical problems.

Once workload is determined, then calculations can be made for the O_2 consumption and expired CO_2 during the evacuation test.

TABLE IX

Evacuation Test Oxygen Consumption Expressed as mL/min, STPD, and as mL/min, STPD, per kg Body Wt (in parentheses) in 0.5 min Intervals from Start of Test.

Subject Number	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0
1	768 (12.5)	882 (14.4)	634 (10.3)	539 (8.8)
2	1019 (13.5)	1193 (15.8)	1413 (18.7)	1303 (17.3)
3	759 (14.3)	1032 (19.4)	657 (12.4)	- -
4	903 (13.5)	1254 (18.8)	953 (14.3)	852 (12.8)
6	1263 (19.0)	1377 (20.8)	1339 (20.2)	1415 (21.3)
7	- -	- -	757 (11.8)	597 (9.3)
8	1122 (15.5)	1057 (14.6)	1173 (16.2)	889 (12.3)
9	769 (14.3)	1047 (19.5)	720 (13.4)	695 (13.0)
10	1415 (18.1)	1201 (15.4)	1328 (17.0)	1104 (14.2)
11	859 (12.7)	944 (13.9)	516 (7.6)	- -
13	1103 (23.1)	707 (14.8)	510 (10.7)	544 (11.4)
18	1336 (18.0)	1258 (17.0)	2022 (27.3)	1993 (26.9)

TABLE X

Evacuation Test Expired Carbon Dioxide Expressed as mL/min, STPD, and as mL/min, STPD, per kg Body Wt (in parentheses) 0.5 min Intervals from Start of Test.

Subject Number	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0
1	1047 (17.0)	1253 (20.4)	806 (13.1)	634 (10.3)
2	631 (8.4)	821 (10.9)	1061 (14.1)	941 (12.5)
3	722 (13.6)	1087 (20.4)	585 (11.0)	- -
4	1094 (16.4)	1547 (23.2)	1159 (17.4)	1030 (15.4)
6	1186 (17.9)	1317 (19.9)	1274 (19.2)	1361 (20.5)
7	- -	- -	674 (10.5)	457 (7.1)
8	772 (10.6)	722 (9.9)	812 (11.2)	591 (8.1)
9	778 (14.5)	1188 (22.1)	706 (13.2)	669 (12.5)
10	1066 (13.7)	872 (11.2)	987 (12.7)	783 (10.0)
11	723 (10.8)	811 (12.0)	370 (5.5)	- -
13	794 (16.6)	355 (7.4)	136 (2.8)	174 (3.4)
18	1231 (17.0)	1127 (15.6)	2144 (29.7)	2105 (29.2)

TABLE XI
Evacuation Test
Maximum Workload per Kg Body Weight*

Subject Number	Watts/Kg Body Weight
1	0.993
2	1.300
3	1.467
4	1.110
6	1.538
7	0.544
8	0.606
9	1.547
10	1.192
11	0.945
13	1.655
18	1.911
Mean	1.234

*Take the maximum workload reached during the 2-min data collection period divided into 30-s increments (Table VIII) and divide by body weight in kilograms (Table II).

DISCUSSION

To establish a work profile to test the effectiveness of a PPBE device, a set workload for all subjects should probably be avoided. A workload suitable for a small (5th percentile) female would not be an adequate test for a large (95th percentile) male. An alternate approach would be to base the imposed workload on a body-weight basis. This would not only give a more reasonable test of the PPBE for a varied subject population, but also facilitate the use of either a bicycle ergometer (for which workload is externally applied) or a treadmill (for which workload is dependent on body weight) for providing the workload[3].

One profile suggested by a member of the international PPBE evaluation group would have two levels of physical activity for all test subjects:

Level 1:	t = 0	: device donned,
	t = 0 to 30 s	: subject seated,
	t = 30 s to 3 min	: effort expended at 60 W for 1 min, 80 W for 1 min, 30 s.

Level 2: t = 0 : device donned,
t = 0 to 12 min 30 s: subject seated,
t = 12 min 30 s to 15 min : effort expended at 60 W for 1 min, 80 W for 1 min, 30 s.

Another suggested test also has two levels of conditions:

Level 1: 20 min at sea level to 10,000 ft with a minimum workload, but within that 20 min, 5 min at an average workload of 80 W, when any one of the following transient conditions shall occur:
180 W for 30 s or
150 W for 1 min or
100 W for 2 min.

Level 2: 5 min at sea level with an average workload of 80 Watts and at any time the following transient conditions shall occur -
180 W for 30" or
150 W for 1' or
100 W for 2'.

PPBE must function properly under the most severe conditions for which intended. If the most severe test were chosen for the test protocol (Level 2 for the first example and Level 1 for the second example above), then it could be assumed that the device would be adequate for a less severe condition (Level 1 for the first example and Level 2 for the second example above). Therefore, there would be need for only one test protocol.

The duration of the test is yet to be agreed upon (15 minutes or 20 minutes), however, some workloads can be identified which could be pertinent to any profile. Physiological considerations and levels of work noted in the CAMI evacuation study suggest that the following workload criteria be considered:

For a low level of work, simulating donning and staying seated after an emergency has been declared (as in an in-flight situation), a workload of 0.7 watts/kg body weight could be applied. This was selected because it approximates a 50-watt workload for a "standard" 70 kg man, which is considered a light workload and is one that could be expected to be maintained for some period of time. This rate would equate to a 34-W workload for the 5th percentile female (48.6 kg) and to a 70-W workload for the 95th percentile male (100.1 kg). As shown in Table XII, this would have resulted in HR's which, when averaged, would produce a HR of 57.9% of predicted maximum HR for the subjects used in the calibration tests.

For a high activity level (although not a maximum effort) a value of 1.2 W/kg appears to be reasonable. The subjects during this test were not expending a maximum effort; i.e., none were climbing over seatbacks, or pushing and shoving to get to the exits, as has been described during some emergencies. As shown in Table XI, the mean of the maximum workloads for the 12 subjects who participated in the evacuation test (2-min data collection period divided into 30-s increments) was 1.234 W/kg. If we apply the 1.2 W/kg to the calibration data for the 16 subjects, it would result in a mean of 67.7% of predicted maximum HR (Table XII) with two subjects exceeding 75% of predicted maximum HR. This would result in a workload of 58 W for the 5th percentile female and 120 W for the 95th percentile male.

For the brief maximum exertion workload, a value of 1.5 W/kg is suggested. This would result in a mean of 73.3% of predicted maximum HR for the 16 calibrated subjects. Three of the 16 would have exceeded 80% of predicted maximum HR, indicating that this workload level would constitute a high exertion level. This 1.5 W/Kg value would result in a 73-W workload for the 5th percentile female and a 150-W workload for the 95th percentile male.

TABLE XII

Workload, Heart Rate, and PPMHR (Percent of Predicted Maximum Heart Rate) for the 16 Calibrated Subjects, When Applying the Three Suggested Workload Rates

Sub No.	0.7 W/kg Body Wt. Work Load	HR	PPMHR	1.2 W/kg Body Wt. Work Load	HR	PPMHR	1.5 W/kg Body Wt. Work Load	HR	PPMHR
1	43	116	58.9	74	147	74.6	92	165	83.8
2	53	93	47.2	90	113	57.4	113	124	62.9
3	37	126	64.6	64	140	71.8	80	147	75.4
4	46	109	55.9	80	123	63.1	100	131	67.2
5	47	118	60.5	81	135	69.2	101	145	74.4
6	46	103	52.8	80	121	62.1	100	131	67.2
7	45	131	66.5	77	149	75.6	96	159	80.7
8	51	127	64.5	87	144	73.1	109	154	78.2
9	38	112	57.4	64	130	66.7	80	140	71.8
10	55	97	49.7	94	114	58.5	117	124	63.6
11	47	115	59.0	81	138	70.7	102	152	77.9
12	50	107	55.4	86	124	64.2	107	134	69.4
13	33	112	58.0	57	135	69.9	72	149	77.2
14	70	131	67.9	120	151	78.2	150	162	83.9
16	70	102	52.8	121	120	62.2	151	130	67.4
18	52	110	55.8	89	129	65.5	111	141	71.6
Mean			57.9			67.7			73.3

If the longer, more severe test period (20 min) is desired, the test might be divided into a low level of work (0.7 W/kg) for 15 min, followed by 2 min at an intermediate level (1.2 W/kg), then 1 min at a peak level (1.5 W/kg), then return to the intermediate level for the final 2 min of the test. Under the assumption that this work profile is acceptable, then other criteria could be developed for evaluating the adequacy of a proposed device. Table VII shows that the highest tidal volume recorded was 2.647 Liters, with two others approaching that level. This could establish that a hood-type device with a breathable-gas mixture should probably have a great enough volume to allow for three Liters of free volume when the volume of the head and neck is subtracted so that the hood would not collapse and draw in ambient air during a single maximum inhalation.

By considering the data from the largest subject used in the calibration runs (#16), estimates can be made for the O_2 required and the CO_2 absorption expected for the 20-min profile as described above. This subject would have consumed an estimated 29 Liters of O_2, with his maximum effort requiring that O_2 be provided at the rate of 2.1 L/min. He would produce an estimated 24.7 Liters of CO_2, which would need to be absorbed, with the maximum workload causing production of expired CO_2 at the rate of 2.0 L/min. This individual was very close to the 95th percentile male (his weight was 100.7 kg; the 95th percentile male weighs 100.1 kg). This young subject was in exceptional physical condition and very efficient for O_2 utilization and CO_2 production. It was noted that on a body-weight basis (Tables IV and VI) several subjects have higher O_2 consumption and CO_2 production. To allow for margins of safety for subjects who might be less well conditioned than our 95th percentile male, the device should probably provide 3.0 Liters of O_2 per minute throughout the 20-min period and should probably be capable of absorbing 40 to 45 liters of CO_2 during this same time period.

In order to provide a guideline for evaluation with workloads based on body weight, one must include in the test population at least one or two individuals who meet or exceed the weight of the 95th percentile male in order to include subjects who require the maximum amount of O_2 and produce the highest levels of CO_2. A wide range of subject sizes must also be included for other considerations, such as goodness of fit and possible inboard leakage. The number of subjects required for a satisfactory test is still undecided.

CONCLUSIONS

Based on this study and these recommendations, several acceptance critera for a passenger protective breathing device should be able to be established, such as:

1) A single profile with realistic workloads;
2) A minimum volume for hood-type devices;
3) A minimum O_2 flow for breathable gas-type devices; or
4) A minimum CO_2 absorption requirement.

The values recommended for these four parameters are:

1) A 20-min work profile consisting of:
   15 min at 0.7 W/kg body weight,*
   2 min at 1.2 W/kg body weight,
   1 min at 1.5 W/kg body weight,
   2 min at 1.2 W/kg body weight.

2) The volume of the hood should exceed the volume that encloses the head and neck by 3.0 Liters.

3) The device should provide 3.0 L/min O_2 for 20 min.

4) The device should be capable of absorbing 45 L of CO_2.

* The subject population studied should include one or two individuals who meet or exceed the weight of the 95th percentile male.

TABLE XIII

Correlation Coefficients for the Graphs of Workload Plotted Against Other Variables

Subject Number	Other Variables: HR	O_2 Consump-tion	O_2 Consump-tion/Kg	CO_2 Produc-tion	CO_2 Produc-tion/Kg
1	.923	.948	.945	.945	.962
2	.972	.960	.960	.962	.962
3*	.923	.942	.942	.731	.736
4	.993	.996	.996	.936	.936
5	.995	.978	.977	.990	.991
6	.992	.993	.993	.985	.985
7	.976	.996	.997	.996	.996
8	.971	.969	.968	.973	.973
9	.959	.968	.968	.965	.964
10	.969	.979	.979	.969	.969
11	.999	.952	.953	.942	.943
12	.998	.953	.954	.960	.959
13	.992	.997	.998	.999	.999
14	.968	.973	.972	.949	.951
16	.989	.976	.977	.976	.976
18	.995	.997	.997	.998	.998

*Third data collection period was from 4 min, 30 s to 5 min rather than from 5 min, 30 s to 6 min due to too high a HR

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3. Froelicher, Victor F., Jr., M.D., Exercise Testing and Training. Yearbook Medical Pub. Inc., Chicago, 1984.

APPENDICES

Appendix A: Individual Subject Graphs for Workload vs. Heart Rate

Appendix B: Individual Subject Graphs for Workload vs. Oxygen Consumption

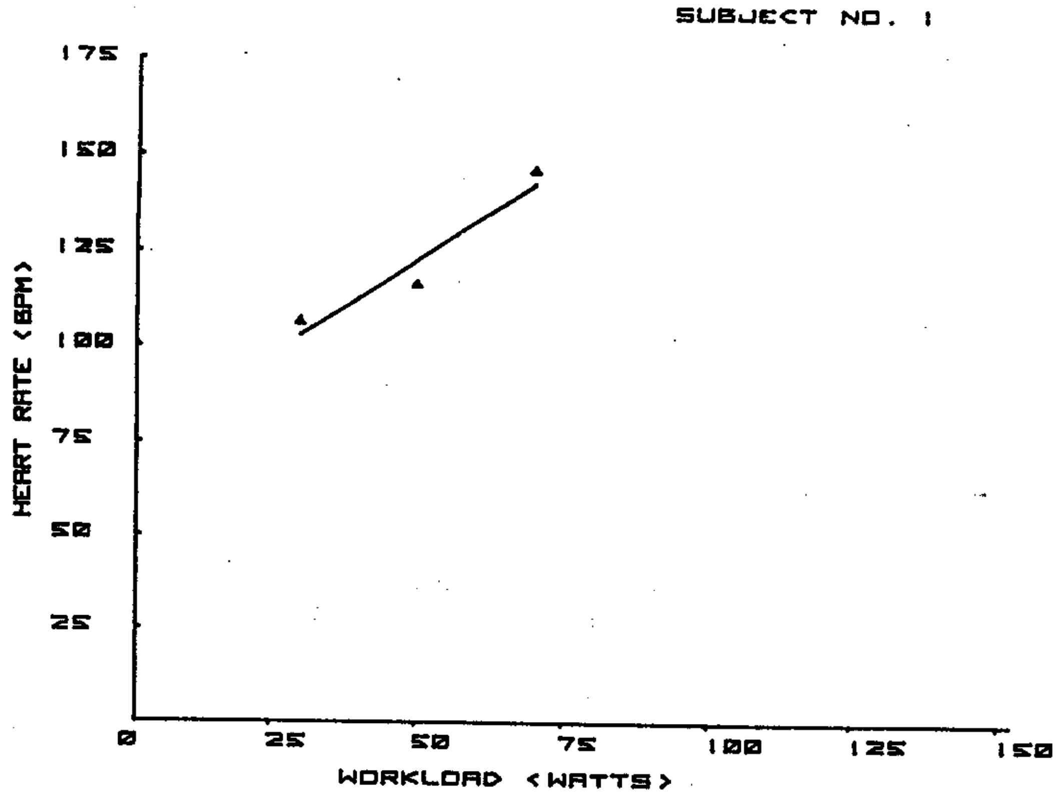
Appendix C: Individual Subject Graphs for Workload vs. Oxygen Consumption per Kilogram Body Weight

Appendix D: Individual Subject Graphs for Workload vs. Expired Carbon Dioxide

Appendix E: Individual Subject Graphs for Workload vs. Expired Carbon Dioxide per Kg Body Weight

APPENDIX A

Individual Subject Graphs for
Heart Rate (BPM) vs. Workload (Watts)



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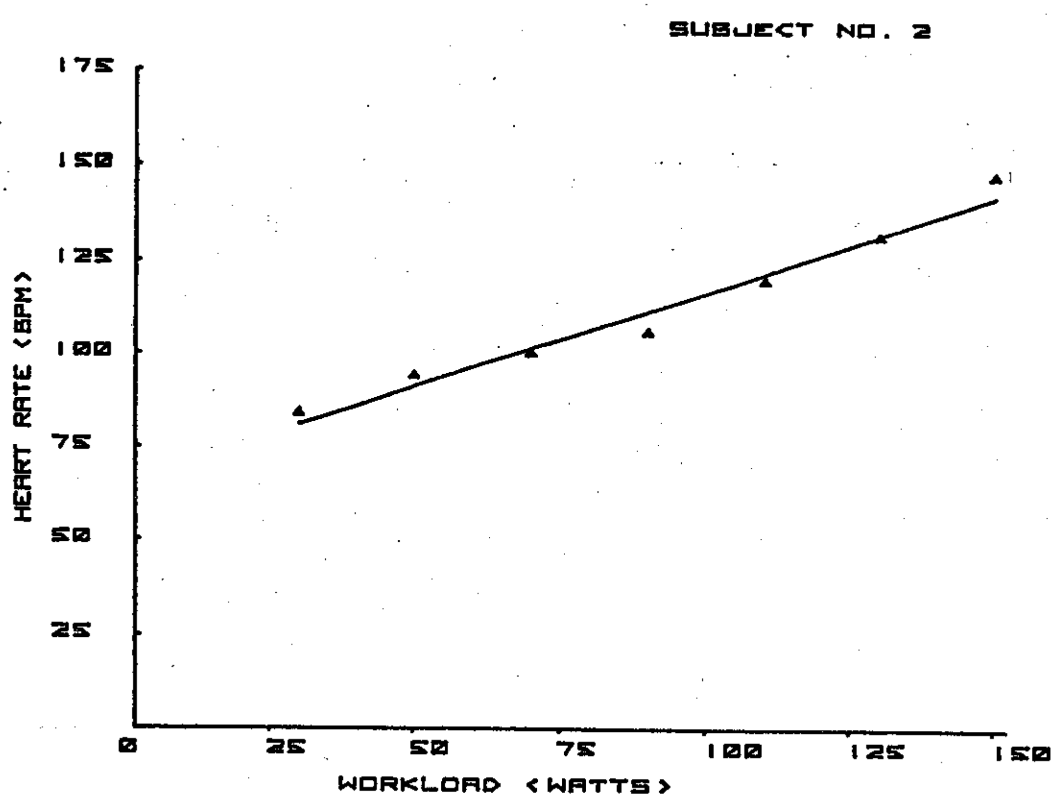

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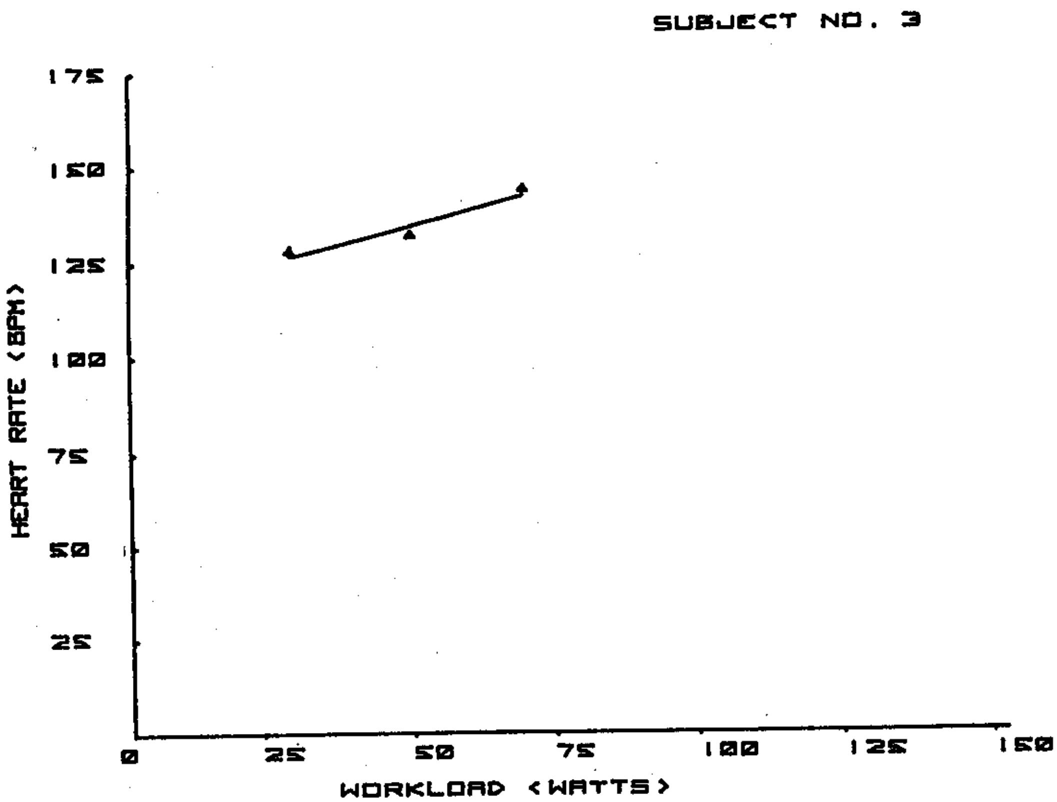

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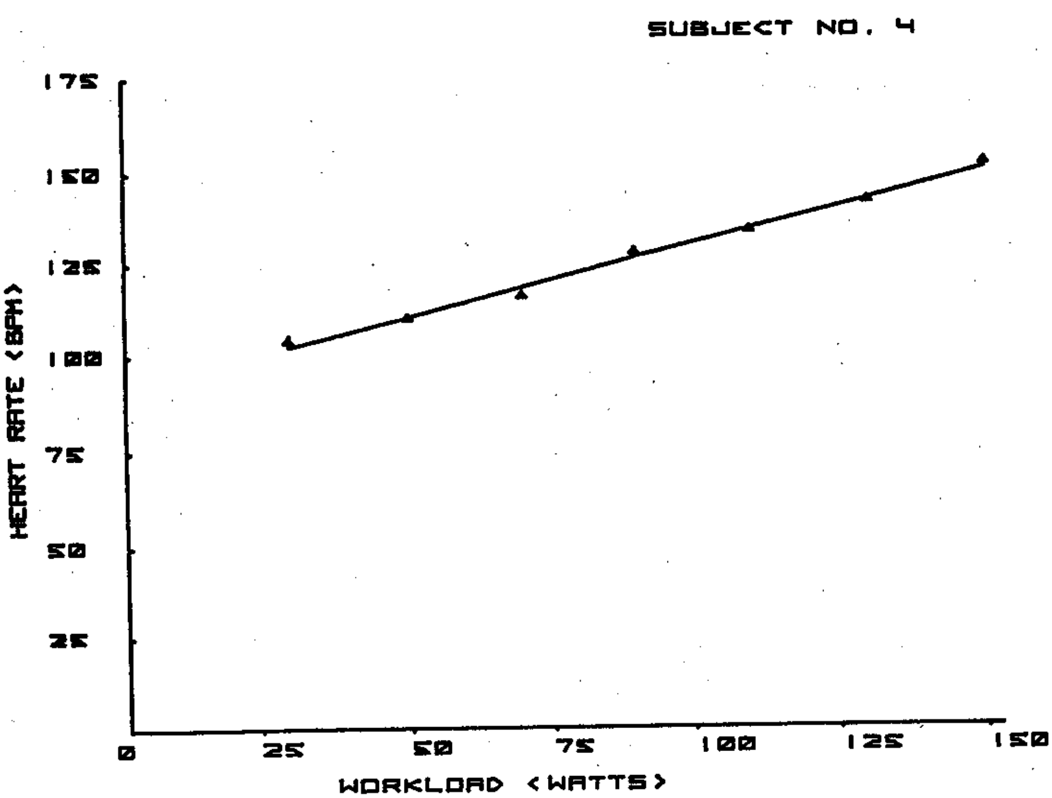

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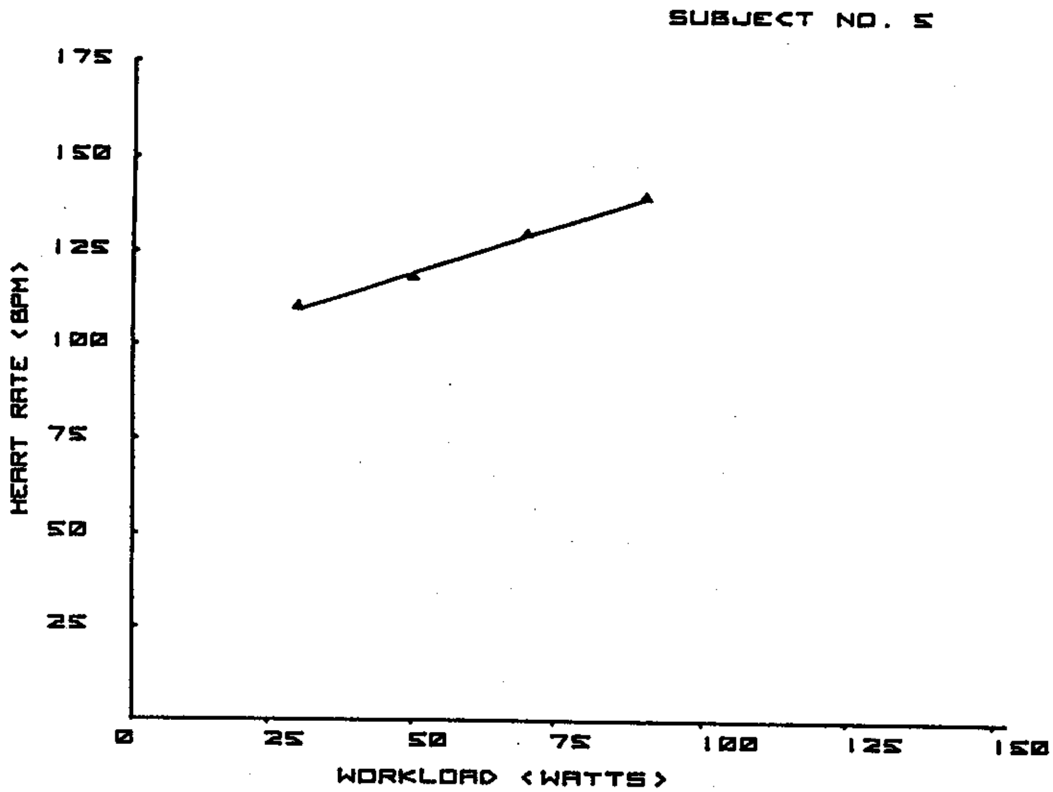

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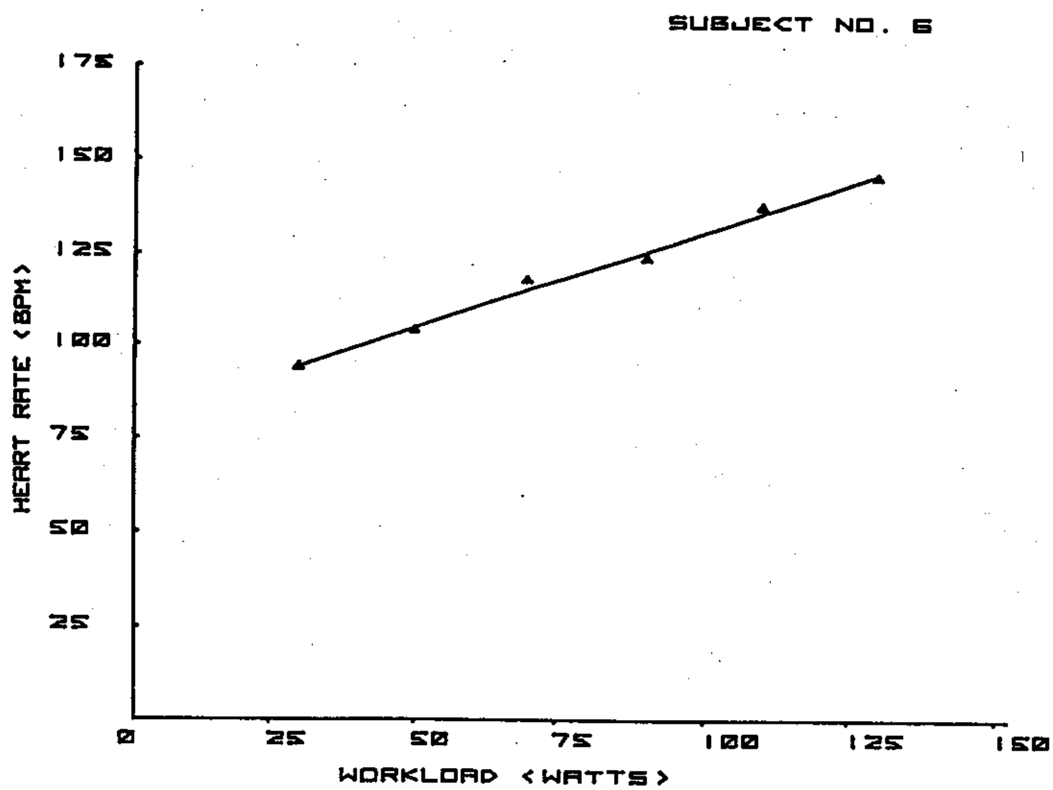

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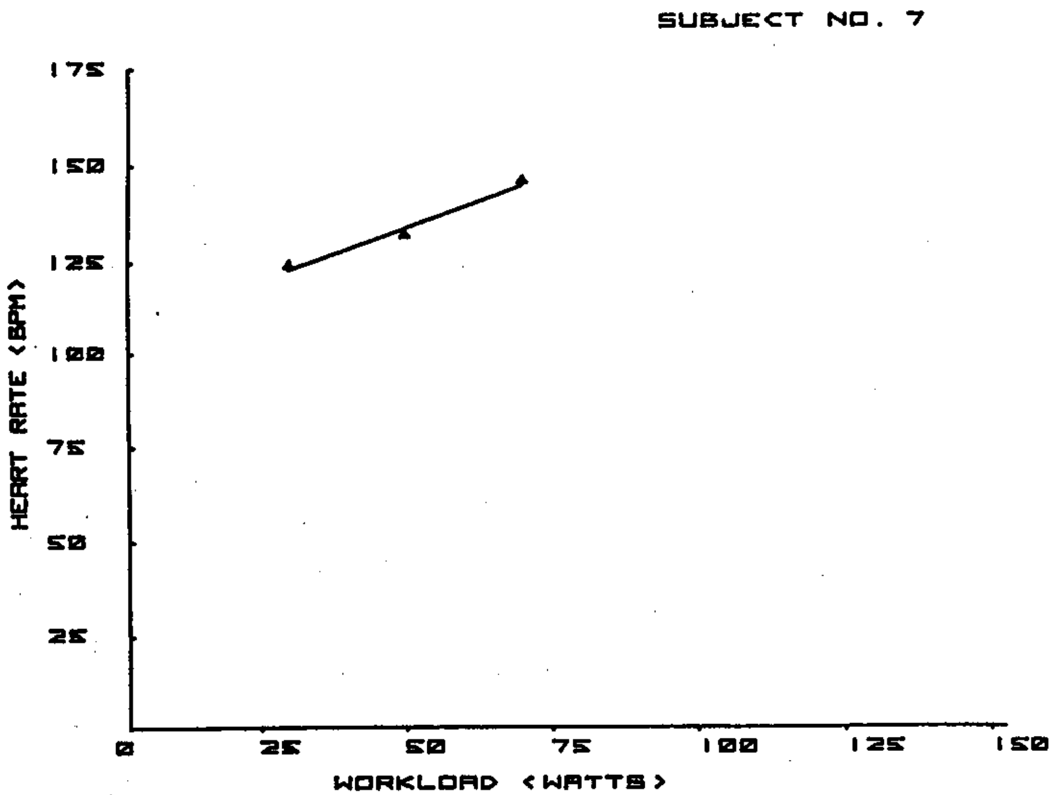

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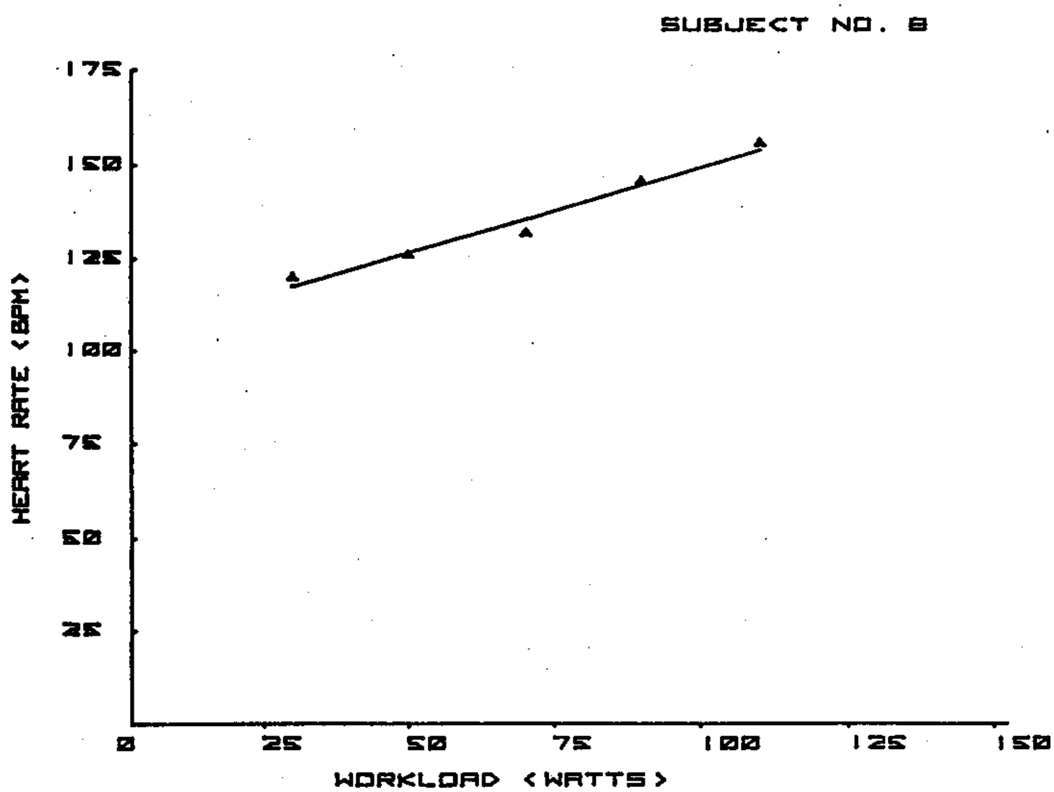

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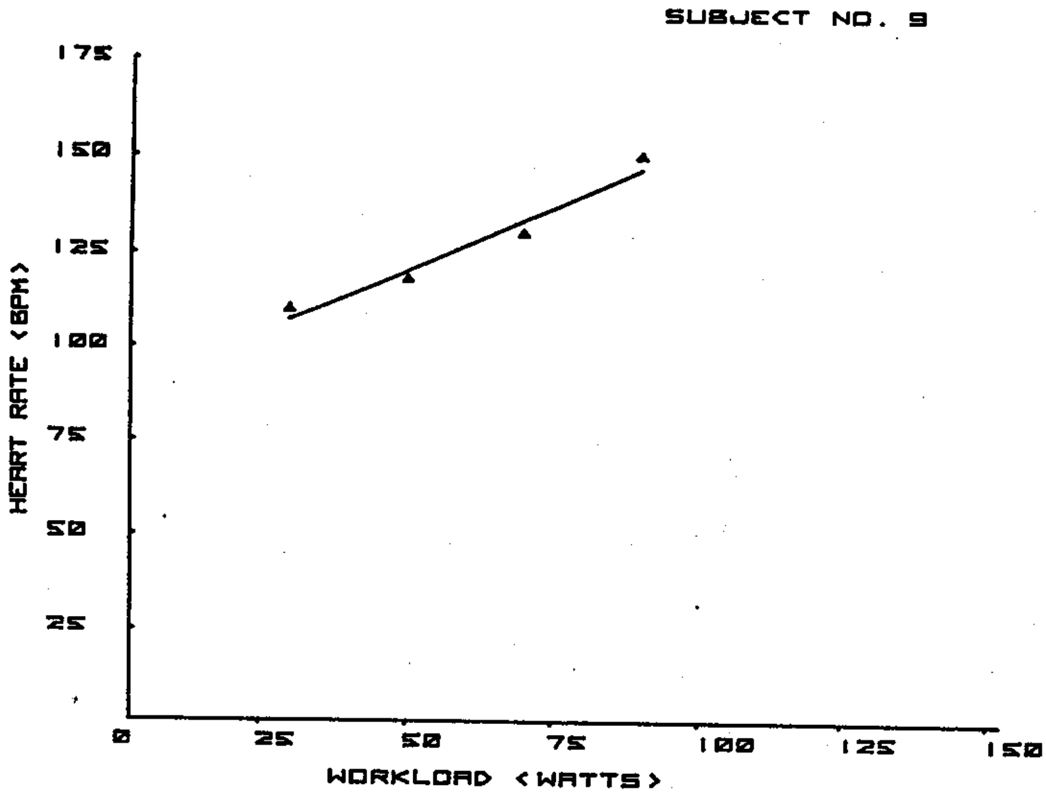

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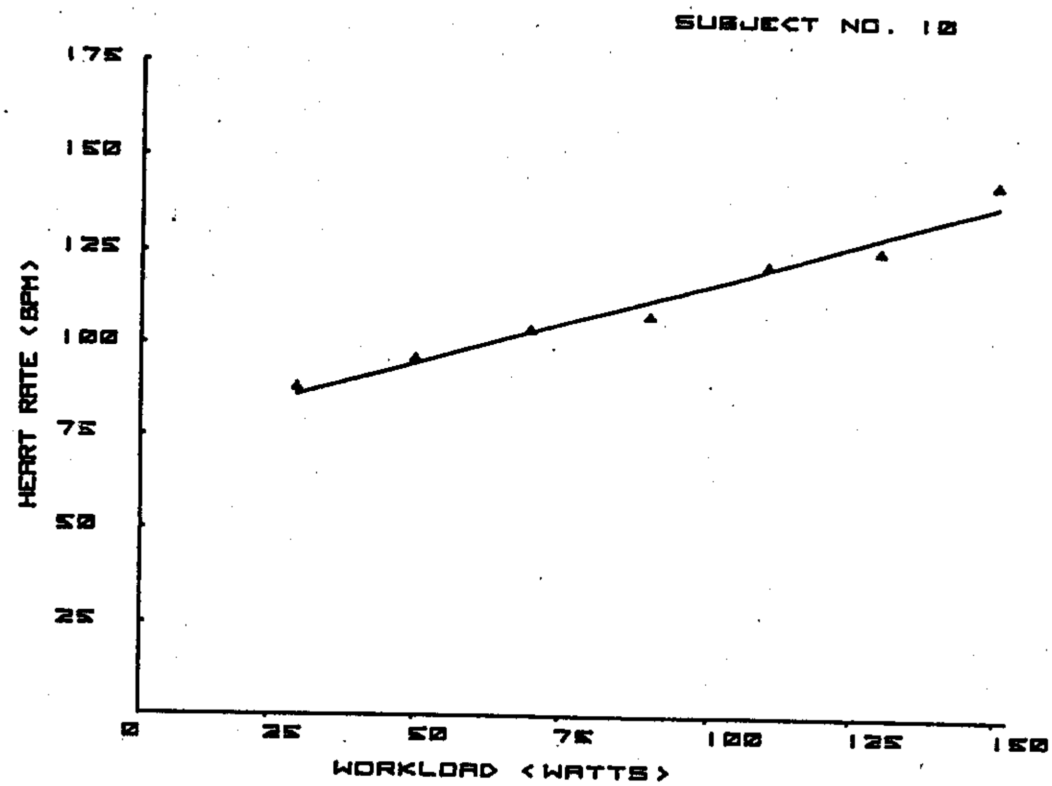

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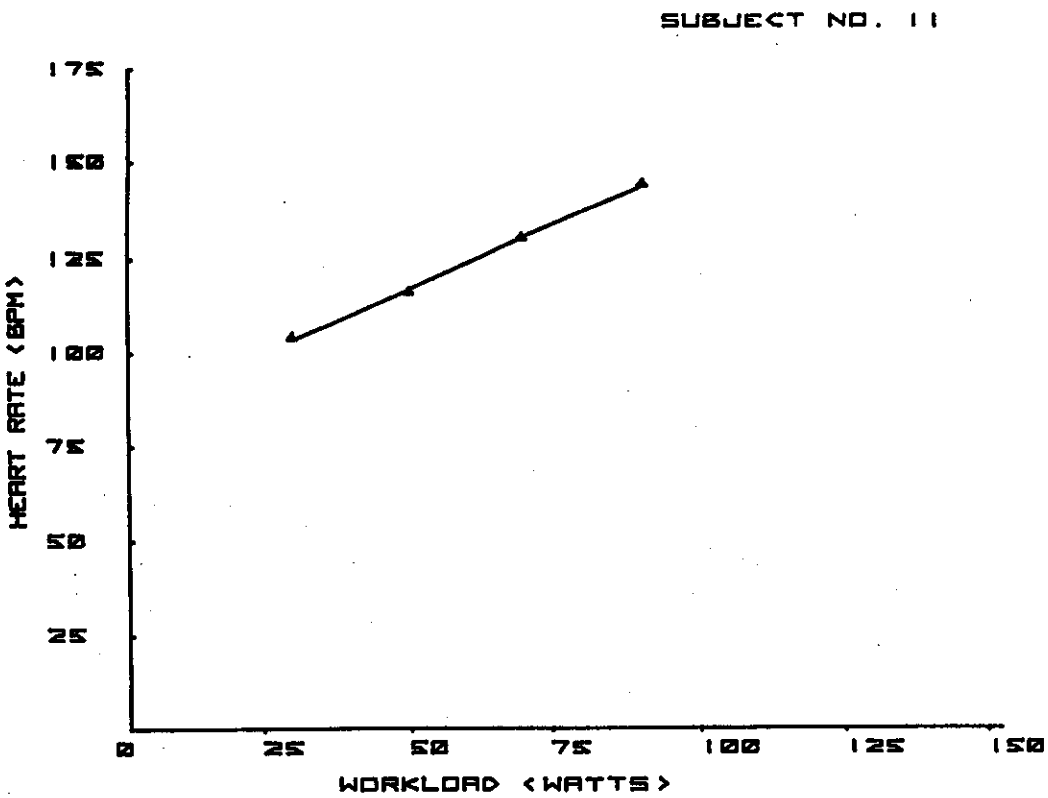

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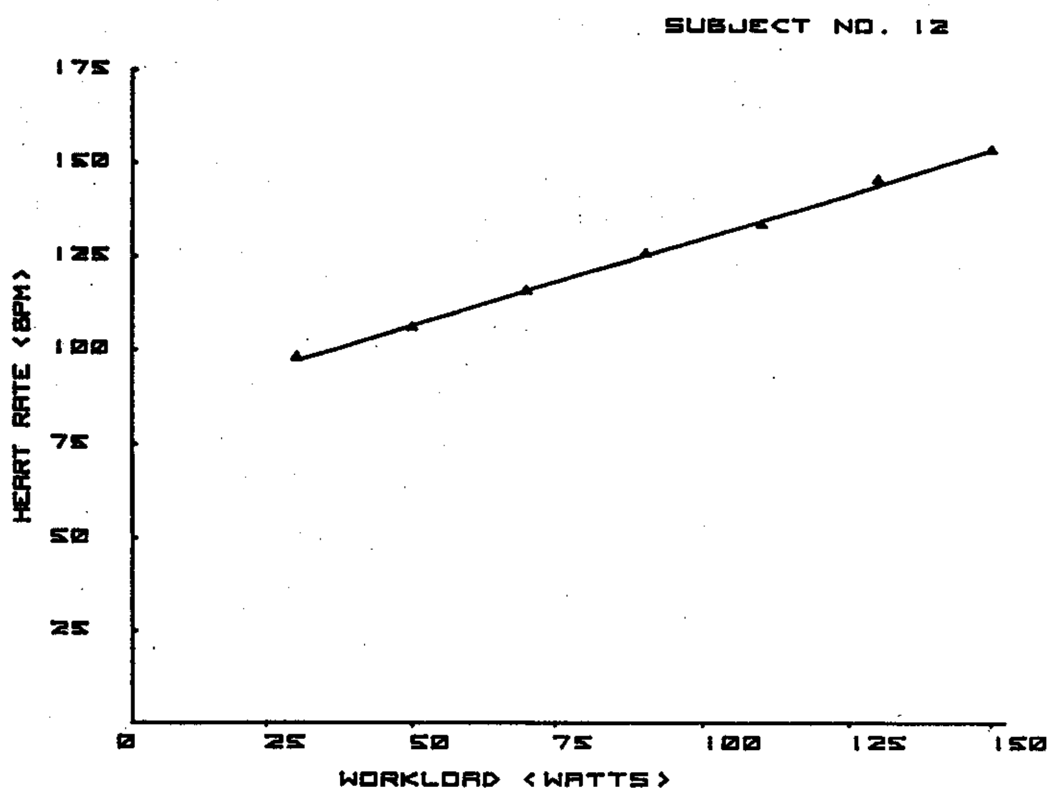

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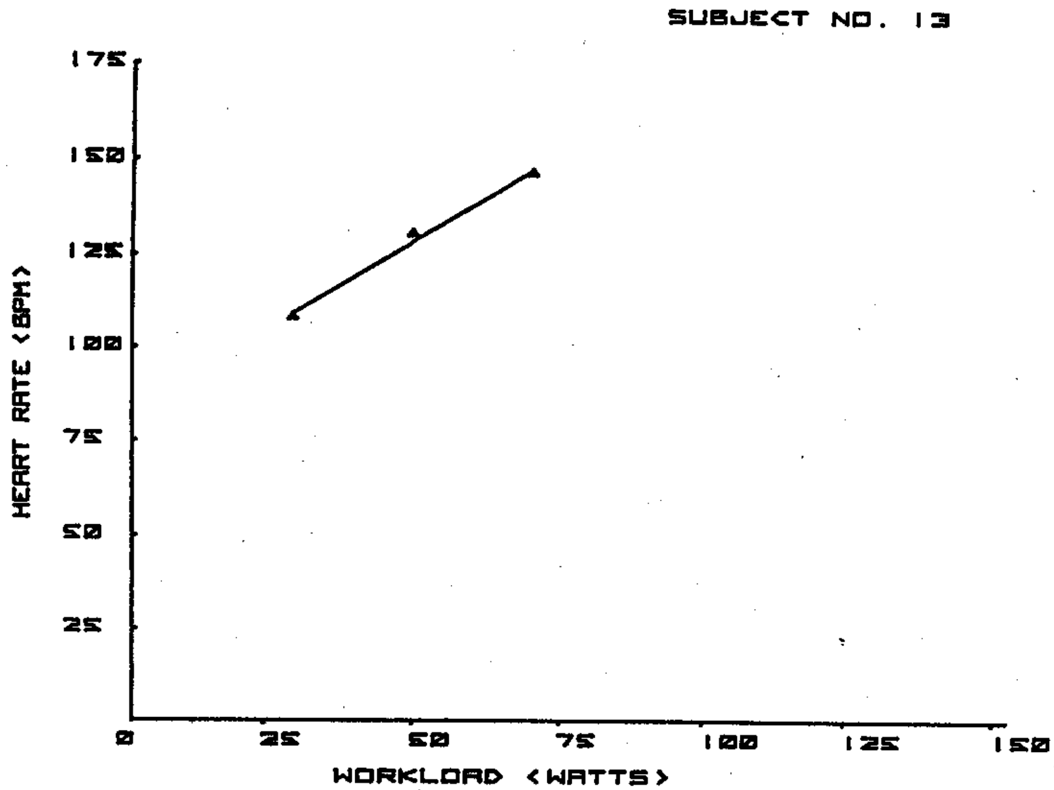

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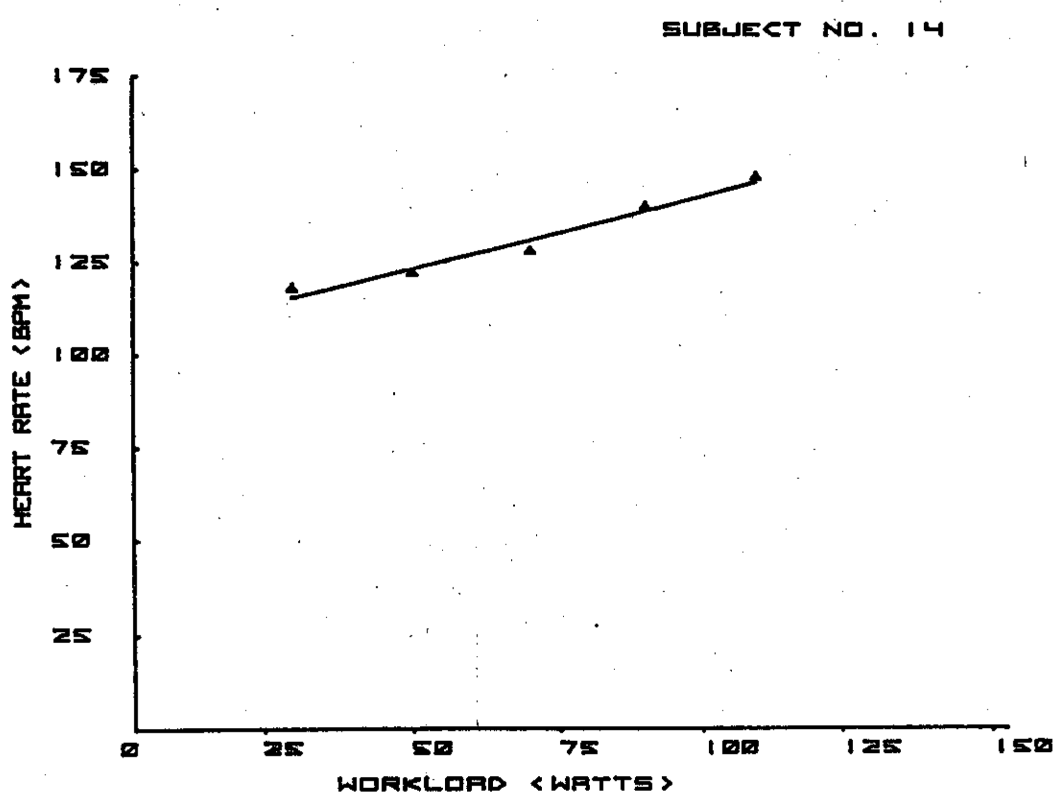

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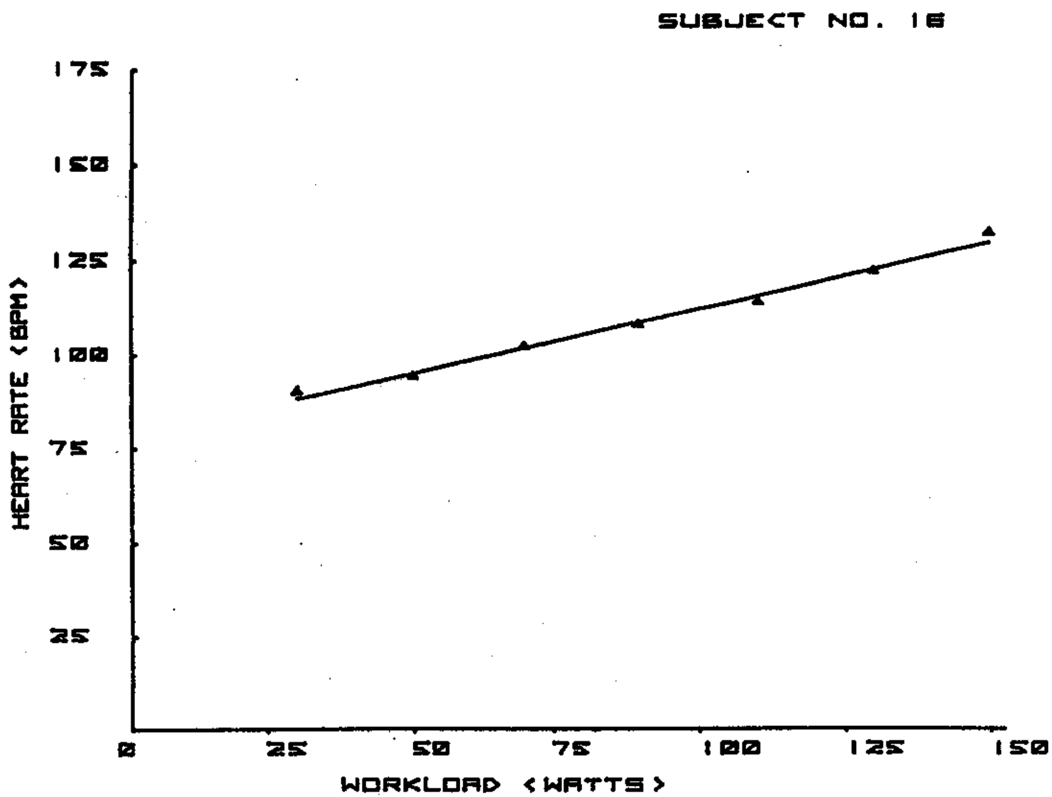

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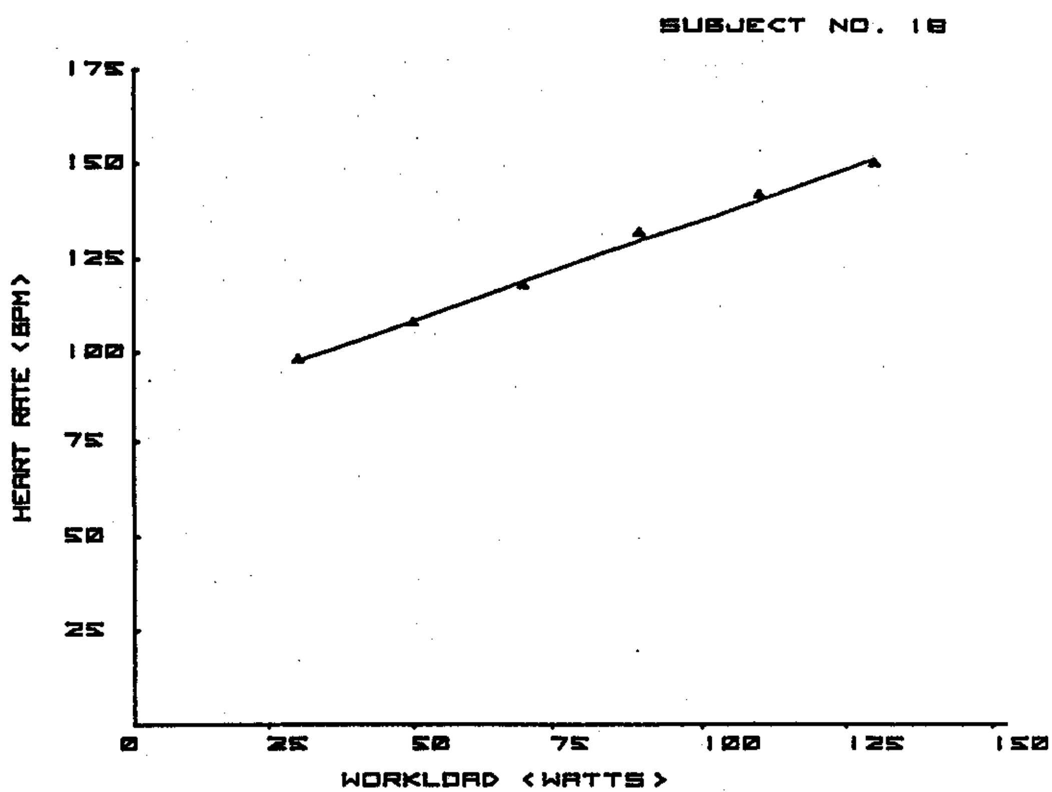
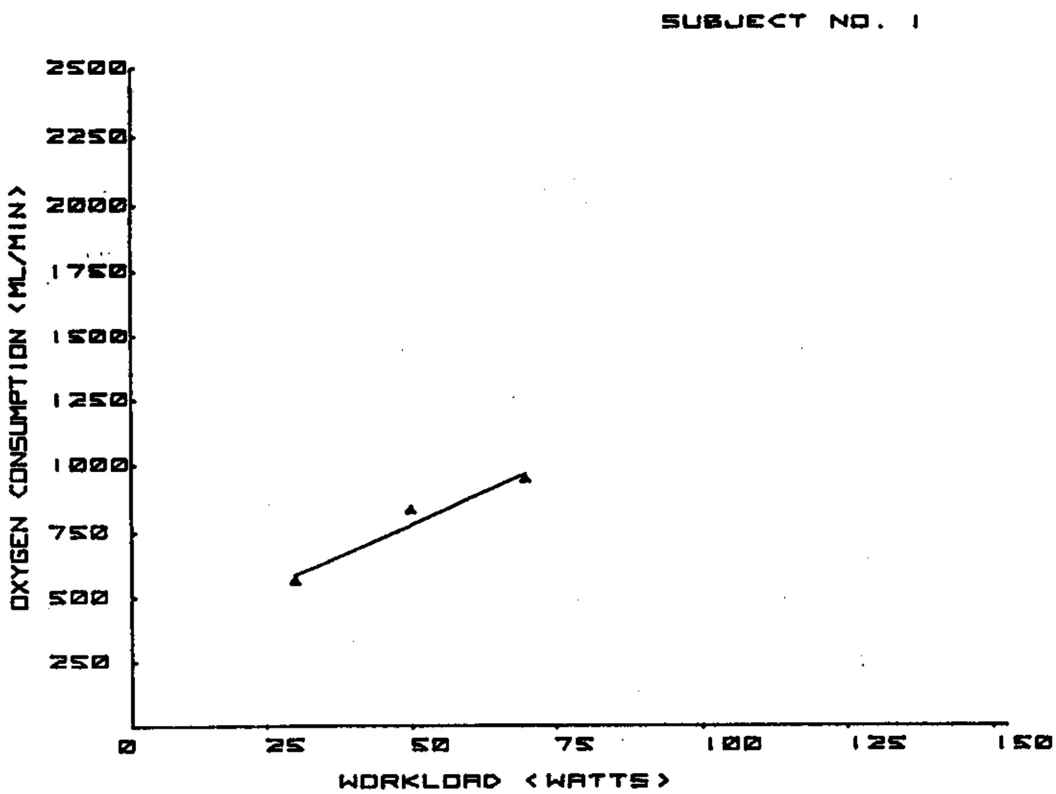


Figure 17

APPENDIX B

Individual Subject Graphs for Oxygen Consumption (mL/min) vs. Workload (Watts)



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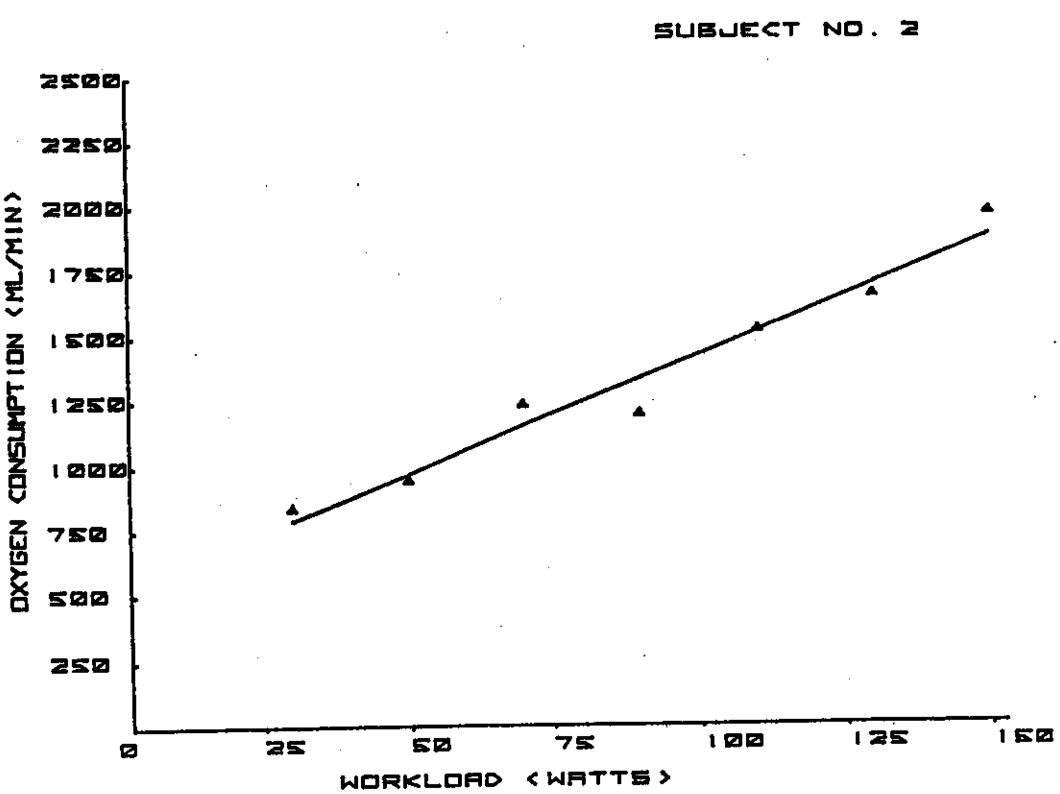

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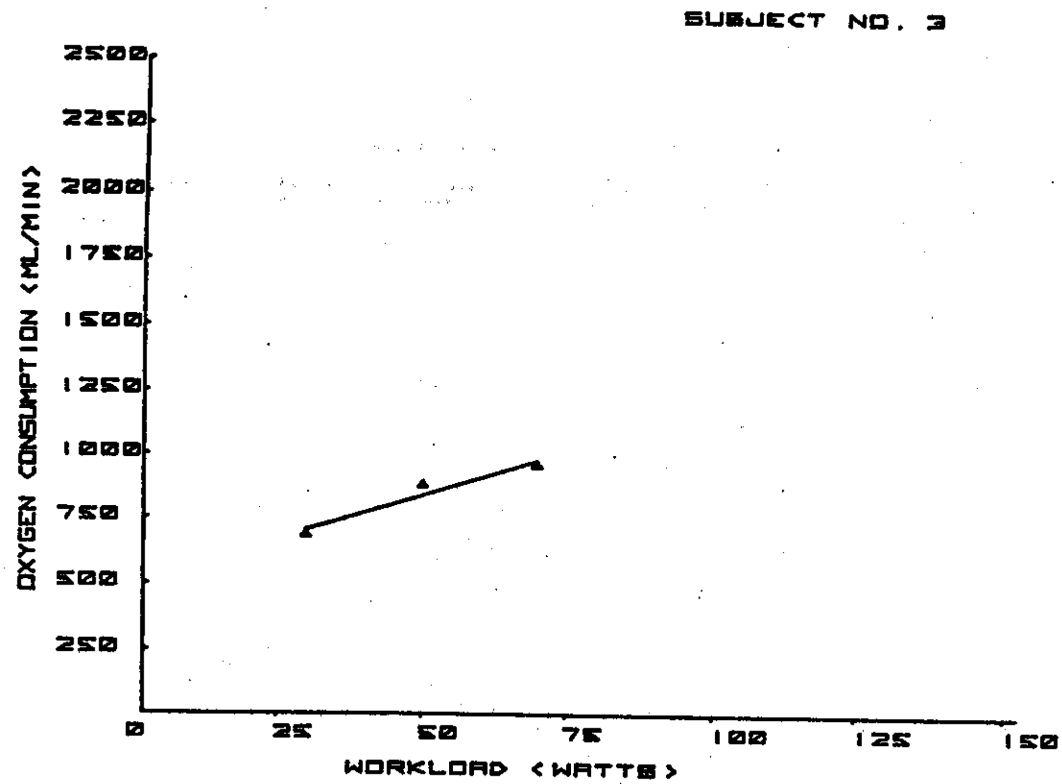

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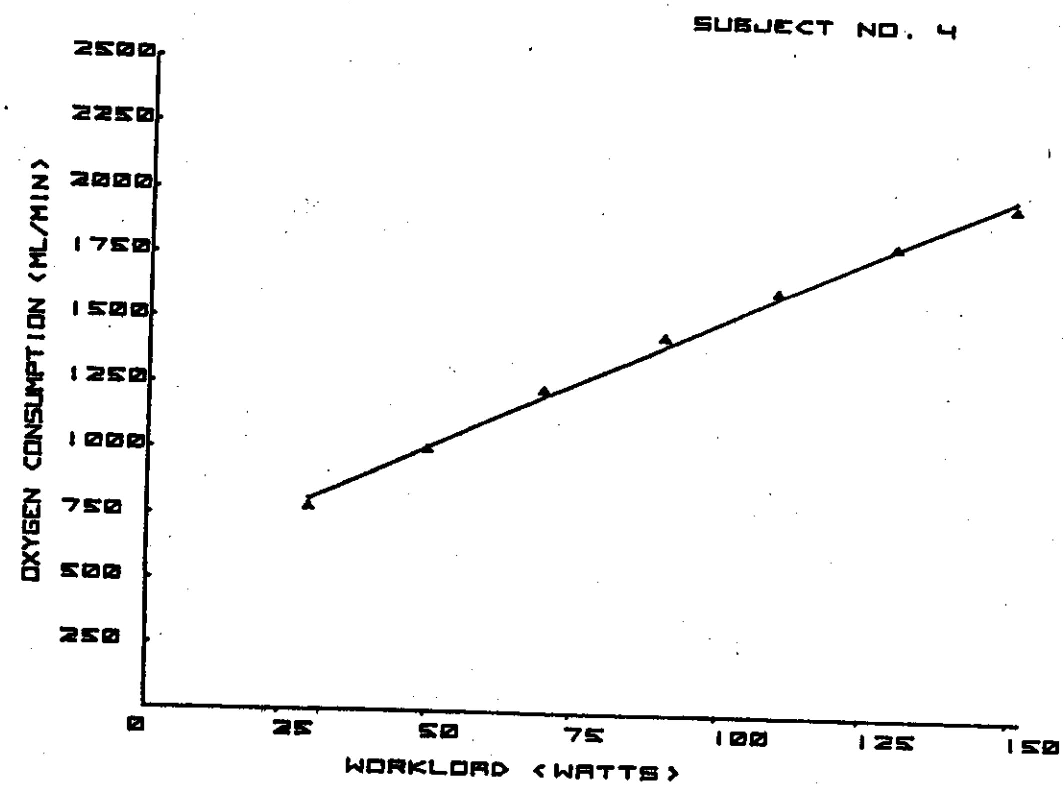

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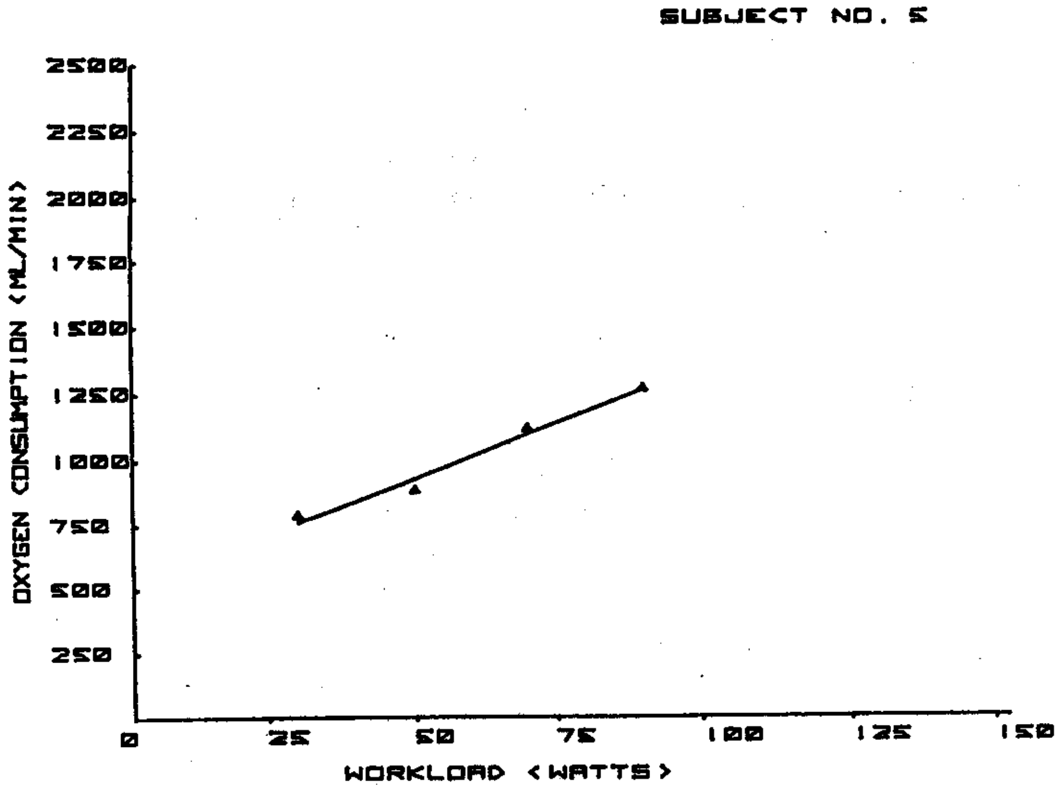

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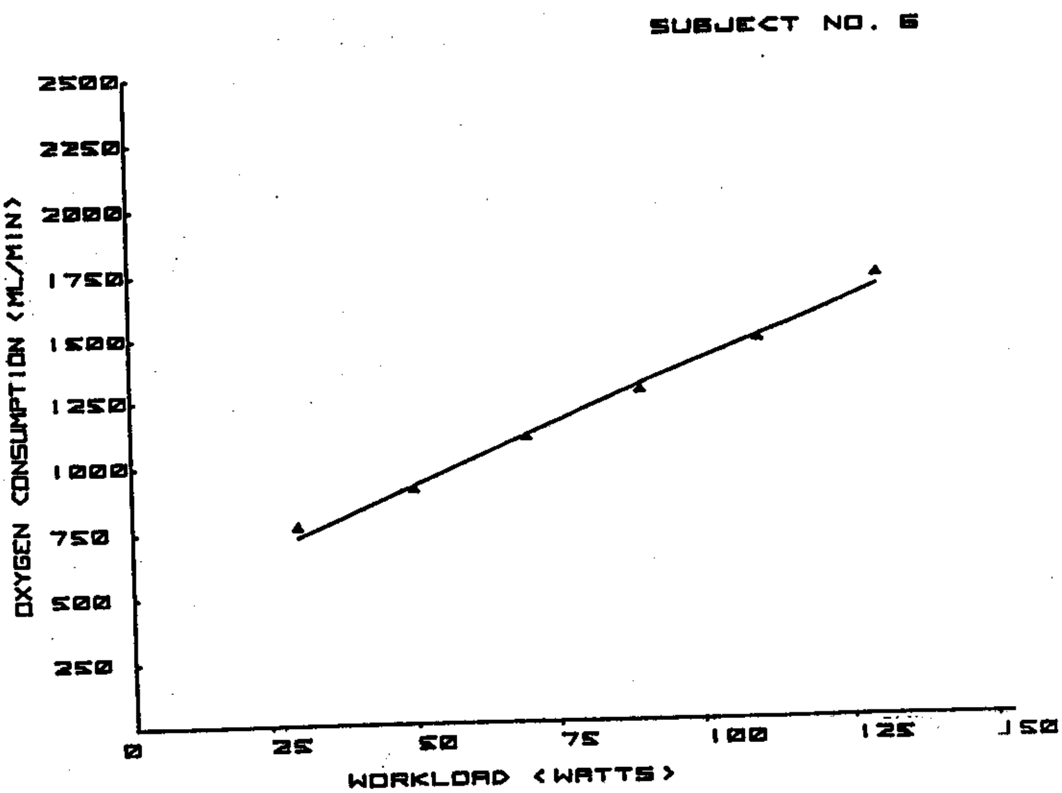

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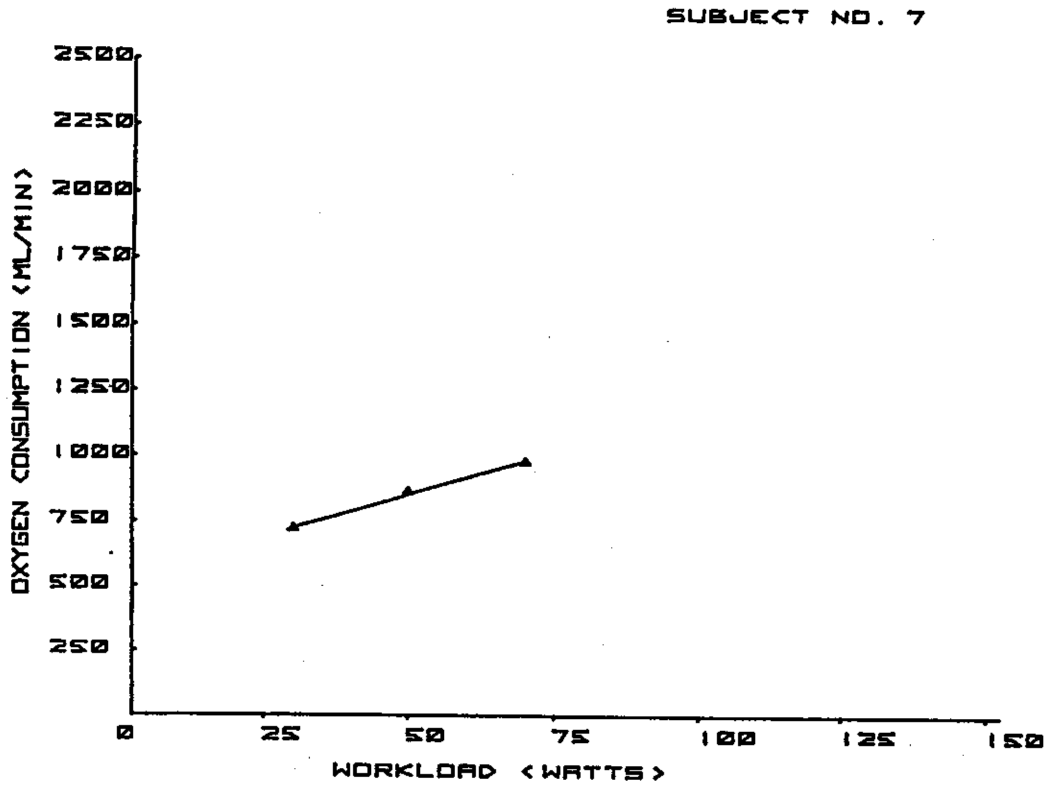

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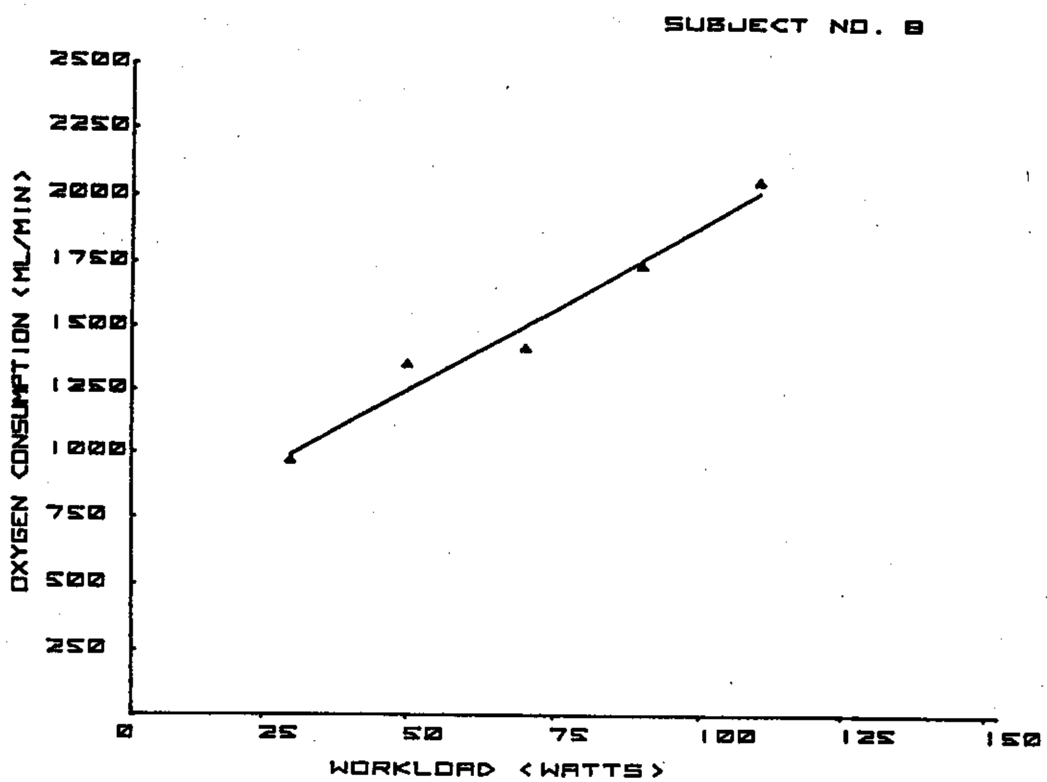

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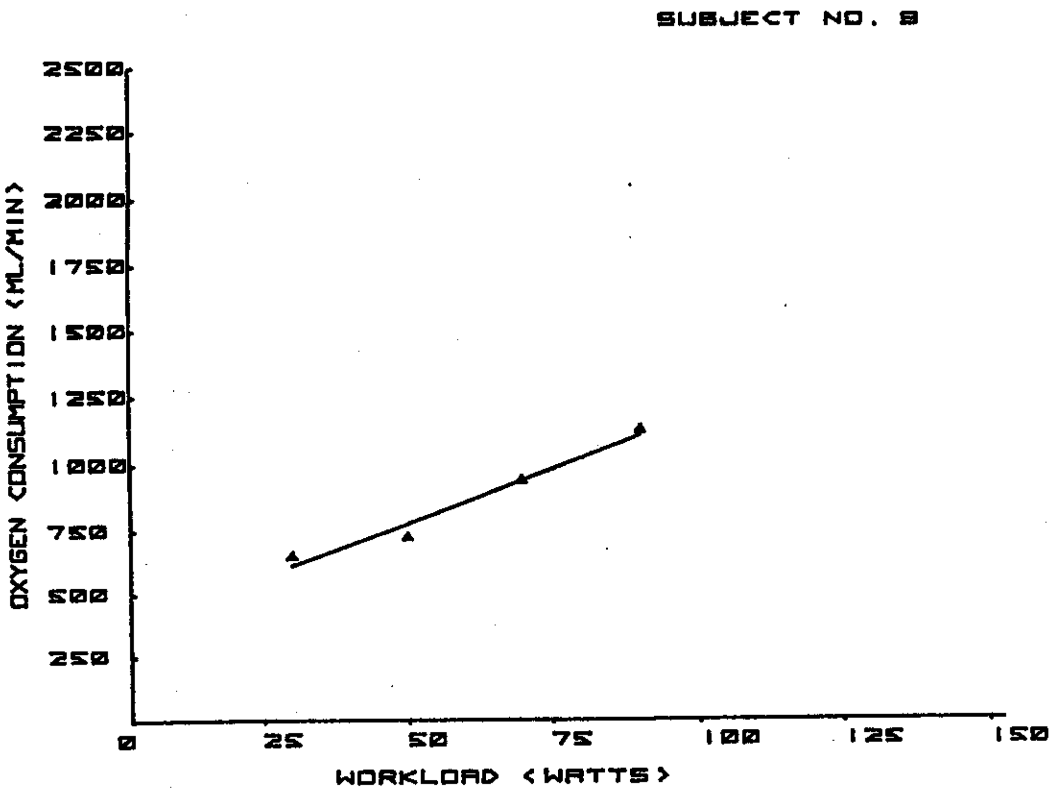

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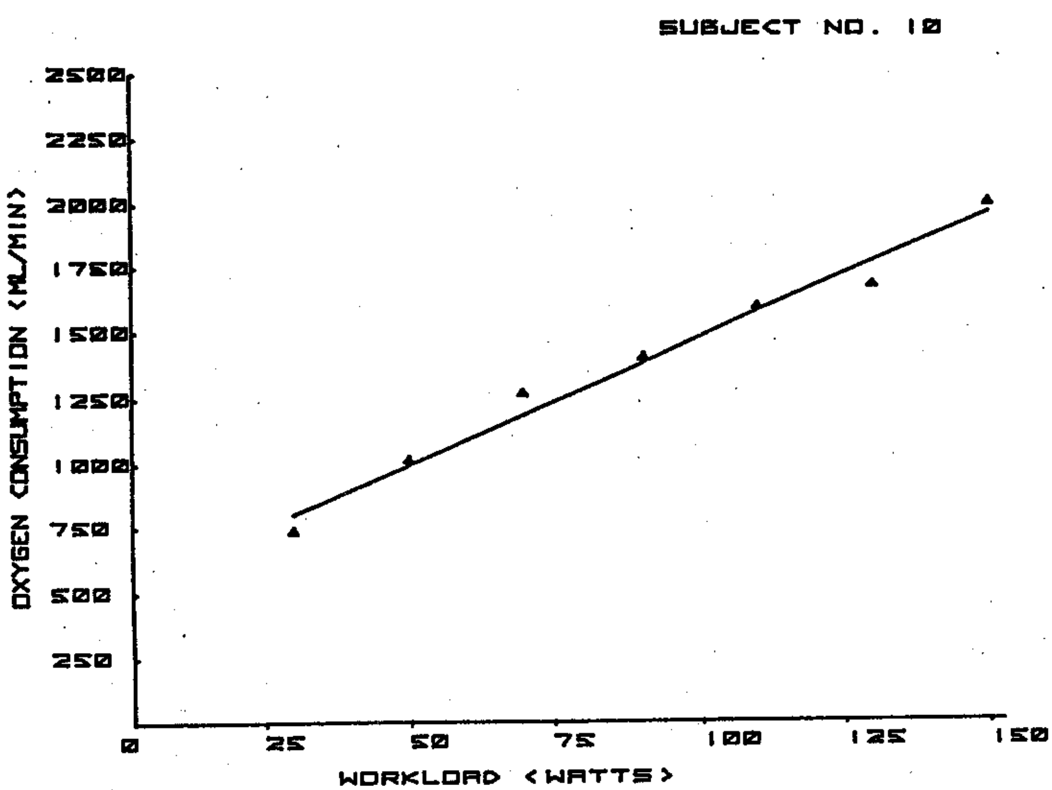

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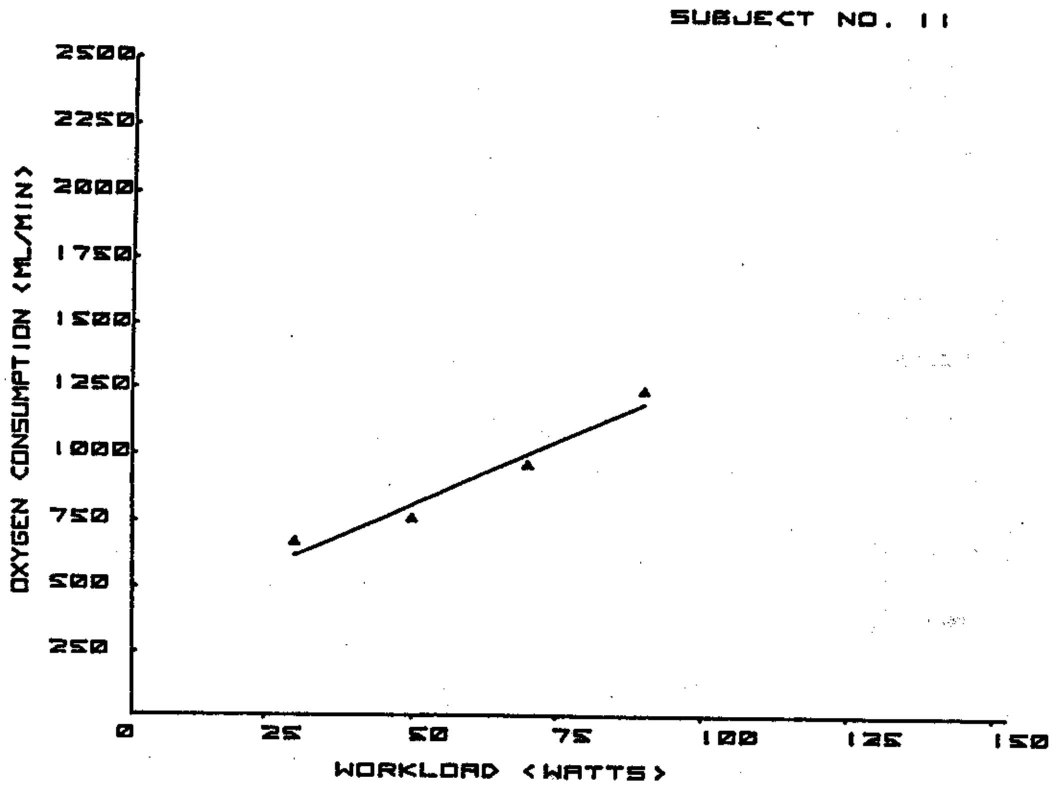

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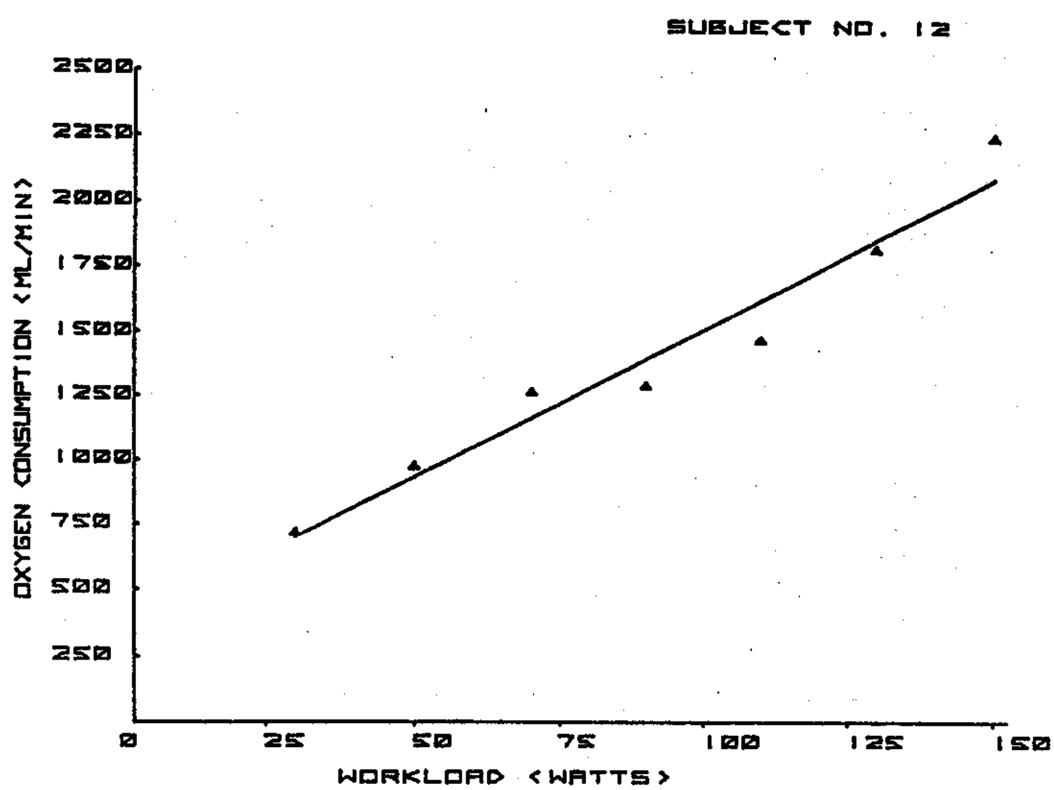

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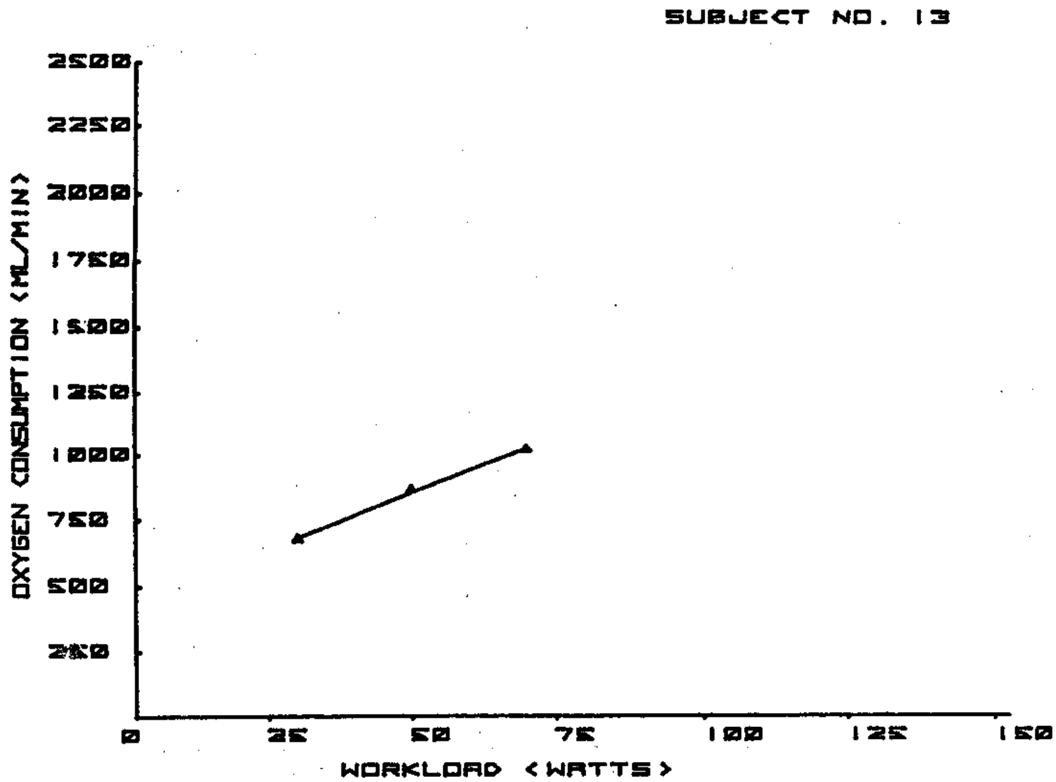

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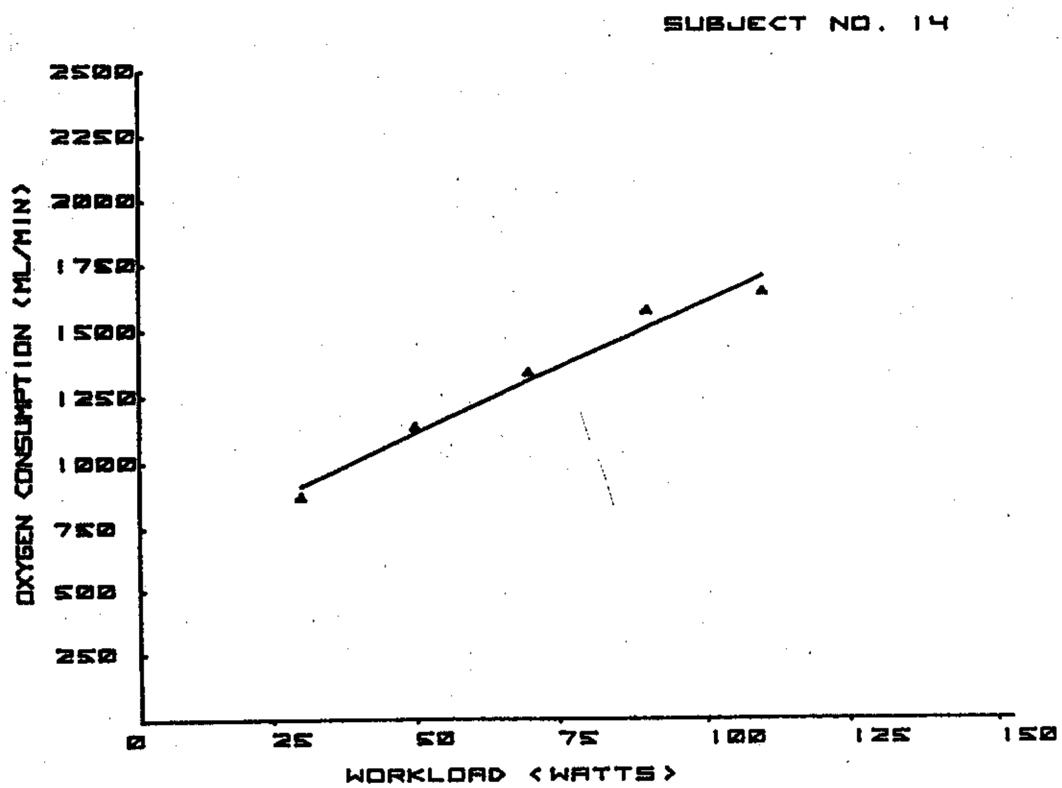

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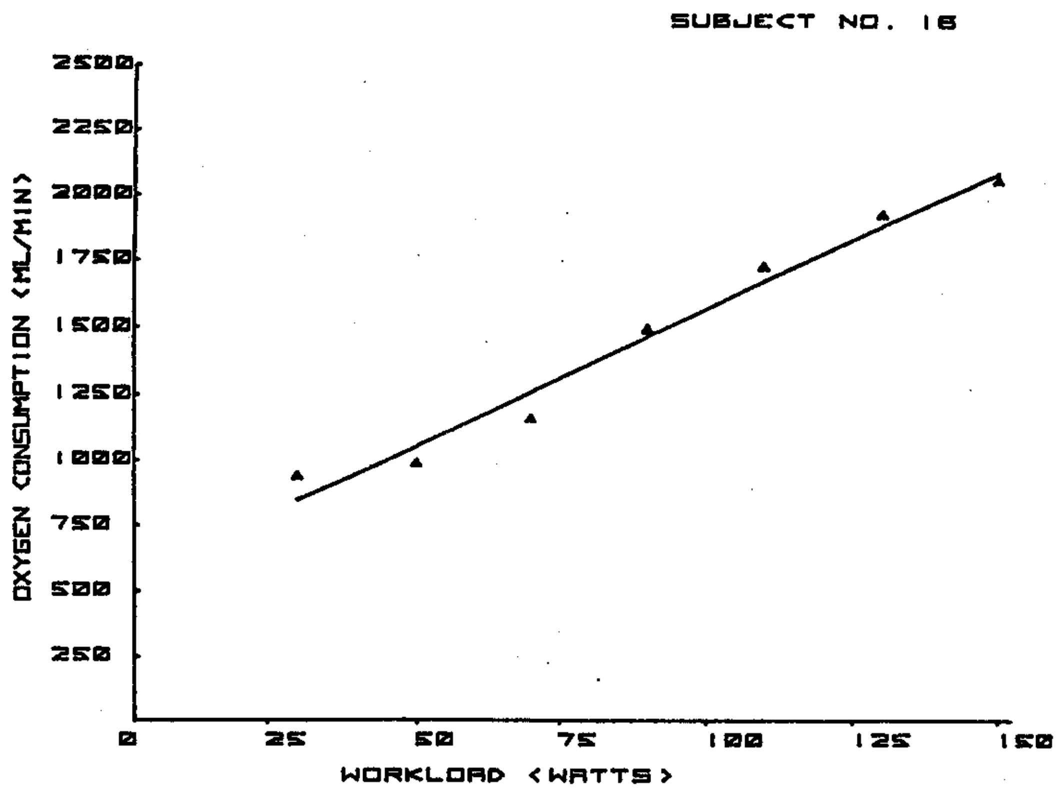

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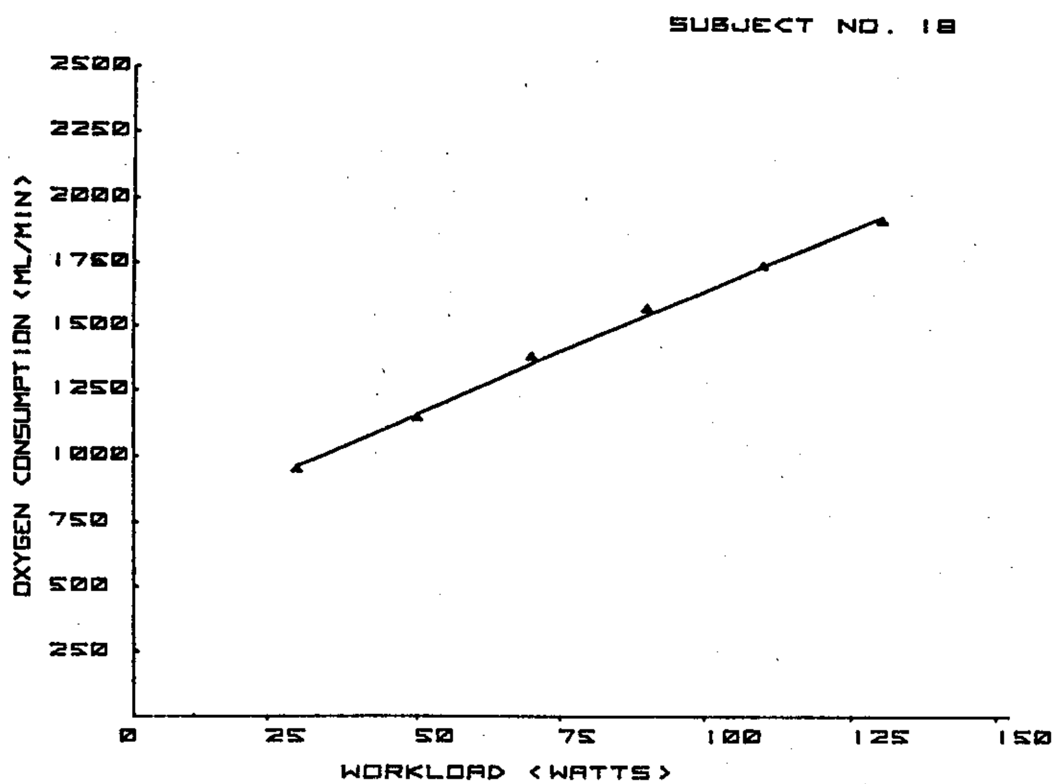
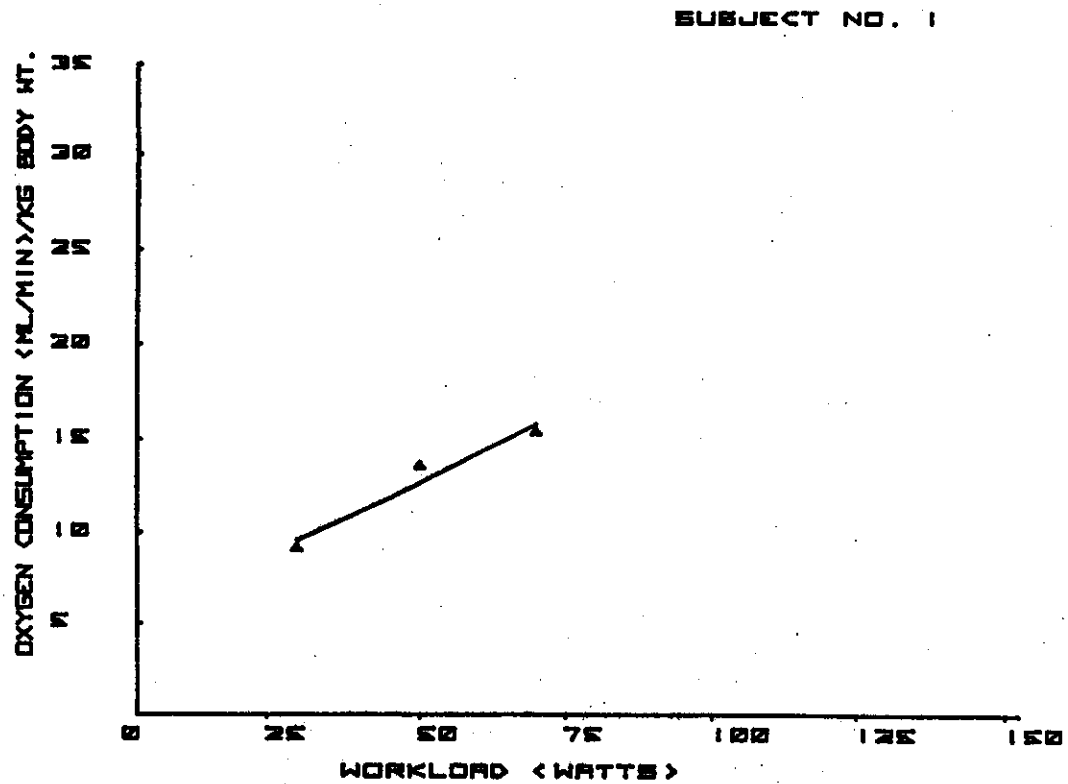


Figure 33

APPENDIX C

Individual Subject Graphs for
Oxygen Consumption (mL/min) per kg Body Wt.
vs. Workload (Watts)



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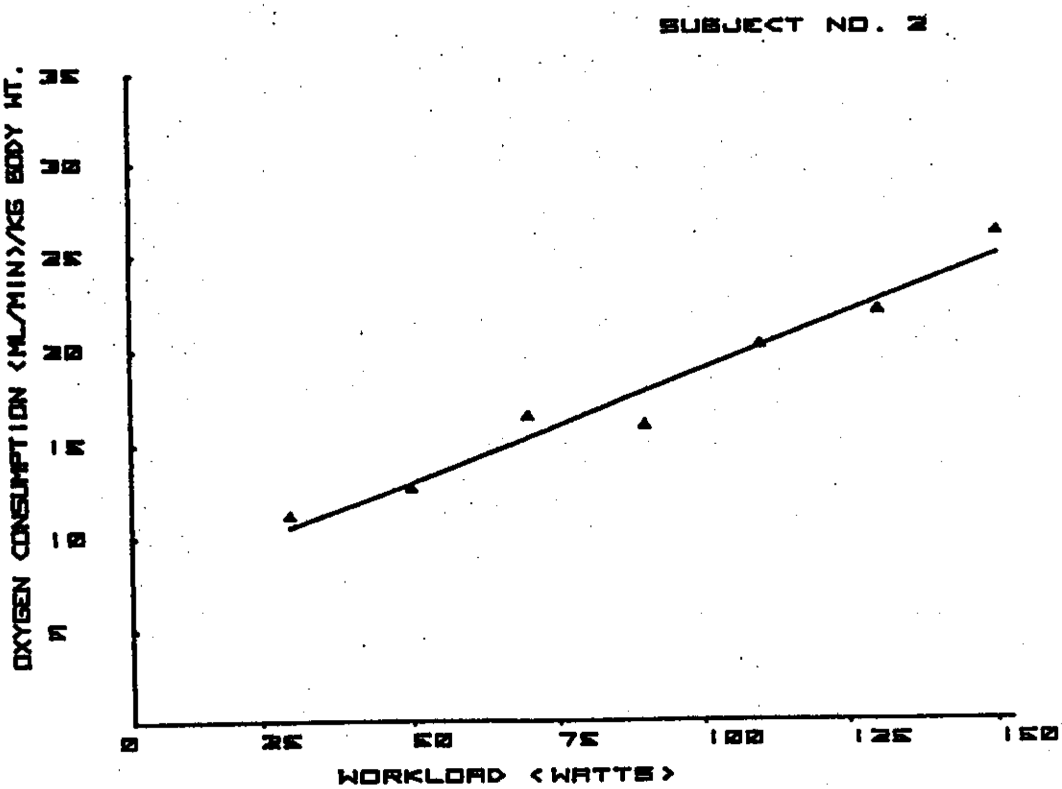

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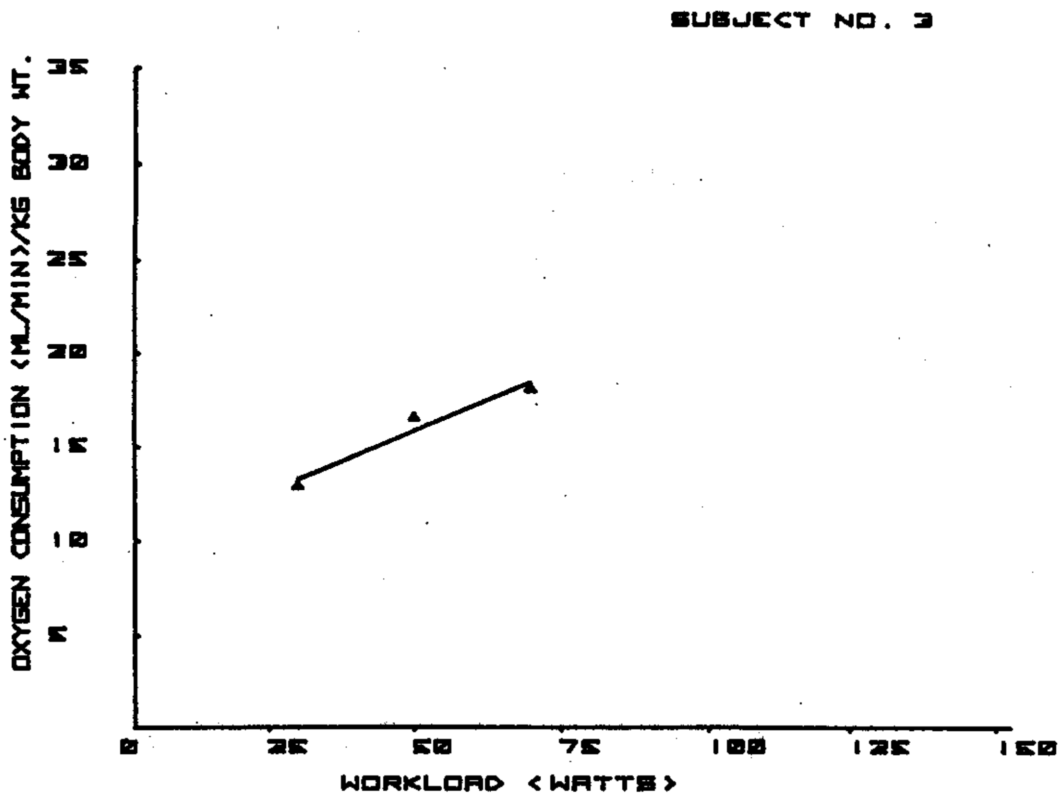

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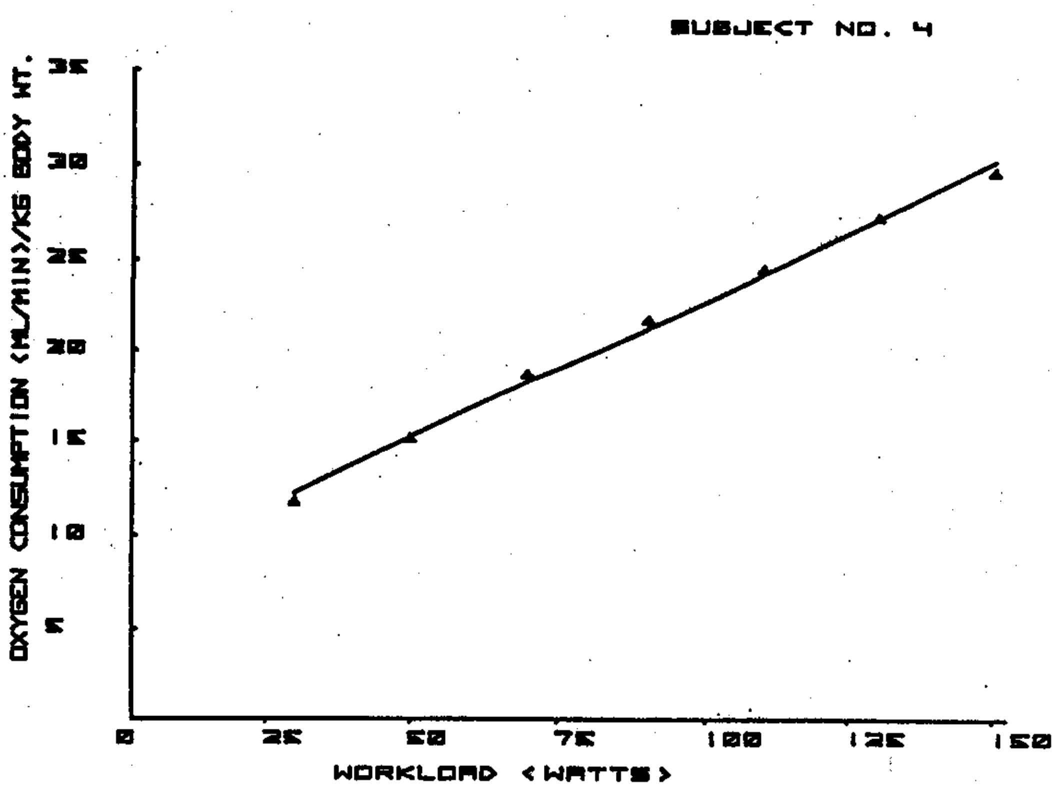

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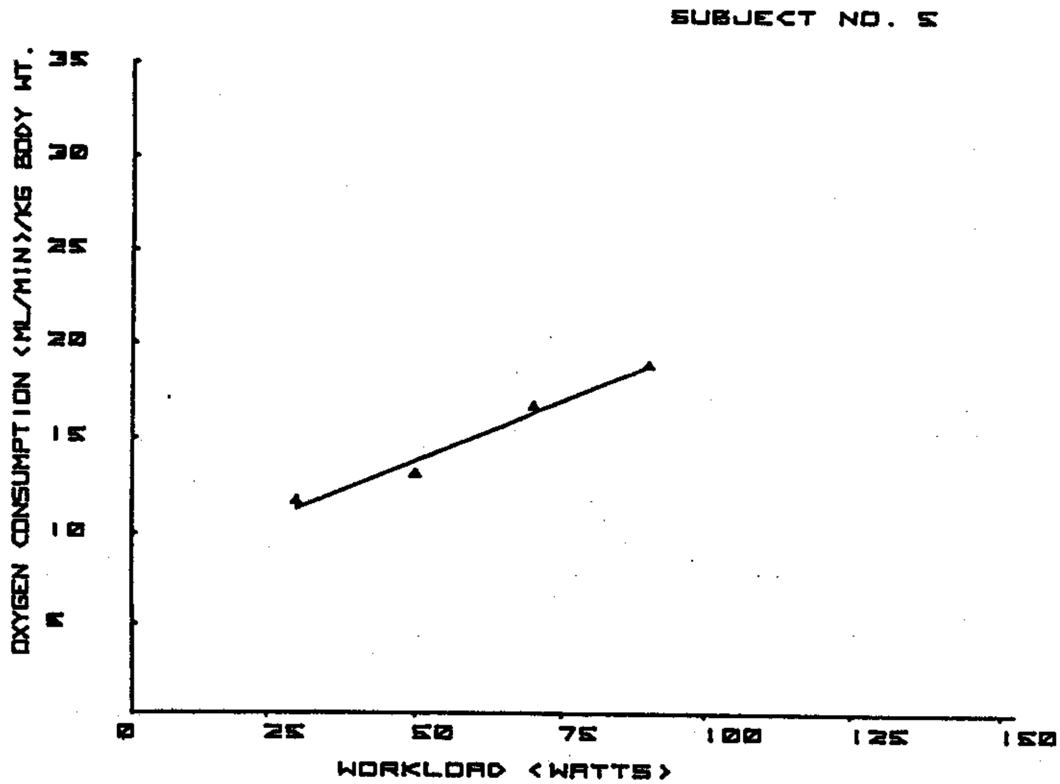

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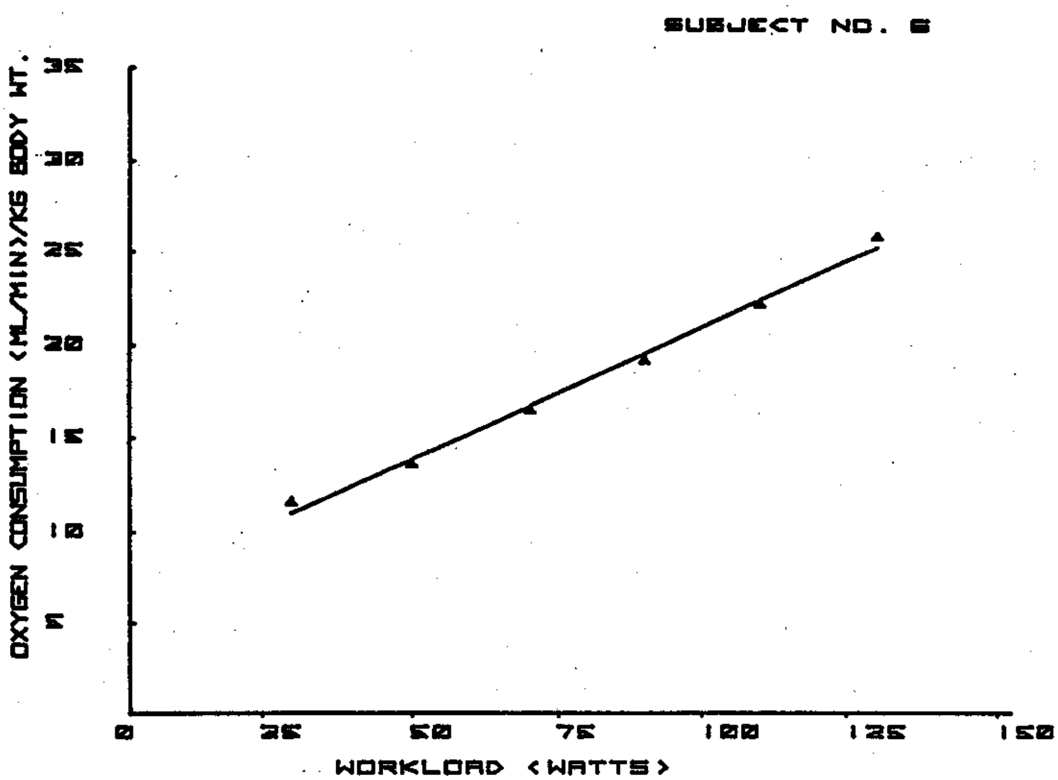

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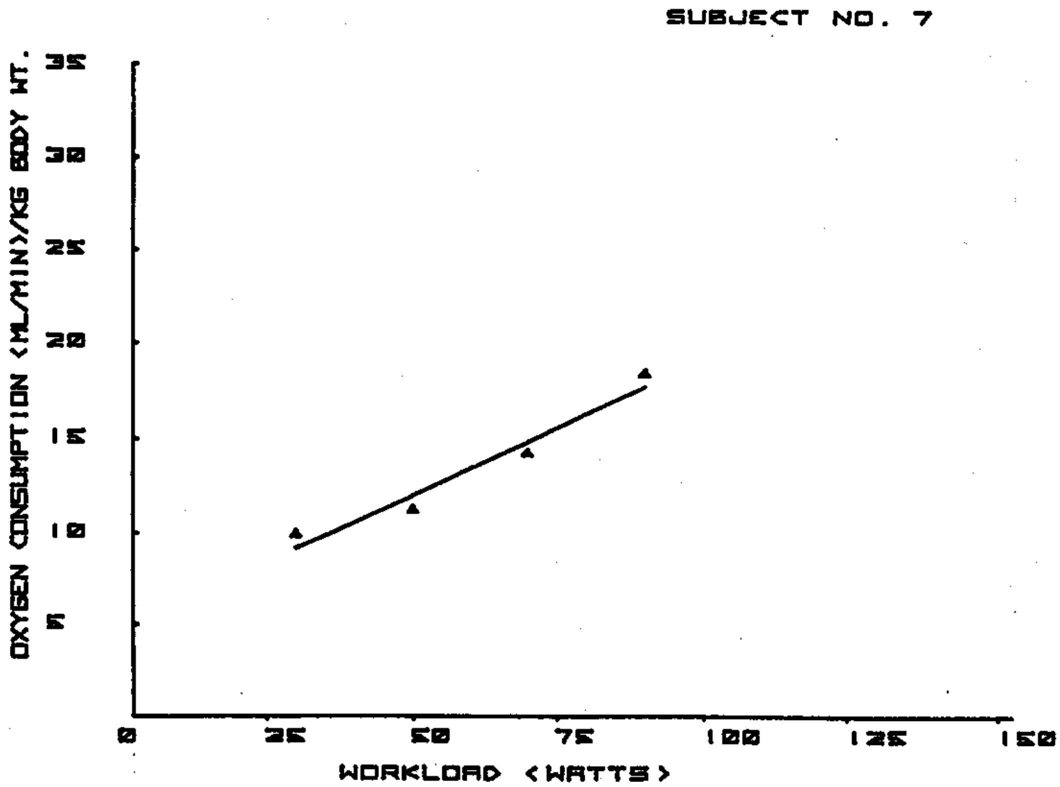

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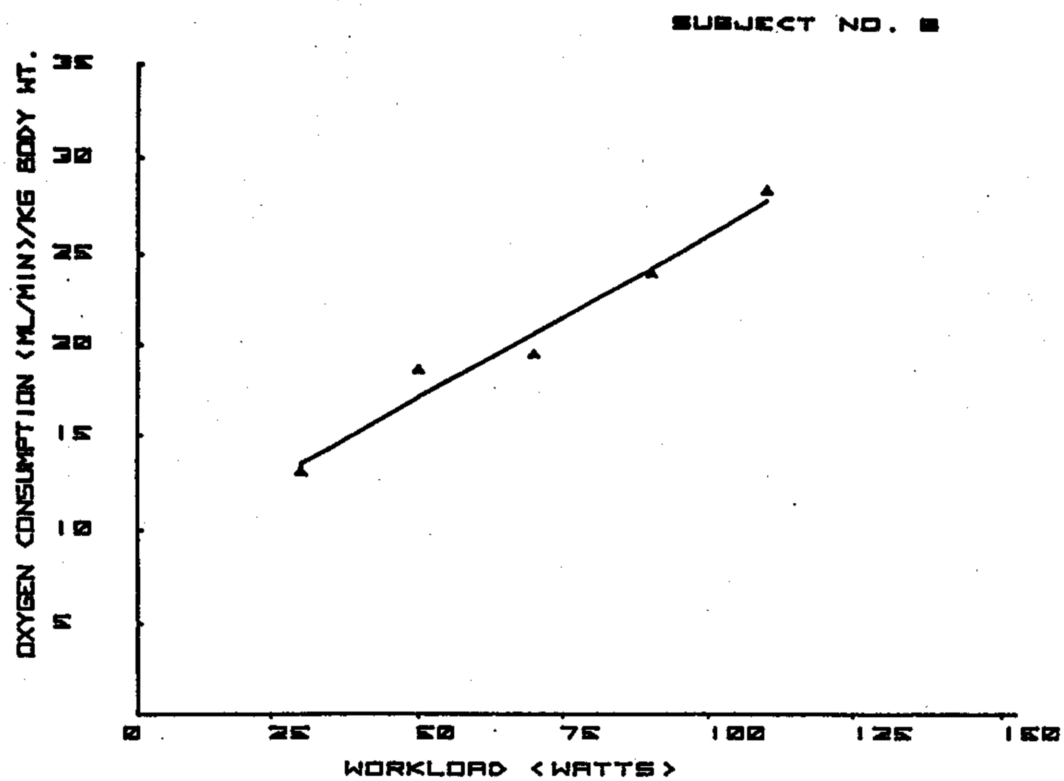

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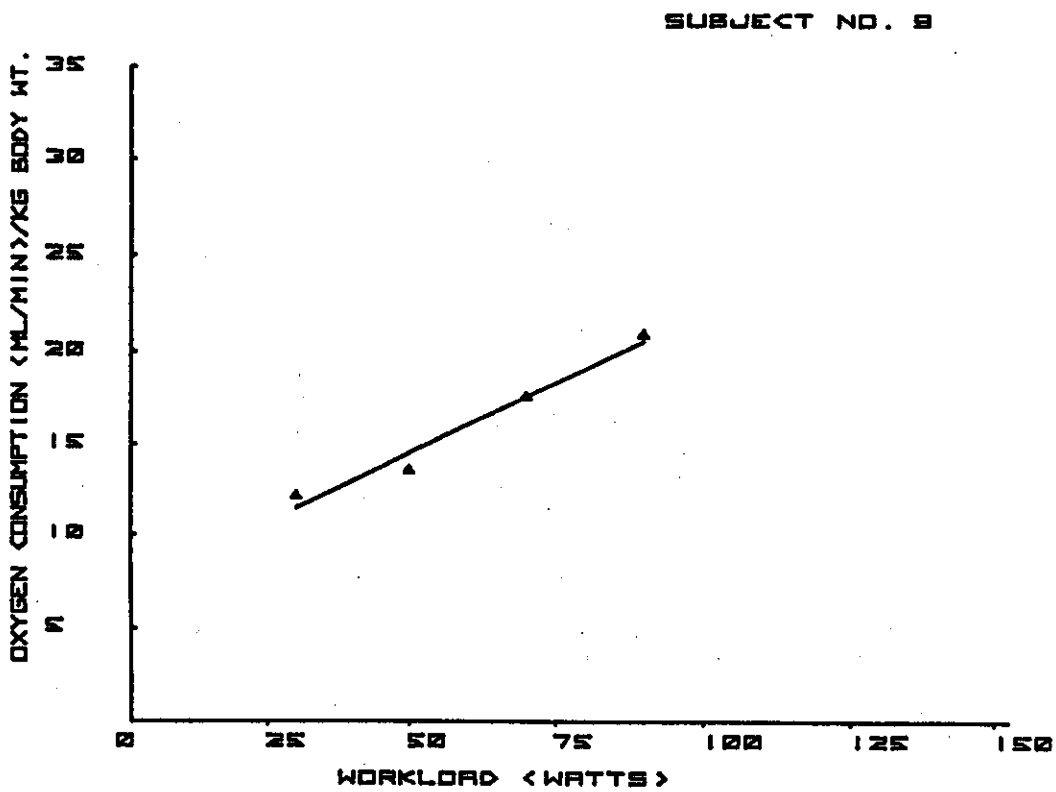

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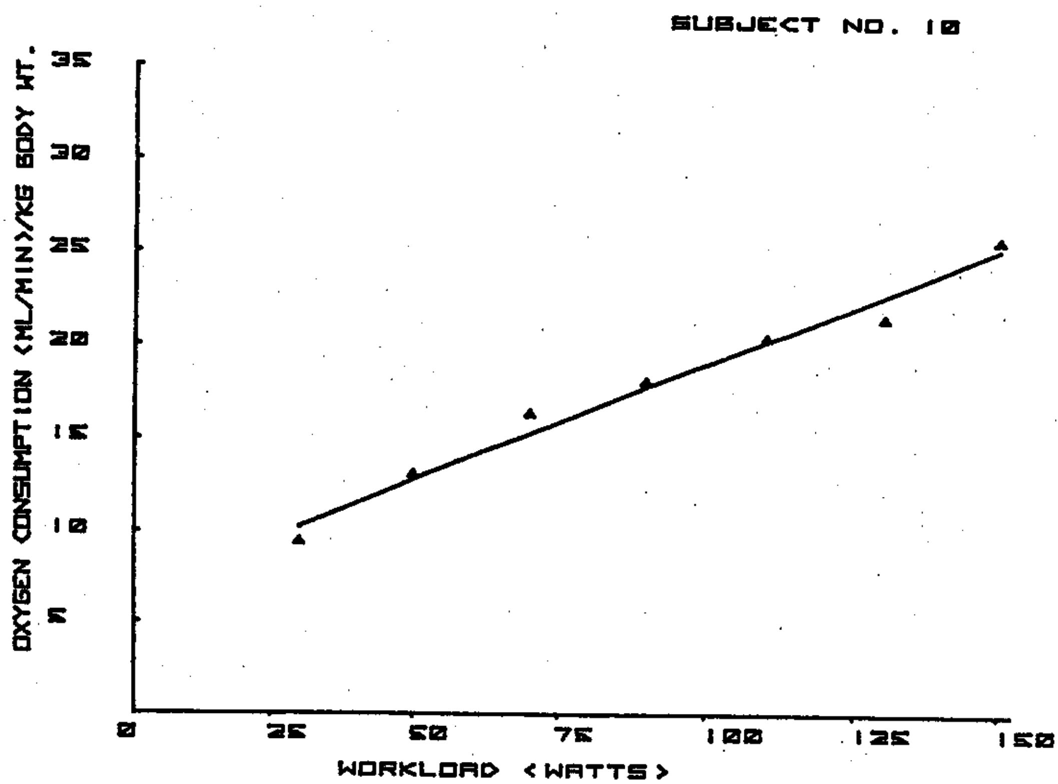

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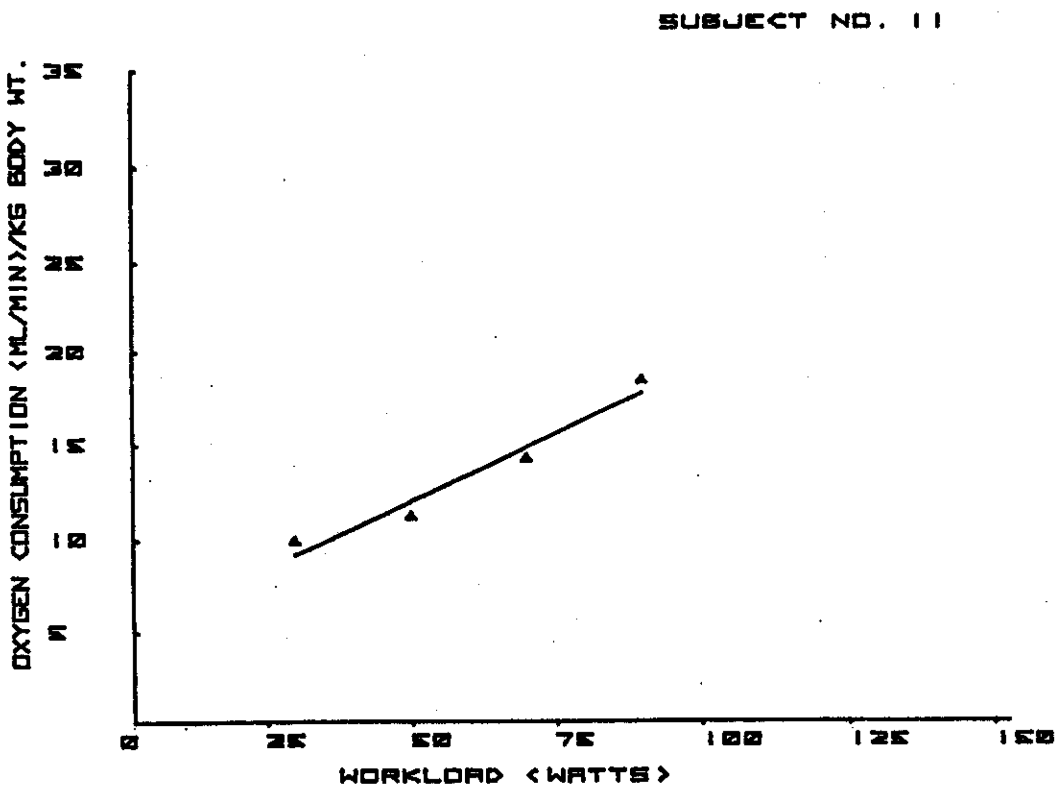

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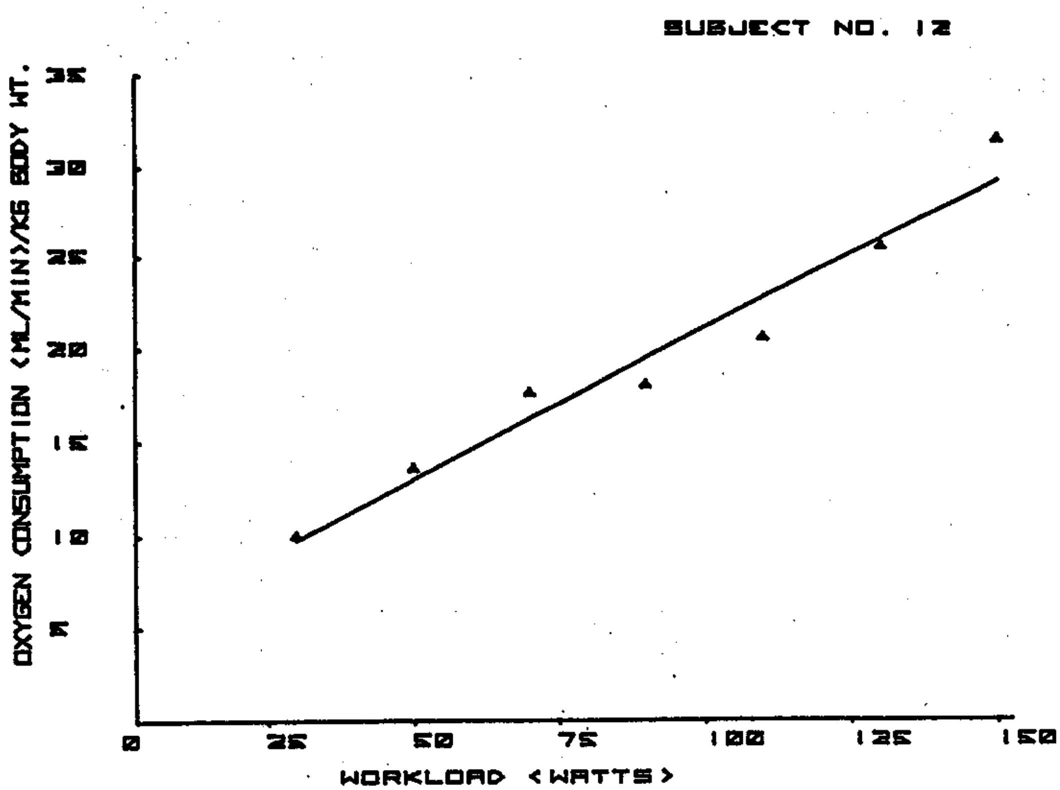

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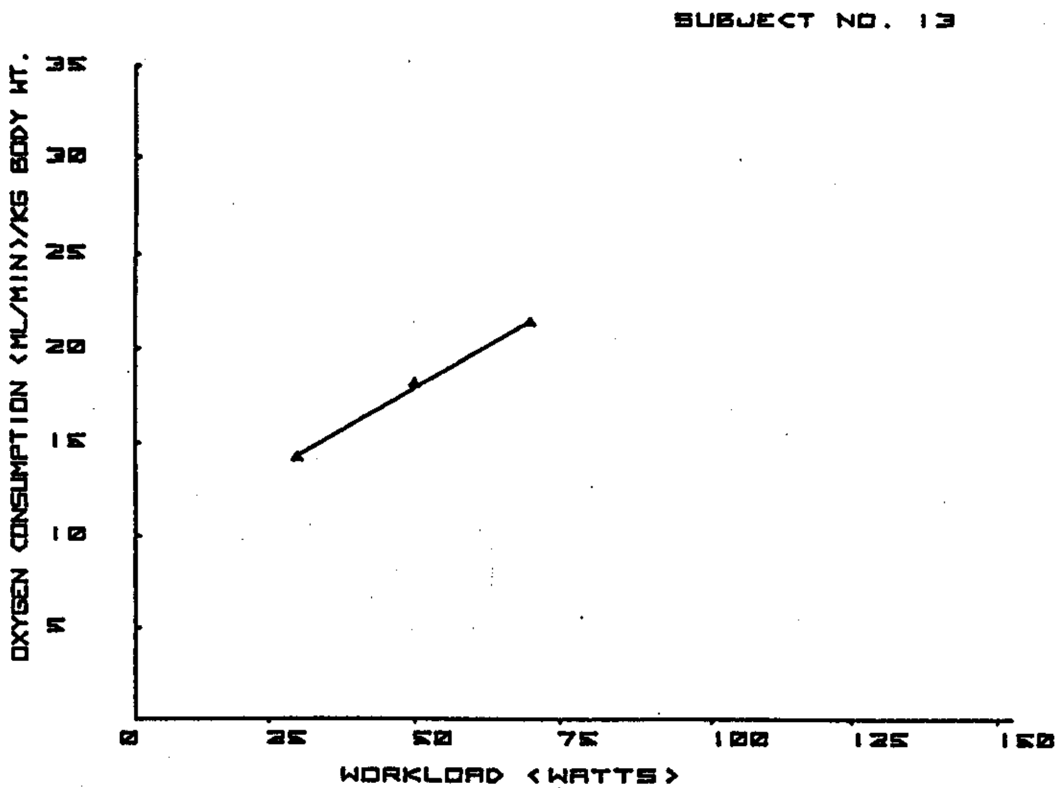

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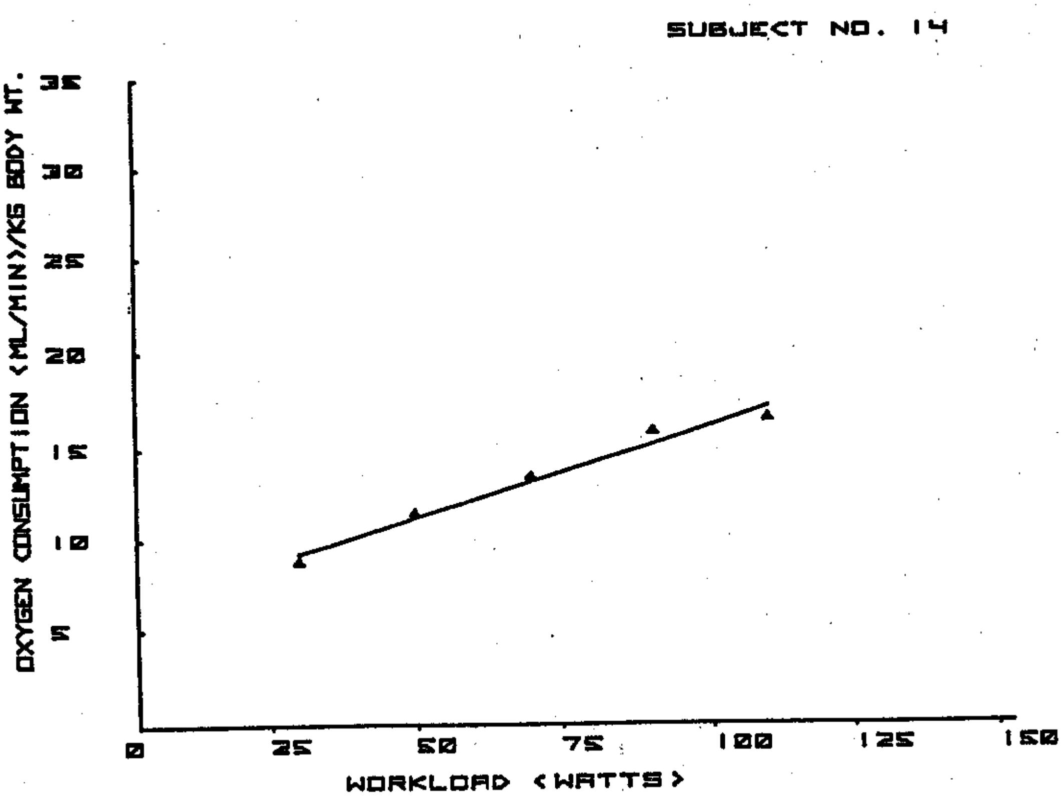

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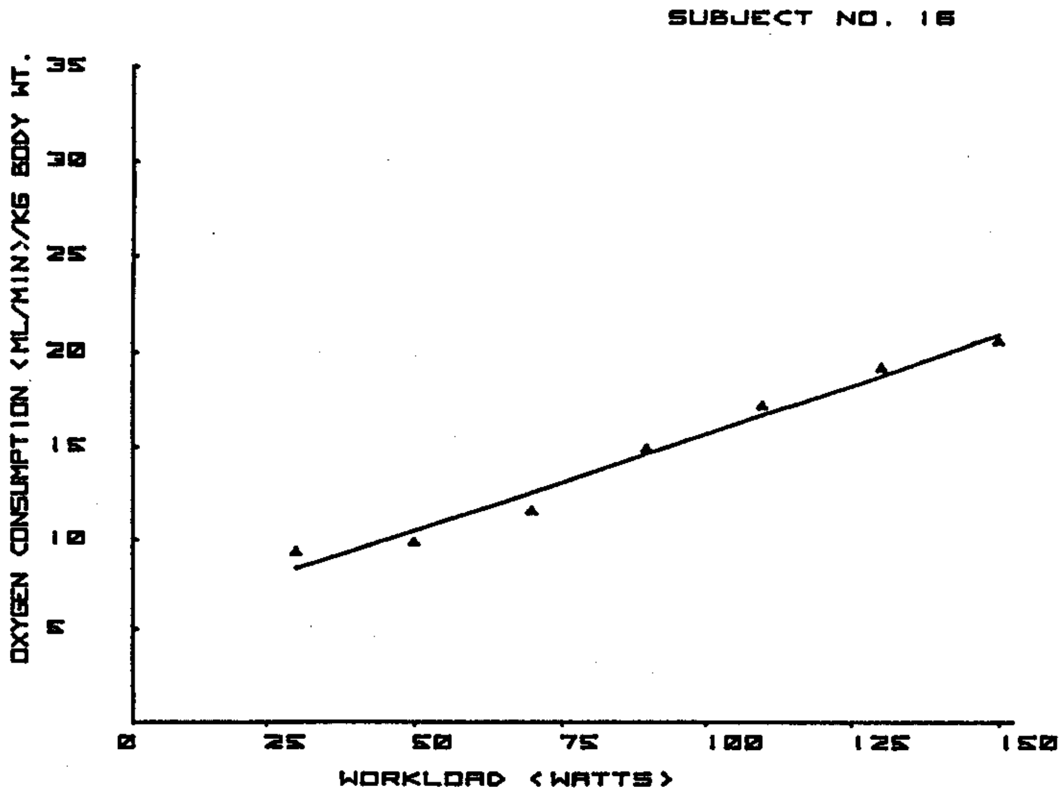

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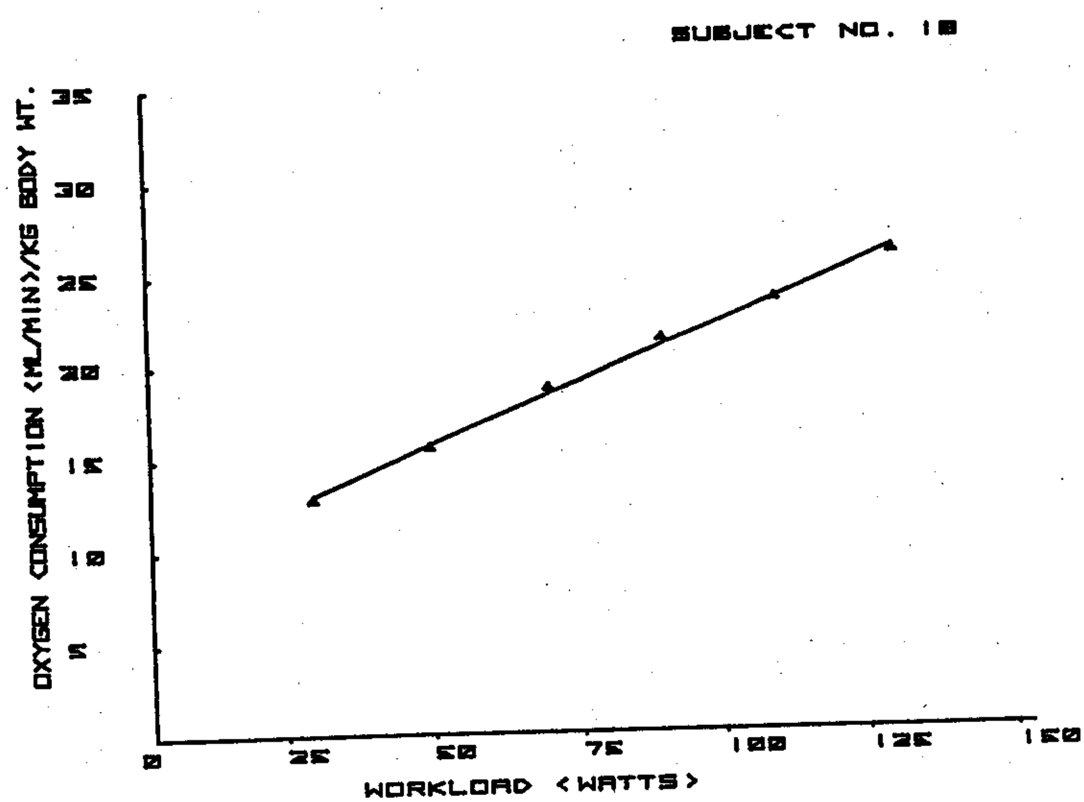
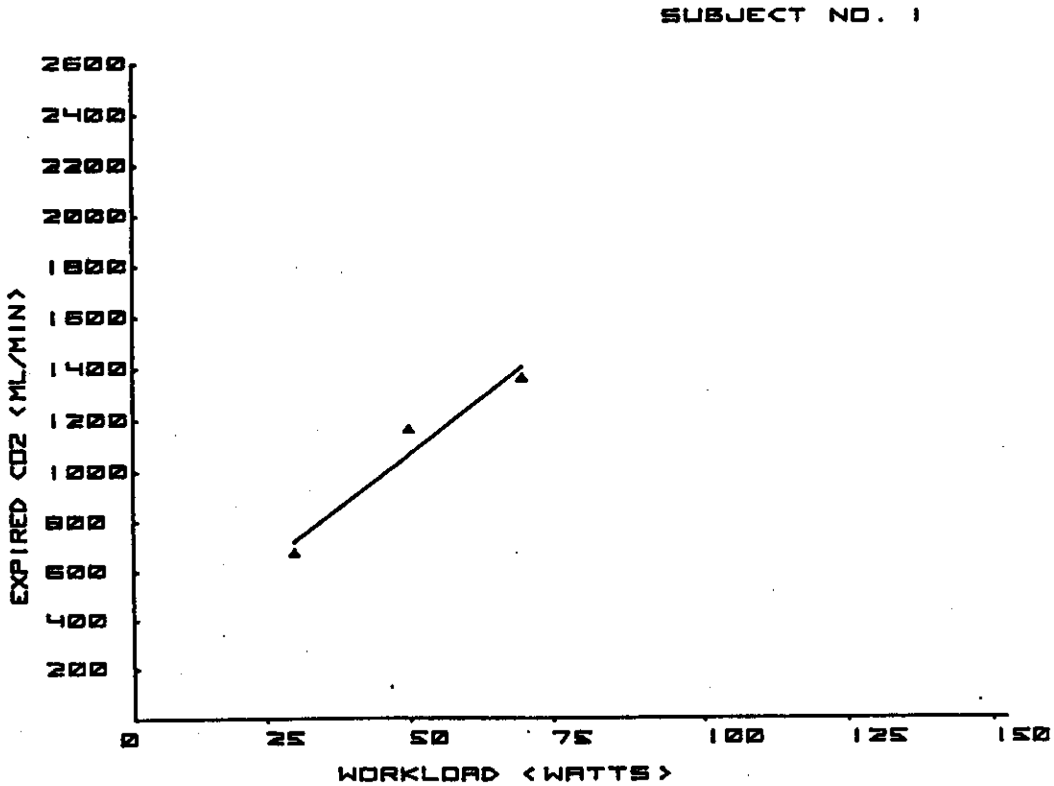


Figure 49

APPENDIX D

Individual Subject Graphs for Expired CO_2 (mL/min) vs. Workload (Watts)



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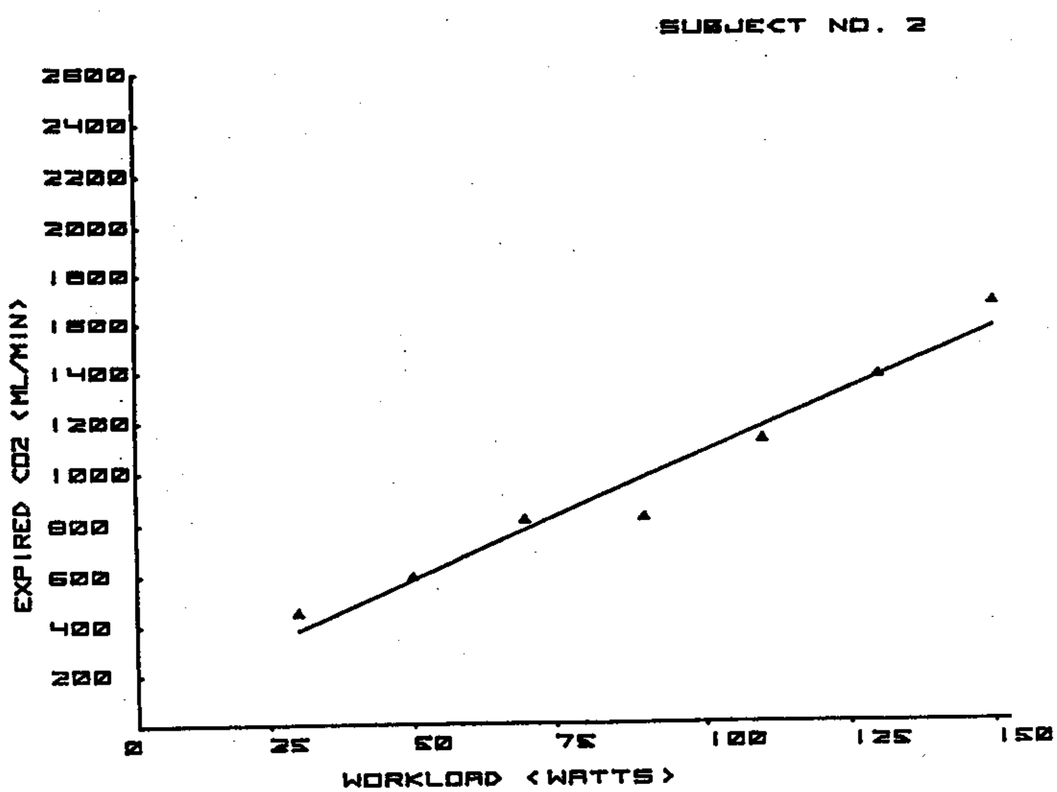

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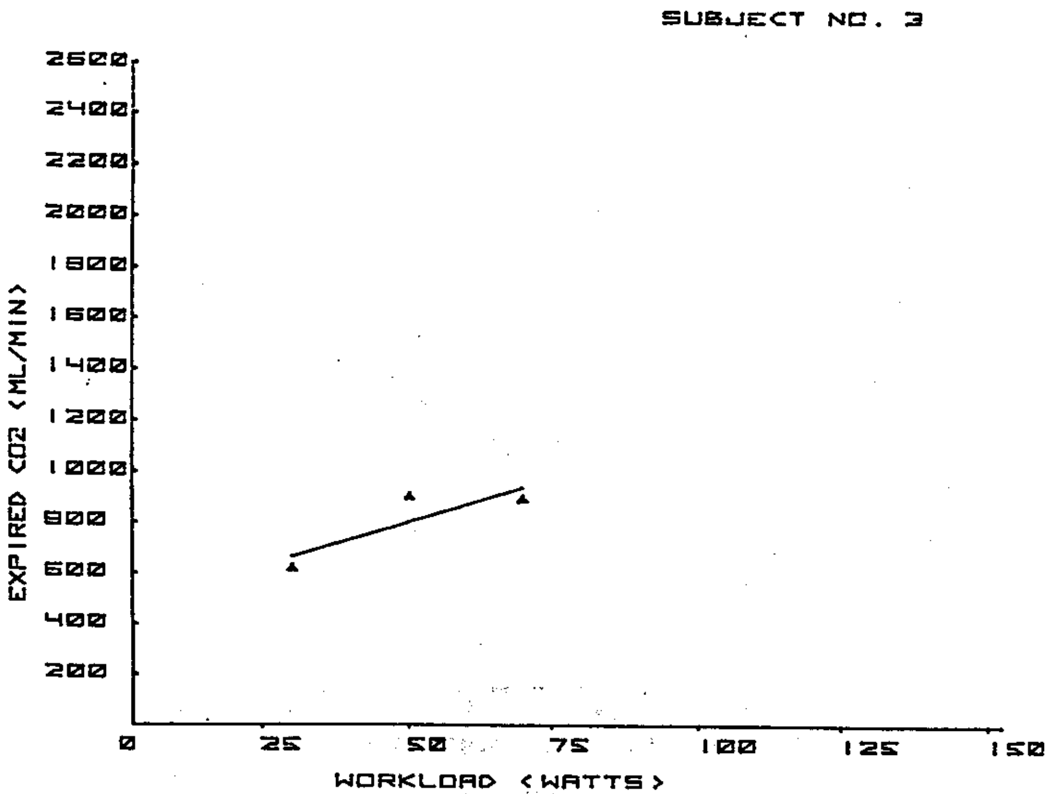

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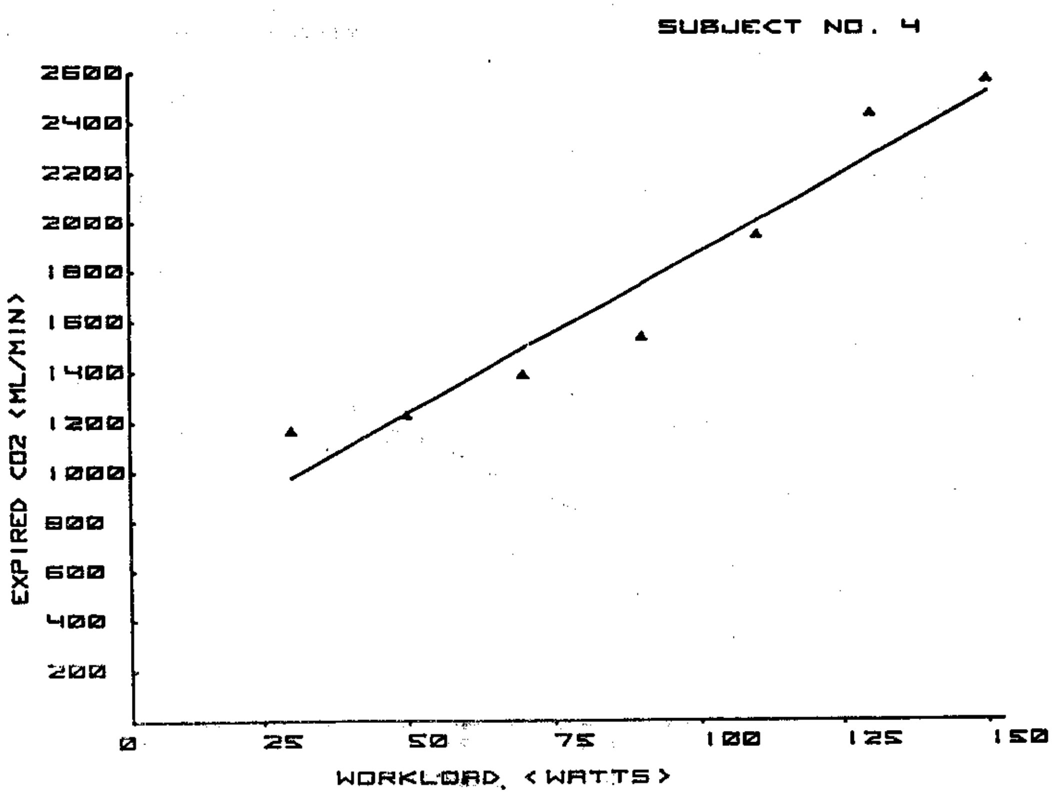

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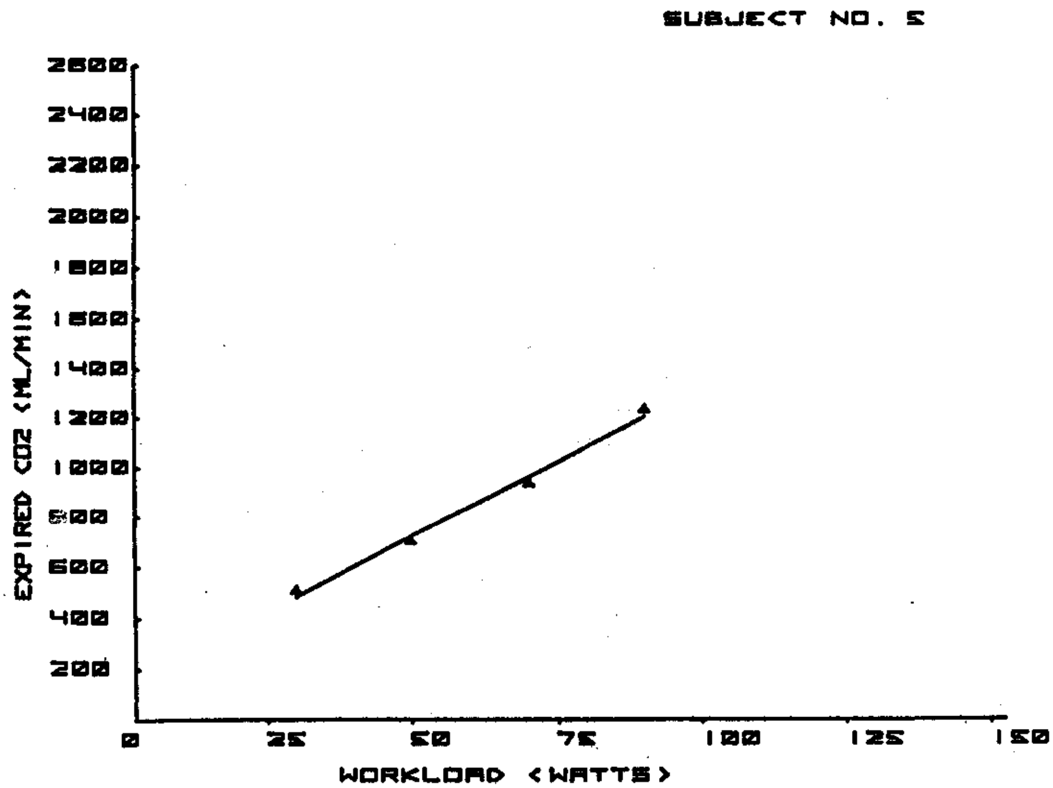

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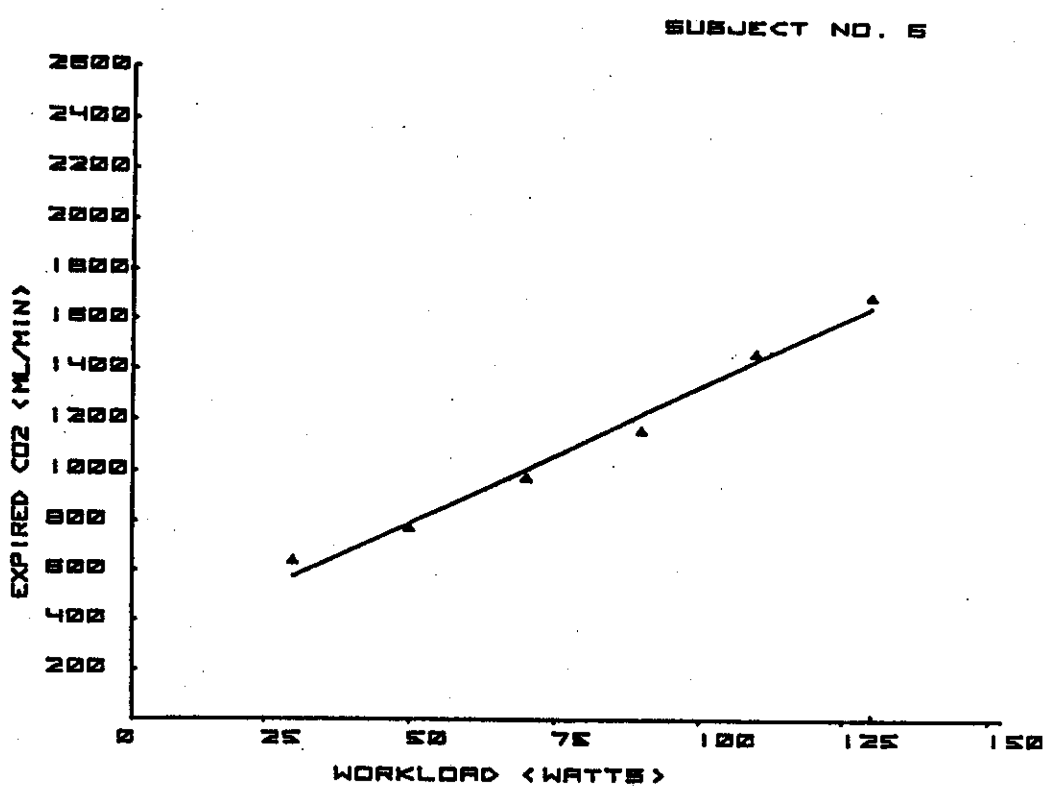

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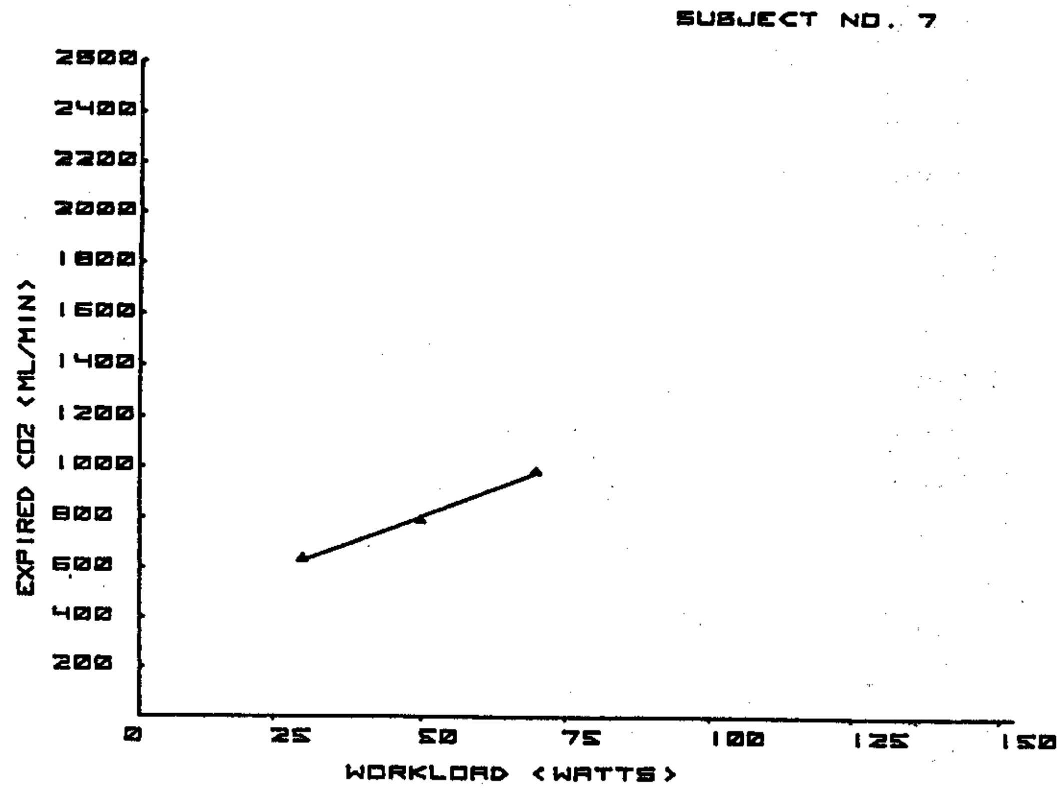

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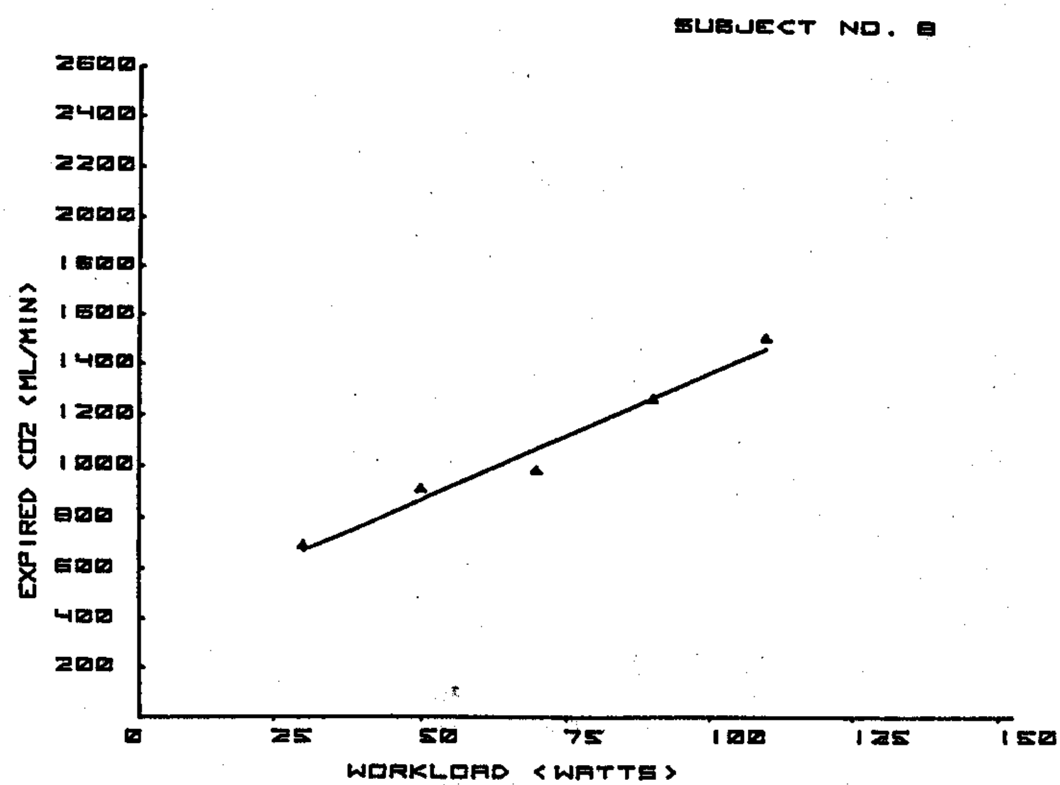

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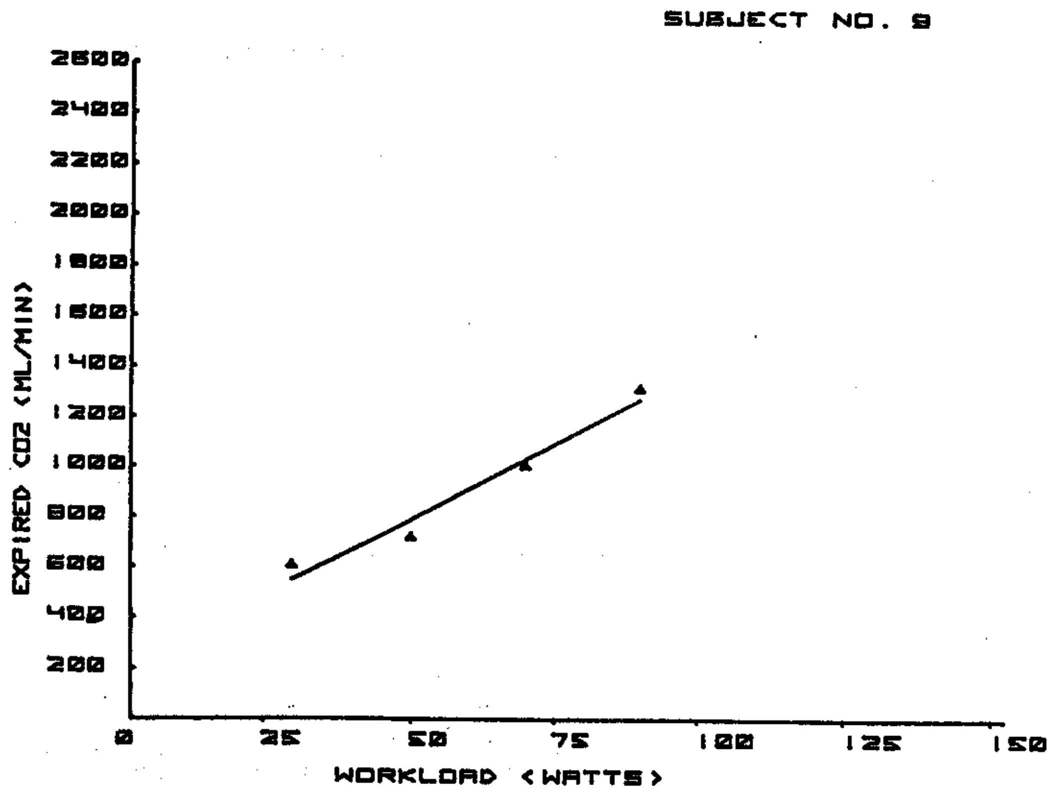


Figure 58

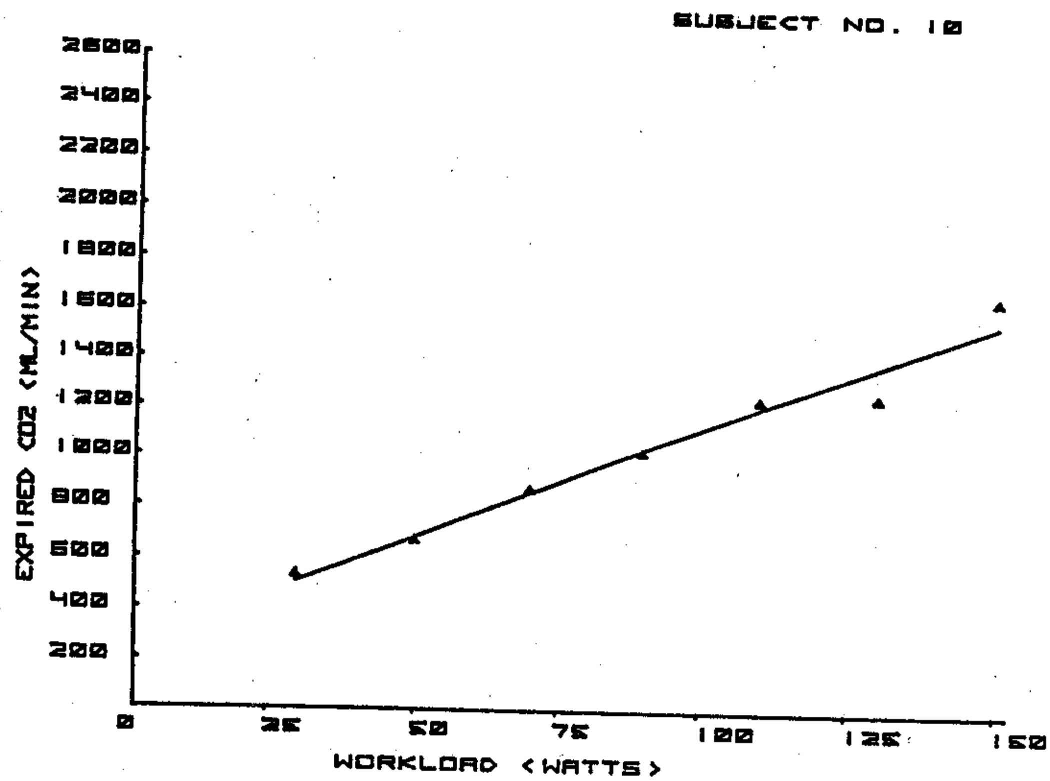
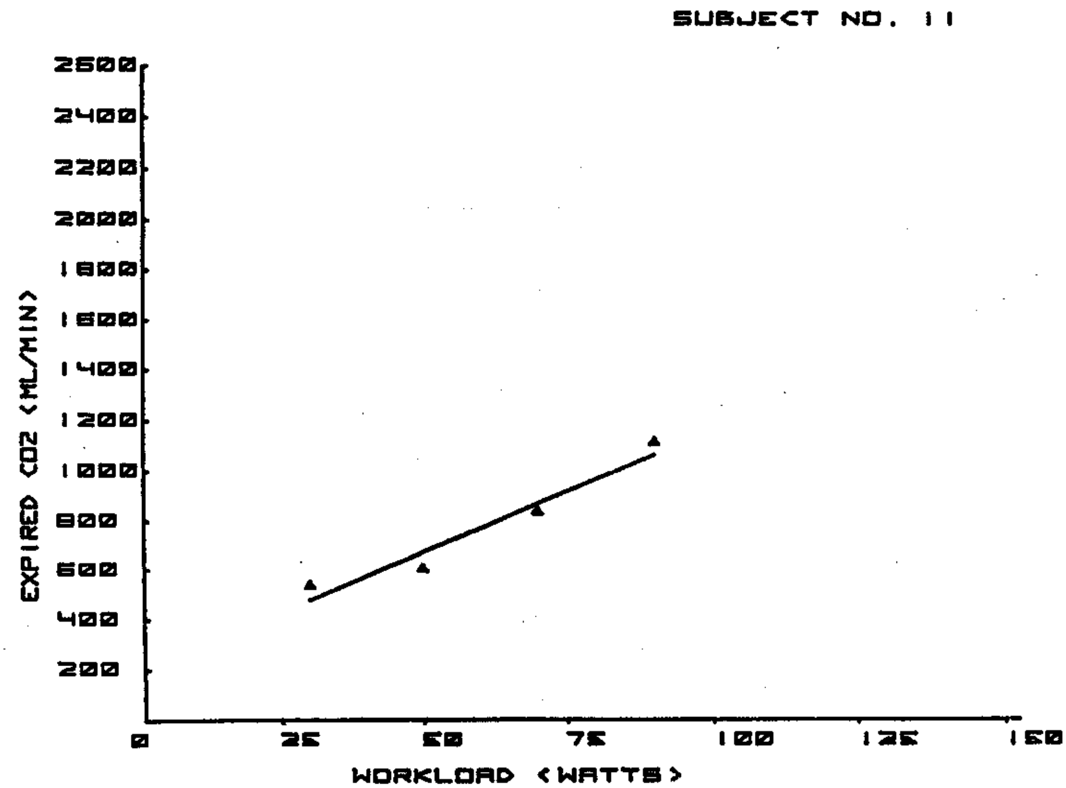


Figure 59



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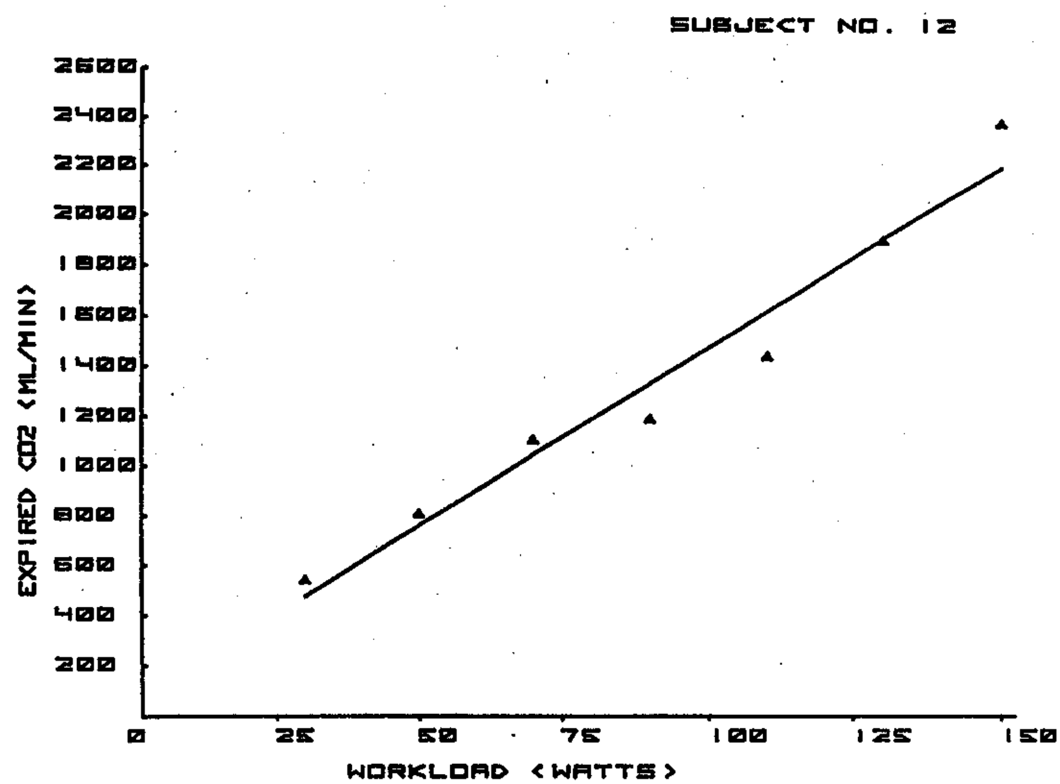

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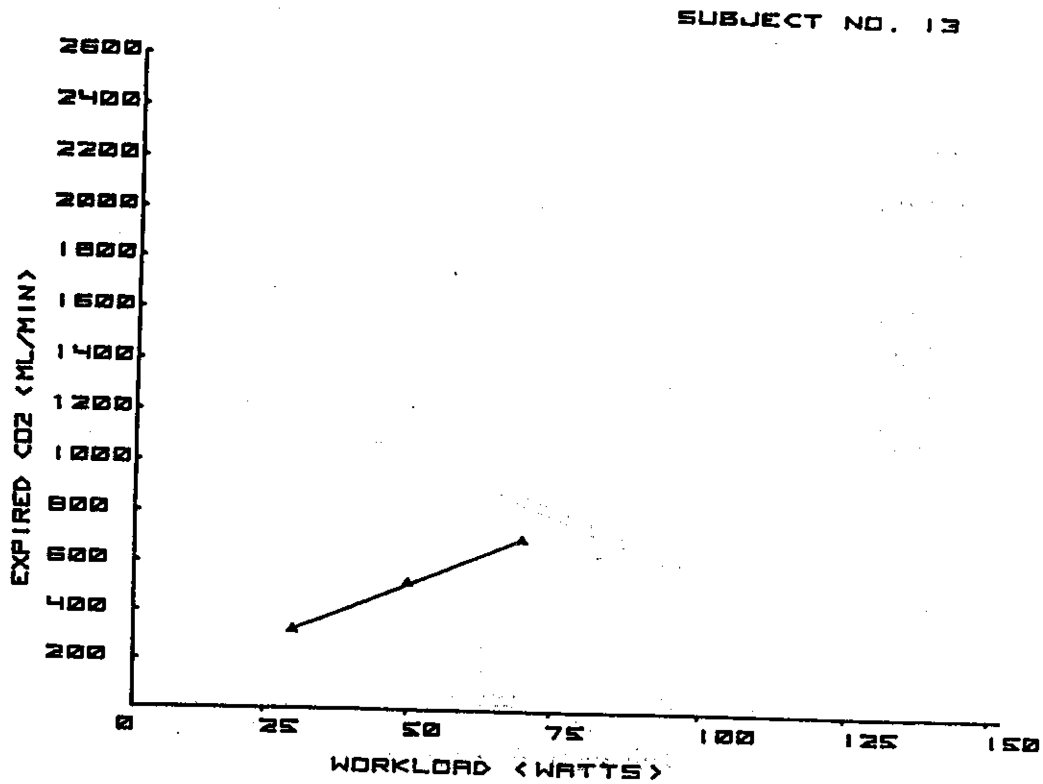
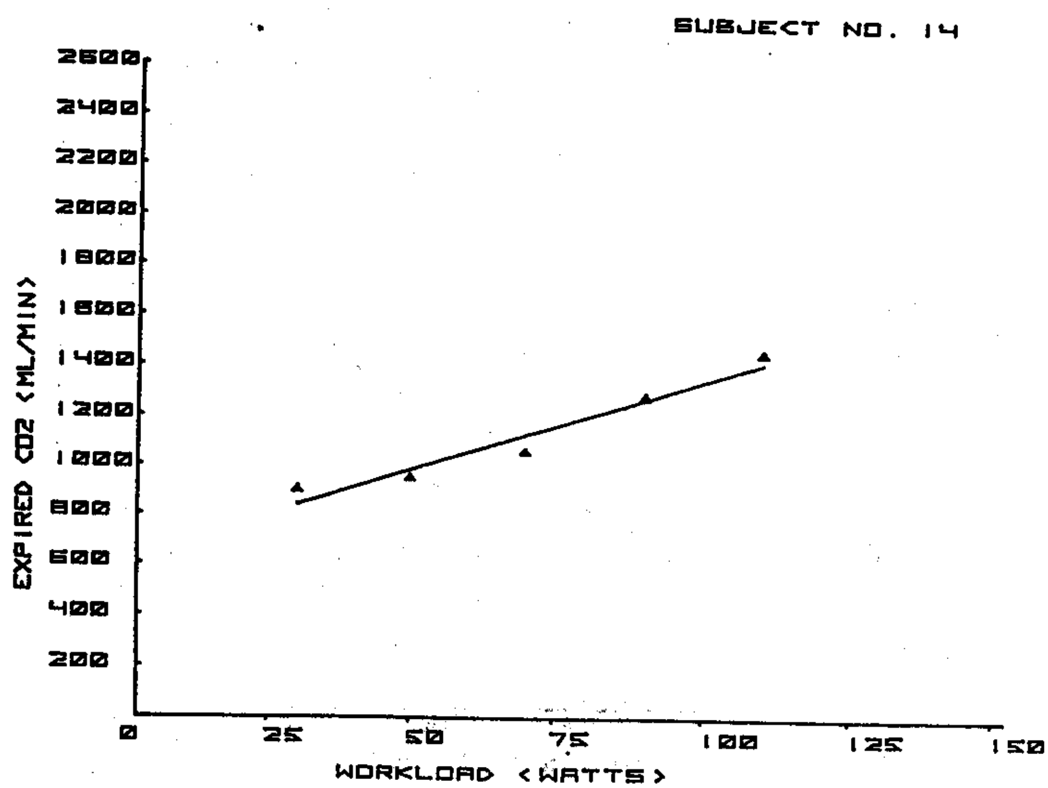


Figure 62



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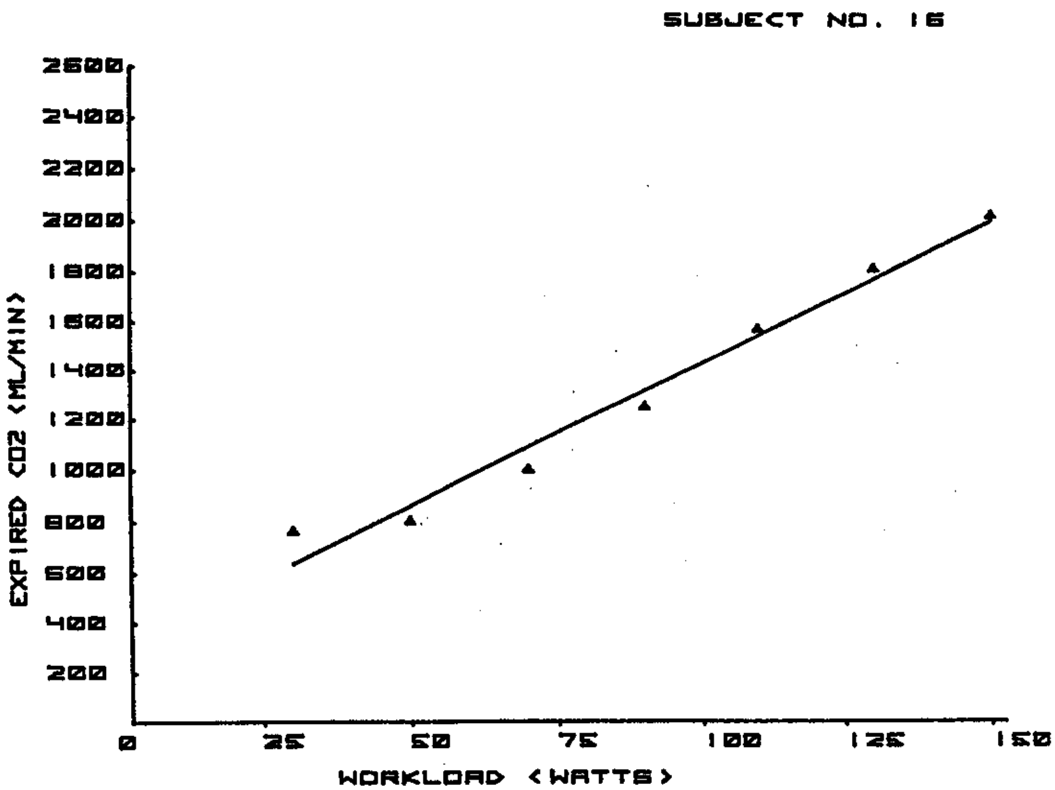


Figure 64

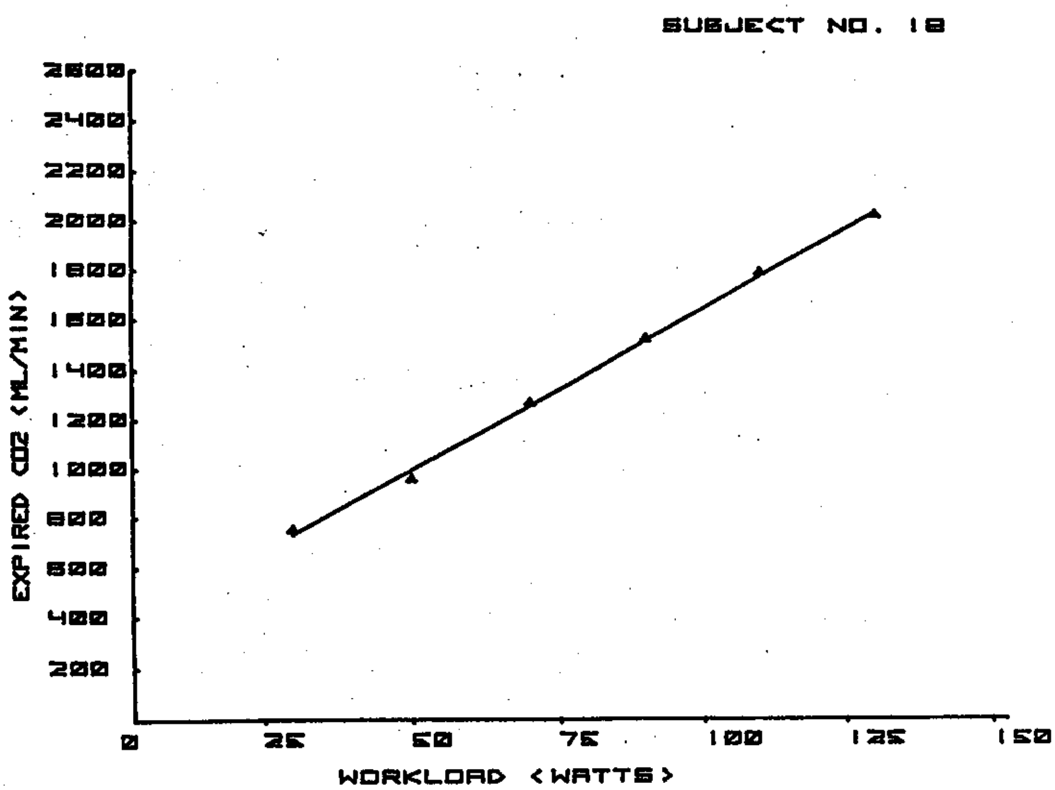


Figure 65

APPENDIX E

Individual Subject Graphs for
Expired CO_2 (mL/min) per kg Body Wt. vs. Workload (Watts)

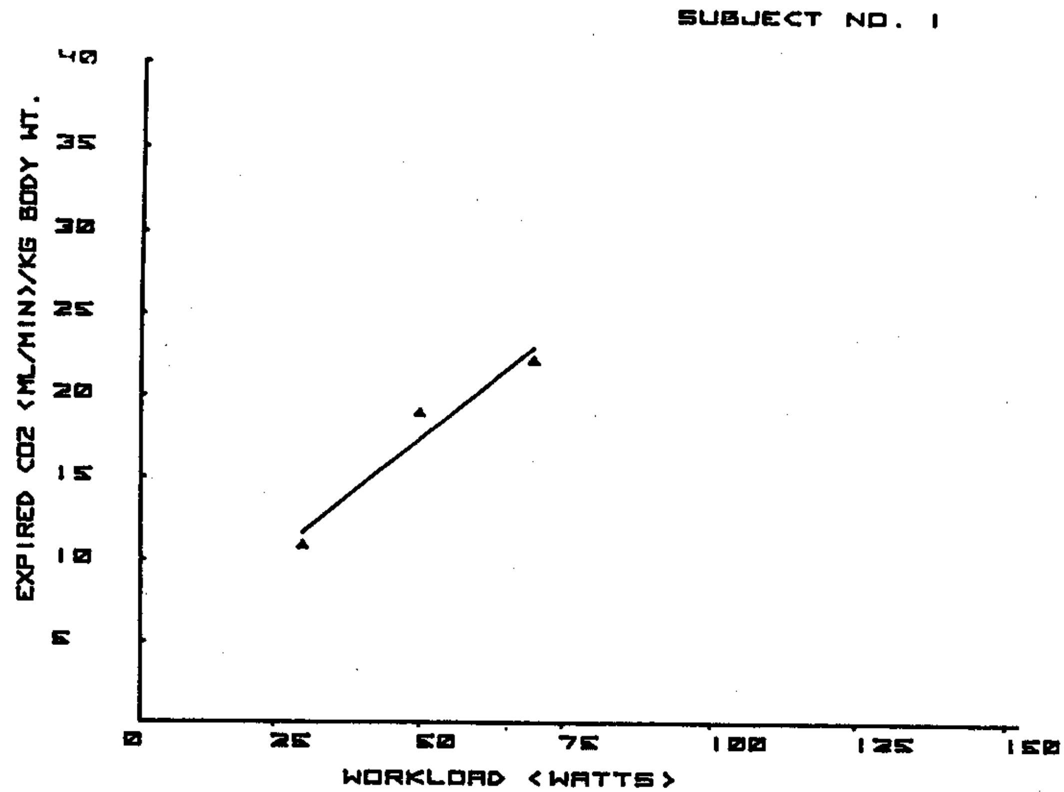


Figure 66

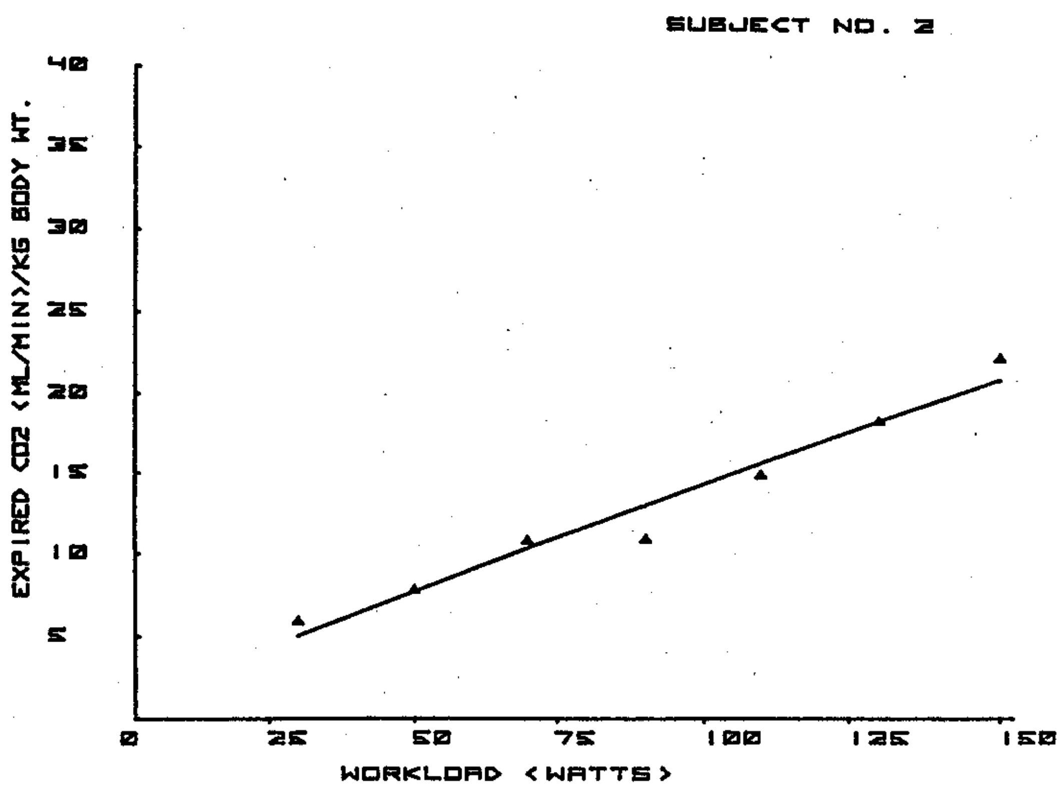
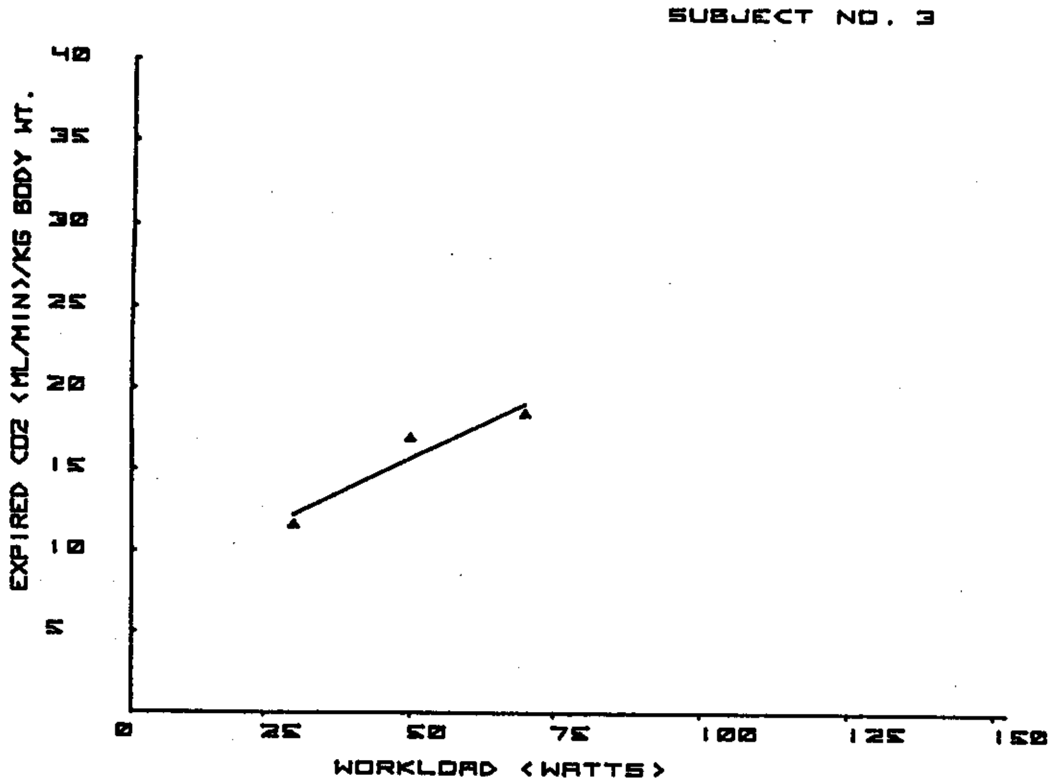


Figure 67



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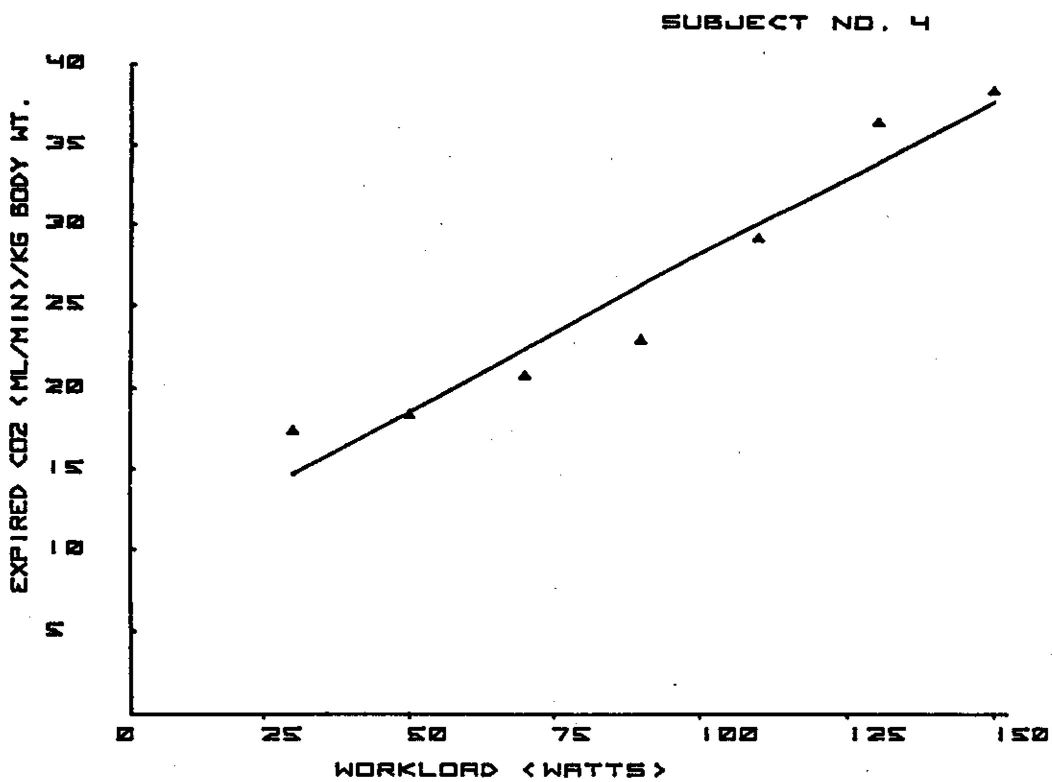


Figure 69

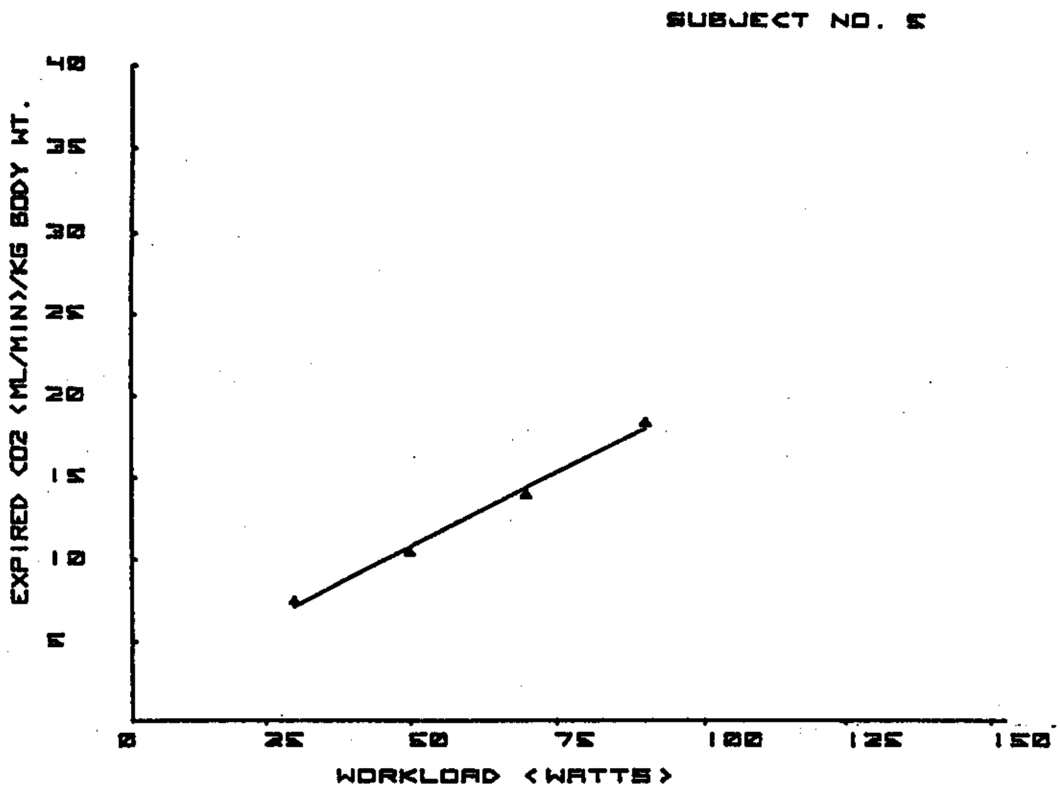
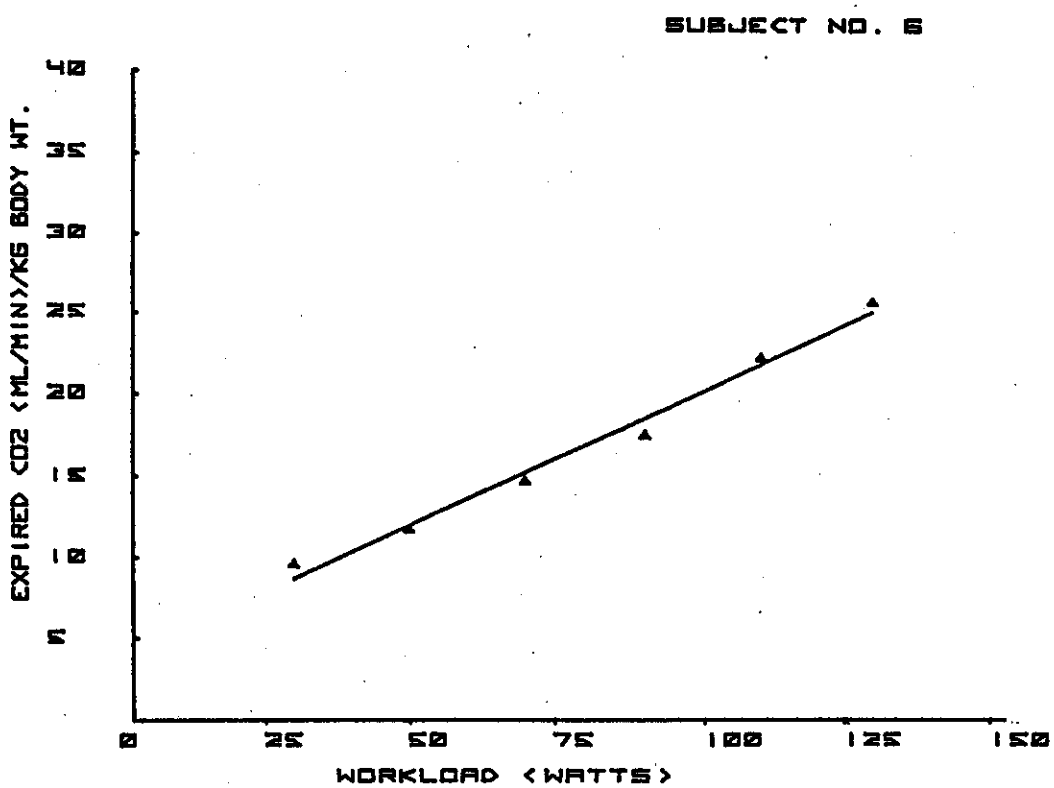


Figure 70



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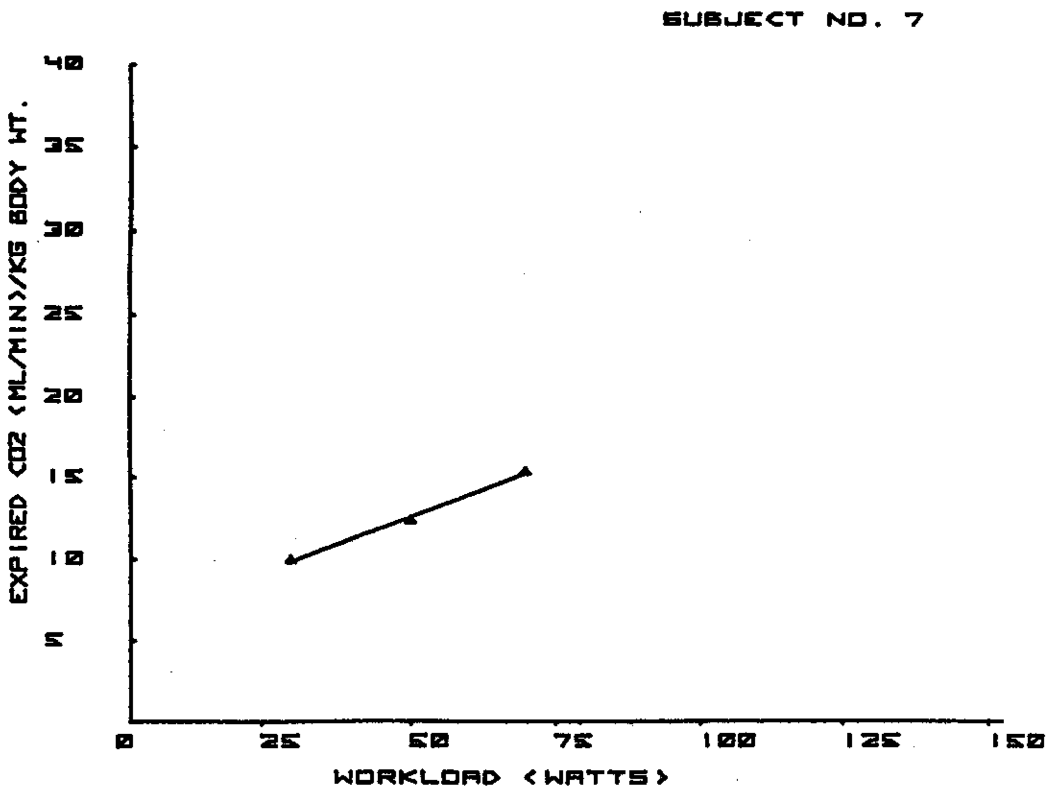

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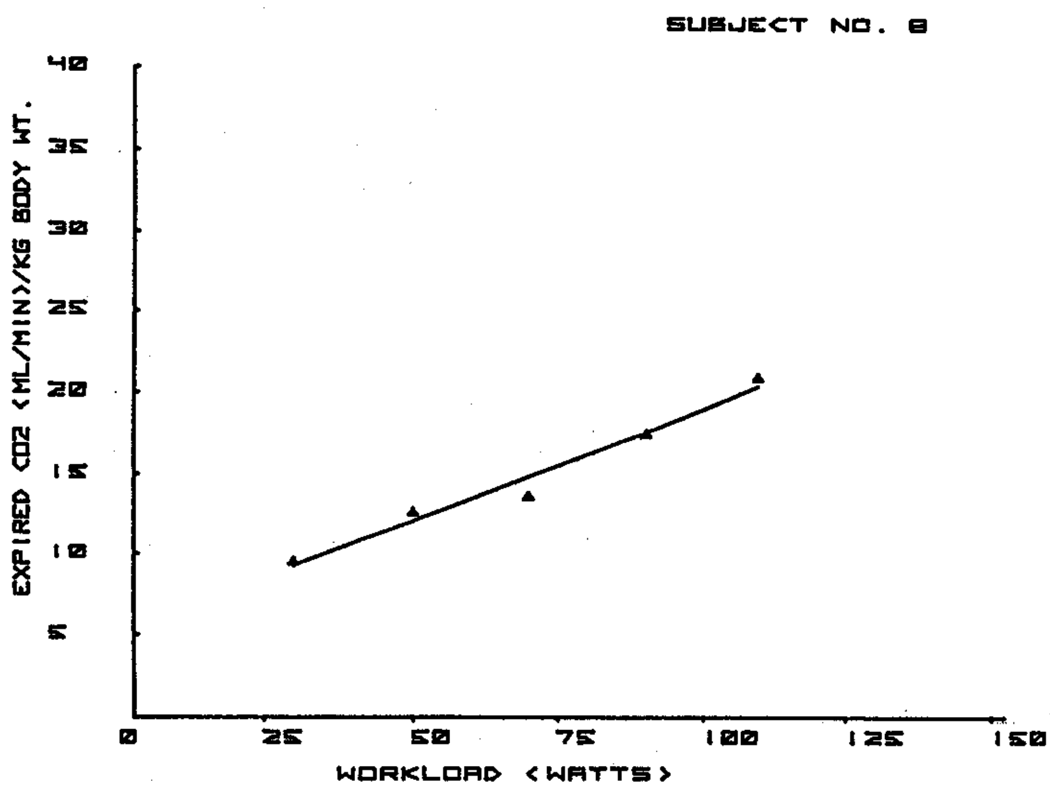

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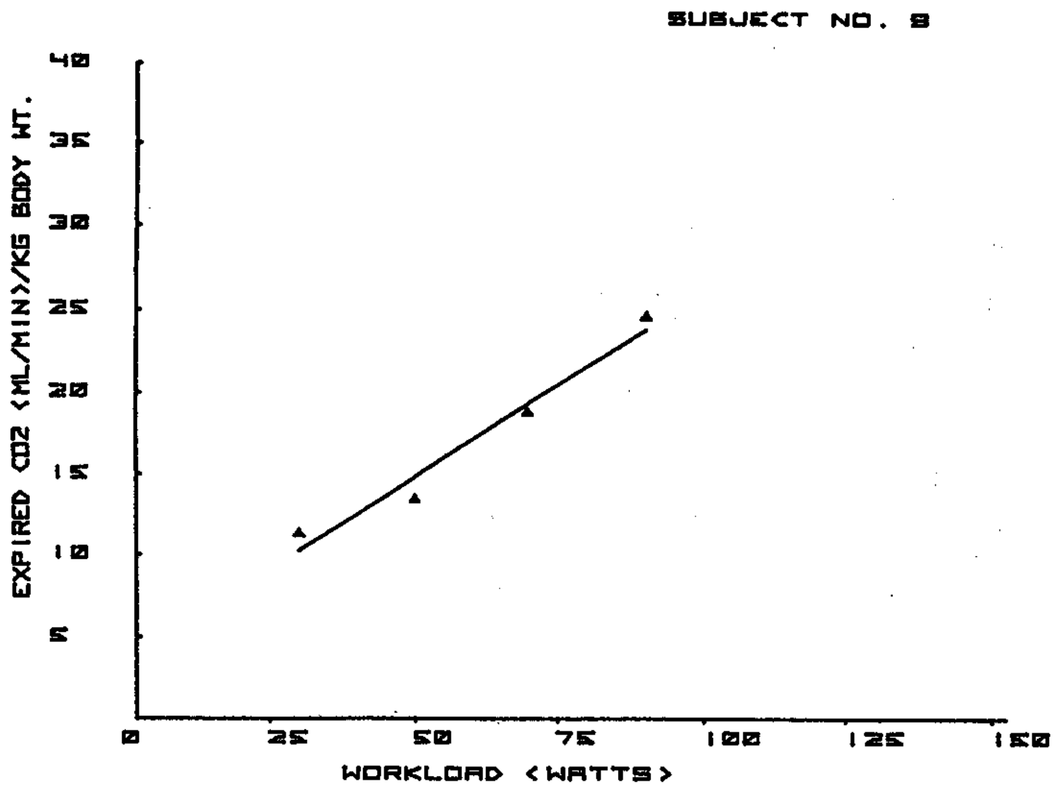
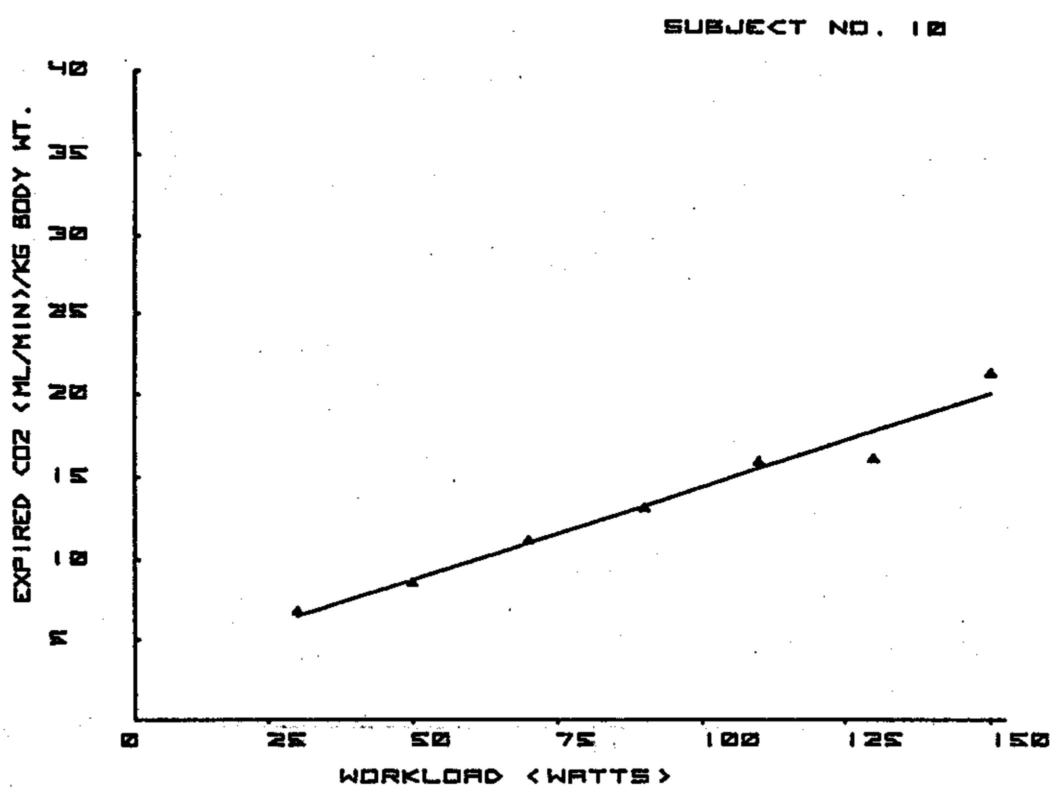


Figure 74



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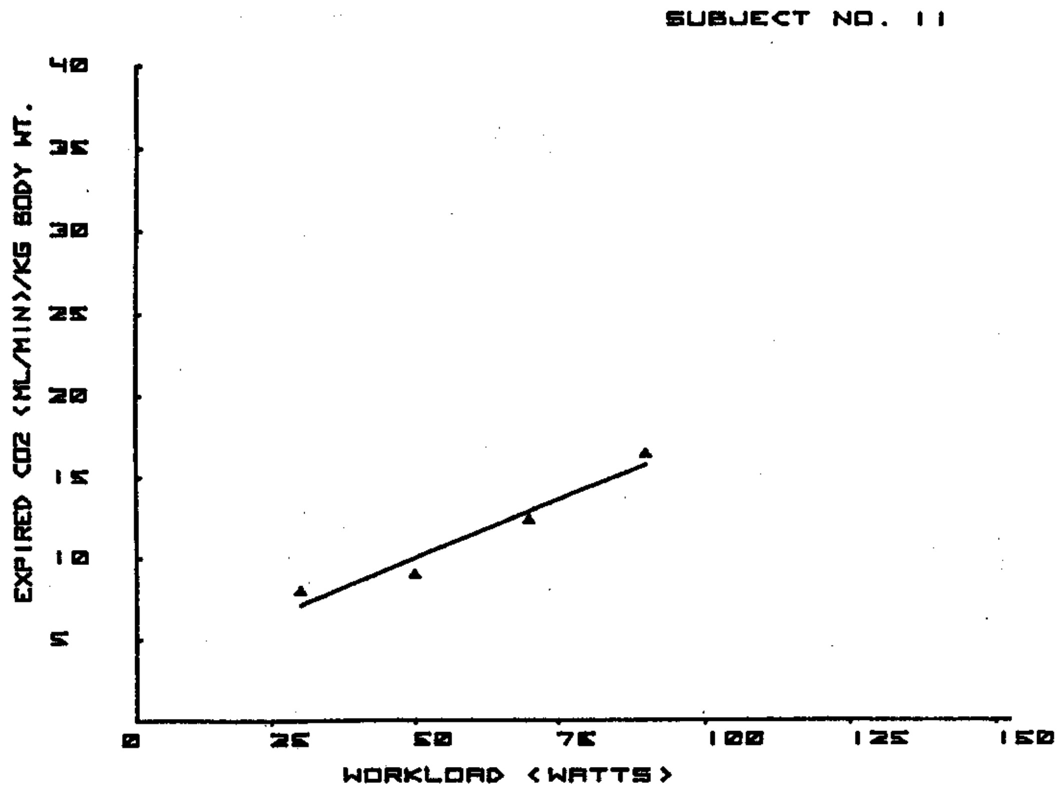
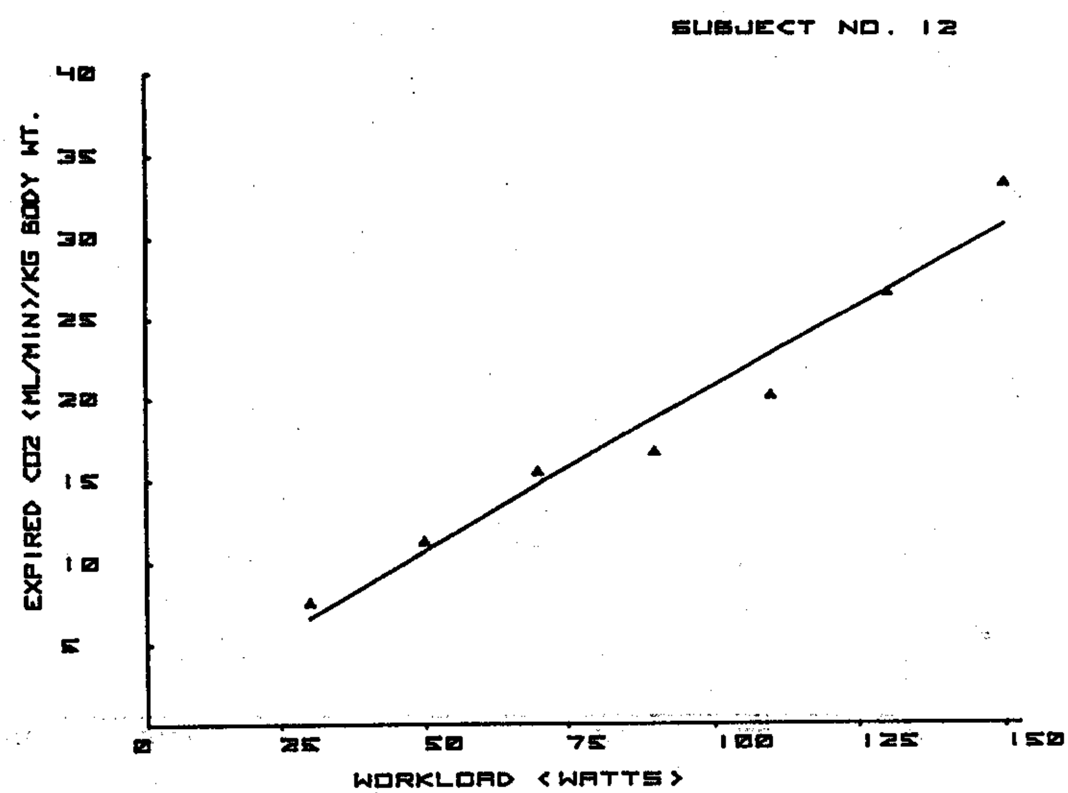


Figure 76



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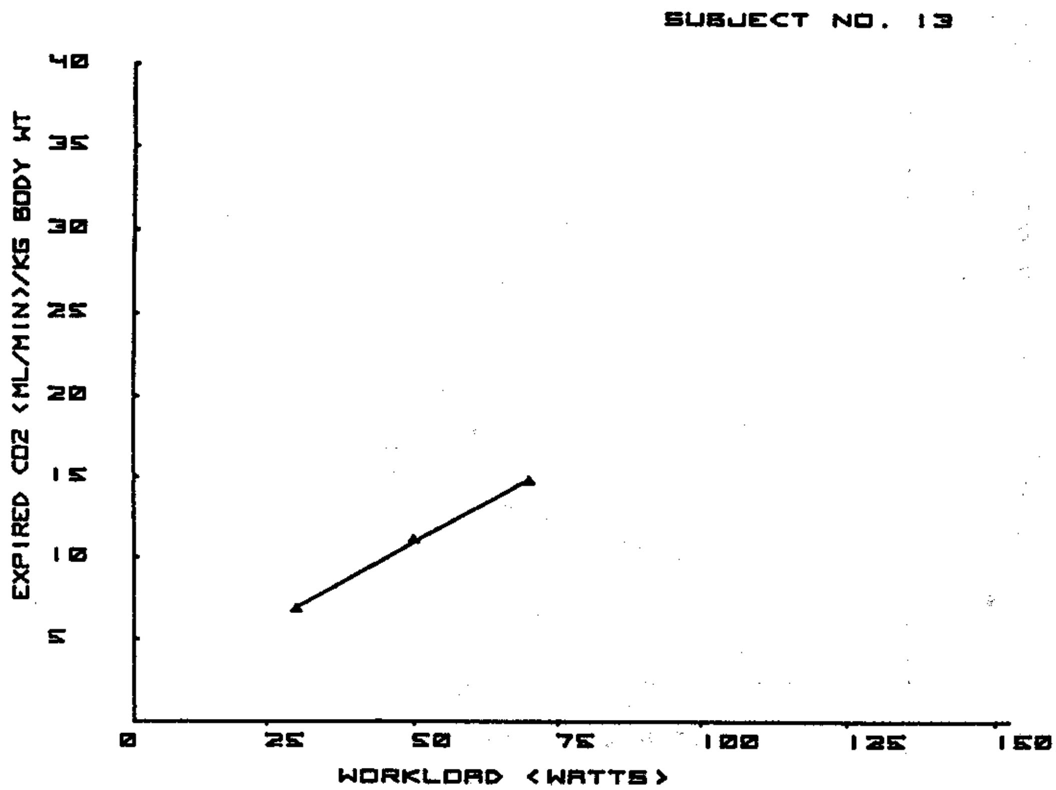

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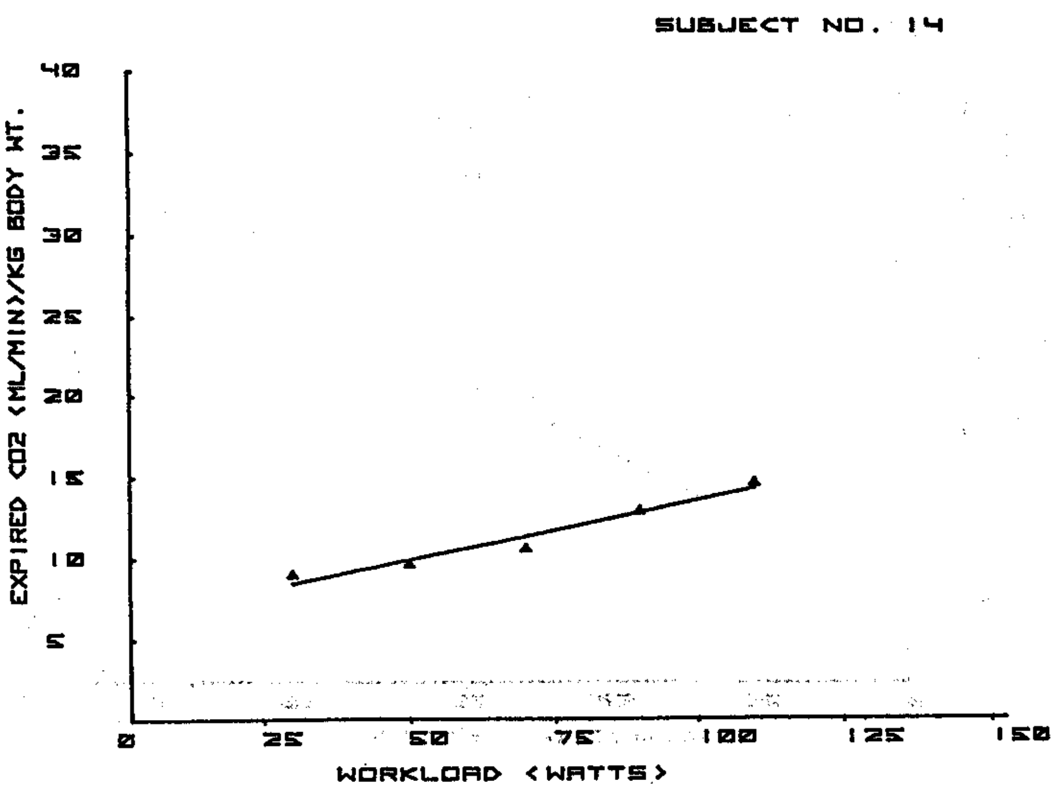

Figure 79

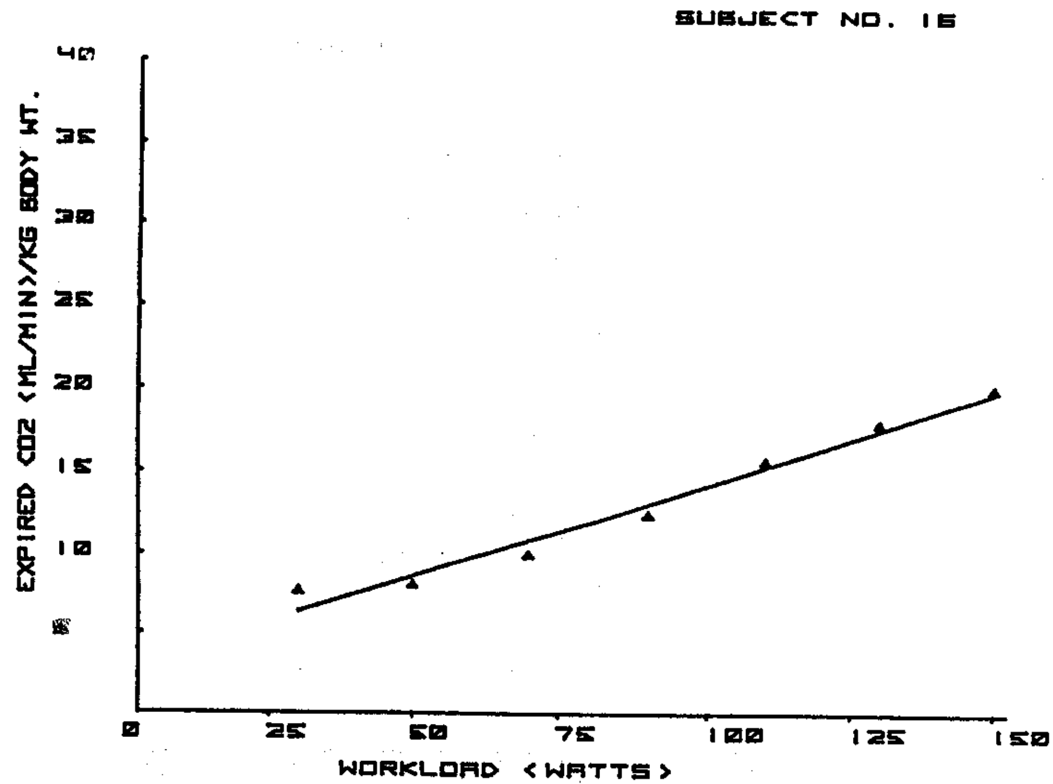

Figure 80

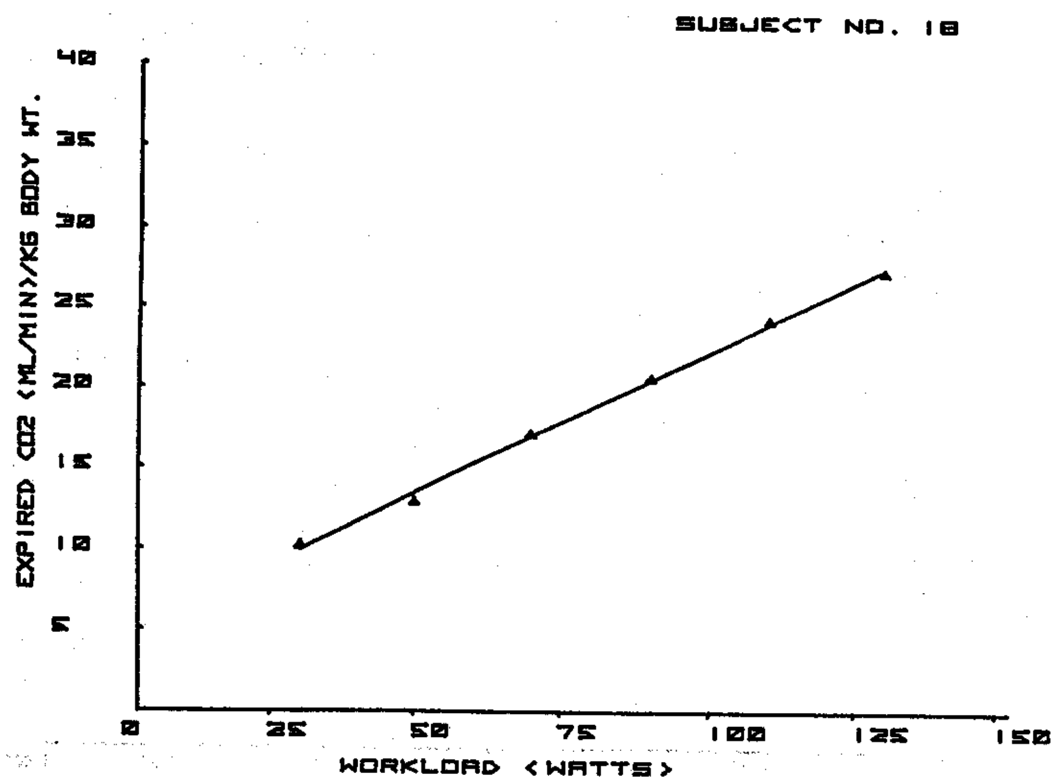

Figure 81