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Breathing oxygen as an aid to recovery after exertion

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BREATHING OXYGEN AS AN AID

TO RECOVERY AFTER EXERTION

By

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TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION AND REVIEW OF LITERATURE	1
	Statement of the problem	2
	Need for the study	2
	Limitations of the study	
	Definition of terms	3
	Review of literature	3
	Summary	7
II.	PROCEDURES OF THE STUDY	8
	Research design	8
	Pilot study	8
	Testing sequence	9
	Air collection	13
	Sampling equipment	13
	Measurement equipment	16
	Ventilation rate	16
	Gas analysis	17
	Oxygen consumption	17
III.	ANALYSIS AND DISCUSSION OF RESULTS	18
	Method of analysis	18
	Analysis of results	19
IV.	SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS	23
	Summary	23
	Conclusions	23
	Recommendations	23

CHAPTER PAGE

SELECTED BIBLIOGRAPHY.................................... 25

APPENDIX.. 28

LIST OF TABLES

TABLE		PAGE
I.	Means of Pulse Decrease, Post Exercise Oxygen Consumption and Ventilation rate.............	18
II.	Means of Pulse Decrease Post Exercise Oxygen Consumption and Ventilation Rate for Runners and Non-Runners................................	19
III.	Pulse Decrease....................................	19
IV.	Oxygen Consumption................................	21
V.	Ventilation Rate..................................	21
VI.	Heart Rate Decrease (Raw Data)..................	30
VII.	Oxygen Consumption (Raw Data)..................	31
VIII.	Ventilation Rate (Raw Data)....................	32
IX.	Raw Data Complete Testing Period...............	33
X.	Order of Treatments..............................	36

LIST OF FIGURES

FIGURE		PAGE
I.	Treadmill Components and Nomenclature..........	10
II.	Subject Ready to Run............................	11
III.	Subject Breathing Oxygen.......................	12
IV.	Collecting Expired Air.........................	14
V.	Collecting Gas Sample..........................	15

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

Breathing pure oxygen as an aid to recovery has been employed by coaches and athletes for a number of years, but it has not been definitely proven if it is a physiological or a psychological aid.

Tanks of oxygen are not an uncommon sight at college and professional athletic contests, and in recent years the number of high schools using them has increased. One of the most publicized uses of oxygen as an aid in sports involved the United States Olympic Hockey team of 1960 who used it at the suggestion of the Russian team and won the Olympic Gold medal.

In spite of the acceptance of oxygen as an aid, some investigators doubt its effectiveness. Karpovich (10) stated that the use of oxygen to hasten recovery after physical exertion was based upon salesmanship rather than upon physiology. The American Medical Association (7) strongly disapproves of the use of oxygen in interscholastic sports because the athlete may exert beyond his normal limits, because of its expected help, and encounter harmful effects. Despite this disapproval athletic coaches and trainers continue to use oxygen with the objectives of increasing the rate of recovery from previous exercise and improving subsequent performance. This use is based on heresay rather than experimental evidence.

Statement of the Problem. This study attempted to determine if oxygen inhalation had any effect on recovery after exertion as measured by net heart rate recovery, ventilation rate, and the recovery oxygen consumption. The problem compared oxygen inhalation with similar inhalations of compressed atmospheric air and normal atmospheric air.

Need for the Study. There have been many studies investigating the use of oxygen as an aid to recovery and performance in athletics. Karpovich (8) found that breathing oxygen increased the speed of swimmers, while Sharkey (14) found no speed increase with swimmers. Both studies found that breathing oxygen did not facilitate recovery. Elbel (4) found that breathing oxygen depressed the heart rate during recovery and thus was of some help. This disagreement in the conclusions of these studies points out the need for further investigations to prove that oxygen is or is not an aid to recovery after physical exertion.

Limitations of the Study. This study was limited to twelve male students at the University of Montana. Six students were members of the university cross-country team and the other six were non-runners selected from the physical education service program at the University of Montana. The testing took place during the last two weeks of January and the first week of February 1965.

The subjects were pretrained in treadmill running. This training did not effect the physical condition of any of the subjects. Because the diets of the subjects could not be controlled the testing was done between six and eight o'clock in the morning while the subjects were in the post-absorptive state.

Definition of Terms.

Steady state. In this study "steady state" refers to the leveling off of the heart rate during exercise.

Resting heart rate. This refers to the heart rate of the subjects taken during the thirty minute period before they started to exercise.

Runners. This refers to the subjects who were members of the cross-country team.

Non-runners. This refers to the students who were not members of the cross-country team.

Ventilation rate. The amount of expired air measured in liters per minute.

Net heart rate. This is the difference between the resting heart rate and the maximum heart rate reached during exercise.

Review of Literature. Many investigations have been conducted in regard to the use of oxygen as an aid to performance and recovery. A brief summary of those studies pertinent to the use of oxygen as an aid to recovery and performance ensues.

Sharkey (14) found that three deep inhalations of oxygen immediately before a swimming race did not help the performance of the swimmer and breathing oxygen did not facilitate recovery.

Karpovich (8) in a similar study with swimmers, found that breathing oxygen for five minutes before a race of one hundred yards increased the speed of the swimmer, but breathing oxygen for five minutes during recovery from the race did not decrease the time needed for the swimmer to recover. He found that the same recovery time was needed when the swimmers breathed oxygen as when they breathed atmospheric air.

In a study with Rao on nine male subjects, who ran to exhaustion on a treadmill, rested for ten minutes and ran to exhaustion again, Karpovich (9) reported that breathing pure oxygen immediately after running did not decrease the time required to recover. The recovery time was the same as when the subjects breathed from a placebo tank of compressed air.

Elbel, Ormond and Close (4), in a study of sixty-three athletes, found that the breathing of pure oxygen during six minutes of rest, air during five minutes of treadmill running and oxygen during nineteen minutes of recovery caused the respiratory rate to decrease during the early part of recovery. It also depressed the heart rate during the first two minutes of exercise and during the recovery period. The depressed heart rate suggests that the breathing of oxygen helped the recovery of the subjects. Michaels and Cureton (11) found the heart rate decreased in relation to the increase in oxygen intake and stroke volume.

In a study by Rowell and associates (13) on four athletes in good physical condition and four non-athletes it was found that the hemoglobin saturation of oxygen decreased with exercise. The hemoglobin saturation of both groups was determined before a three month period of intensive training and also at the end of this period. The athletes were found to have a hemoglobin saturation of oxygen of 97.5 per cent at rest and 84.4 during exercise while the sedentary group had percentages of 95.4 at rest and 91.4 during exercise. The above shows that in athletes who are well conditioned and pushing themselves to the limit of their capacity, arterial desaturation of oxygen can take place. Karpovich (9) stated that when the heart rate increased and there was a positive pressure of oxygen in the lungs, the hemoglobin would absorb more oxygen. With more oxygen available, the hemoglobin saturation level of oxygen would remain higher during exercise, thus the recovery time would be shortened.

Bannister and Cunningham (1), conducted a study with four men, two athletes and two non-athletes. When they ran on a treadmill at six and one-half miles per hour breathing oxygen it took twelve to twenty-one minutes, depending on the gradient, to run to exhaustion. Using the same technique but breathing air instead of oxygen it took only six to nine minutes to reach exhaustion. They stated that the addition of oxygen to the inspired air always improved performance considerably and often resulted in the establishment of a steady state during exercise which would normally produce rapid exhaustion.

Benedict, Lee, and Strieck (2) reported that the heart rate of a subject was lower when he breathed highly oxygenated air during rest. They also found the same results when the subject used oxygen during exercise. This lowered heart rate was not observed when the subject breathed atmospheric air.

Pembrey, Cook, Hewlett, and Karpovich were reported in the study by Benedict, Lee, and Strieck (2) as concluding that breathing oxygen after exercise gave quicker relief from symptoms of distress than breathing atmospheric air. In the same review Miyama, Barach, and Parkinson were reported to have found that the heart rate was lower when the subjects breathed oxygen after exercise than when they breathed atmospheric air. Miyama also was reported as stating that breathing oxygen both before and after exercise gave a more satisfactory recovery from fatigue.

Hill and Flack (6) reported that the fatigue which follows exertion seems to be mainly cardiac in origin and is due to the lack of oxygen. When oxygen was inhaled during exercise the lasting power of the subjects was increased and the after fatigue lessened. They also reported that the heart rate was lowered by breathing oxygen.

Summary. Most investigations show that breathing oxygen before exercise has no effect on recovery and very little on improved performance. Morehouse and Miller (12) state that in laboratory tests nearly all workers agree that the breathing of oxygen following exercise has little effect on the rate of recovery, but breathing oxygen during exercise is beneficial, although there is disagreement concerning the degree of benefit.

The psychological aspects of benefit from oxygen inhalation during athletic contests should not be underestimated.

CHAPTER II

PROCEDURES OF THE STUDY

Research design. This study was primarily concerned with the effect breathing pure oxygen had on the recovery rate of runners and non-runners. Runners and non-runners were used to see if breathing oxygen would be of more benefit to the trained athlete or to the untrained person. It was hypothesized that the ability to lower the hemoglobin saturation, as evidenced by the trained runners in the study by Rowell and associates (13), might be one factor resulting in the contradictory results of the previously noted studies. Hence the decision to compare untrained subjects with trained endurance runners. It was therefore necessary to use a treadmill speed that the non-runners could maintain and still enable the runners to reach a steady state.

Pilot study. A pilot study was conducted to determine the following: the speed of the treadmill, the length of running time necessary to reach a steady state, the capabilities of the student assistant, and the clarity of the instructions to the subjects. The pilot study also provided the subjects with ample training in the use of the treadmill and breathing apparatus.

The study was administered over a period of nineteen testing days from January 18, 1965 to February 8, 1965. All tests were conducted in the Human Performance Laboratory of the department of Health and Physical Education and Athletics at the University of Montana. Six male students were selected from the required physical education program and six from the cross-country team at the University of Montana. The testing of each subject was randomized in order to avoid the introduction of a training effect.

Testing sequence. Each subject was tested in the post-absorptive state. When the subject arrived at the laboratory he weighed himself, measured his height, and recorded them on the daily testing data sheet. He then sat on a stool on the treadmill and rested for a period of thirty minutes. During this thirty minute rest period the subject's oral temperature was taken and the electrodes that connect to the cardiotachometer were placed on his body. The three electrodes were placed at approximately the lateral aspect of the fifth right and left ribs and the dorsal aspect of the first thoracic vertebra. The subject's resting heart rate was determined at this time. At the end of the thirty minute rest period the stool was removed and the subject ran for five minutes at a treadmill speed of 235 yards per minute (approximately eight miles per hour). Upon completion of the run the treadmill was stopped, the stool was replaced on the treadmill and the subject sat down and breathed either pure oxygen, compressed air, or atmospheric air for one minute.

FIGURE 1.
TREADMILL COMPONENTS
AND NOMENCLATURE

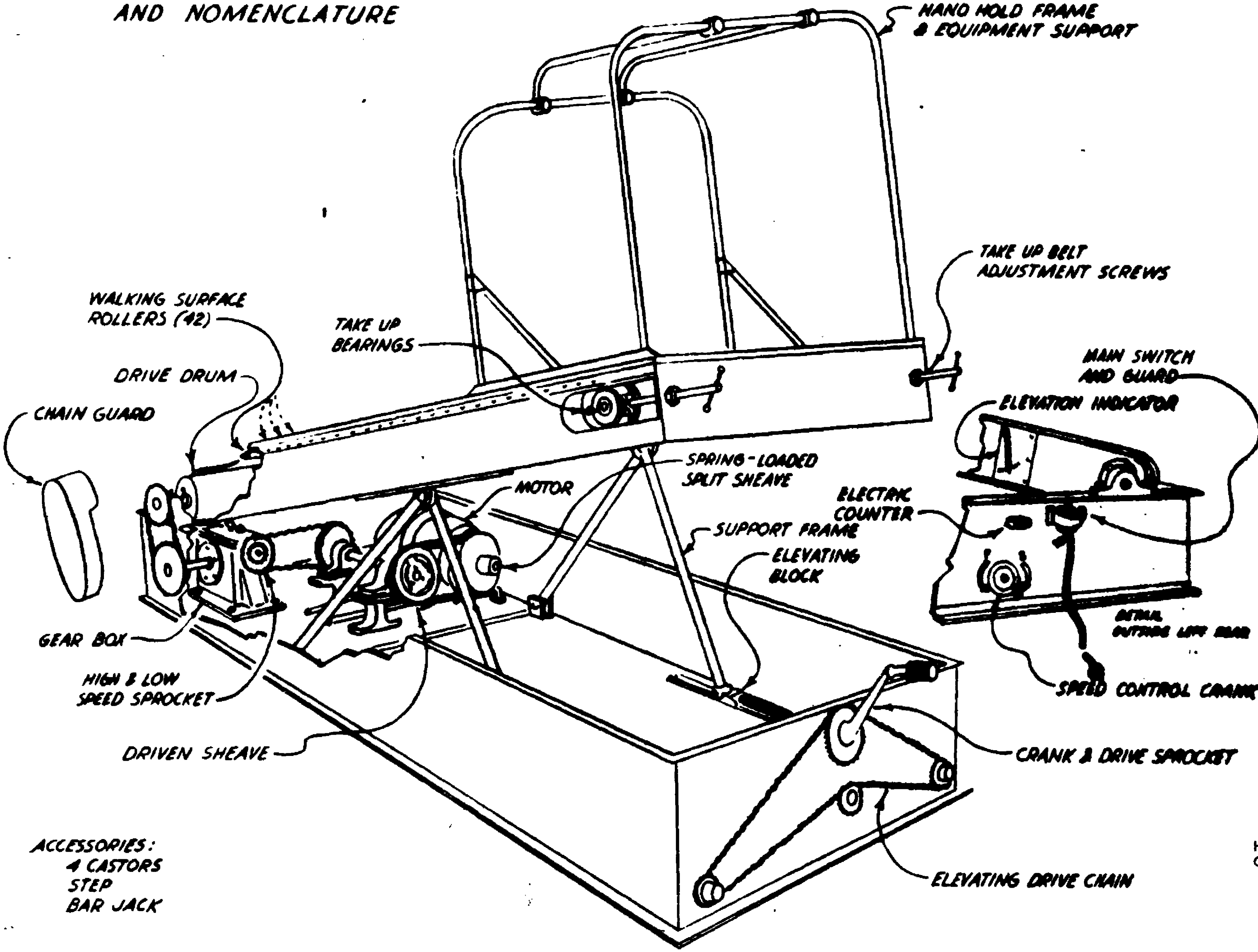

FIGURE II

SUBJECT READY TO RUN

A. Two-way valve to Douglas gas bag and atmosphere
B. Automatic one-way breathing valve
C. Cardiotachometer
D. Treadmill

FIGURE III

SUBJECT BREATHING OXYGEN

A. Oxygen tank
B. Compressed air tank
C. Face mask for oxygen breathing

With five seconds left of the one minute period the subject stood up and got ready to run for another five minutes. At the end of the second run the subject placed the mouthpiece of the breathing valve into his mouth while the student assistant placed a nose clamp on the subject's nose. The subject rested on a stool during the recovery period. The subject's expired air was collected for three minutes in a Douglas gas bag. Each subject was tested three times, breathing oxygen once, compressed air once, and atmospheric air once. The subjects did not know whether they were breathing the oxygen or the compressed air. They were told that the two tanks contained different percentages of oxygen. The tests were scheduled one week apart to further reduce possible training effects.

Heart rates were recorded every twenty seconds during the running and the one minute rest between runs and every fifteen seconds during the three minutes of gas collection.

Air collection. The open circuit method for the collection of expired air was used. The subject used a nose clamp and a mouthpiece which was attached to an automatic one-way valve. This valve let the subject inhale atmospheric air while his expired air went into a rubber hose connected to a two-way valve which directed the air into a Doublas gas bag.

Sampling equipment. The expired air sample was collected

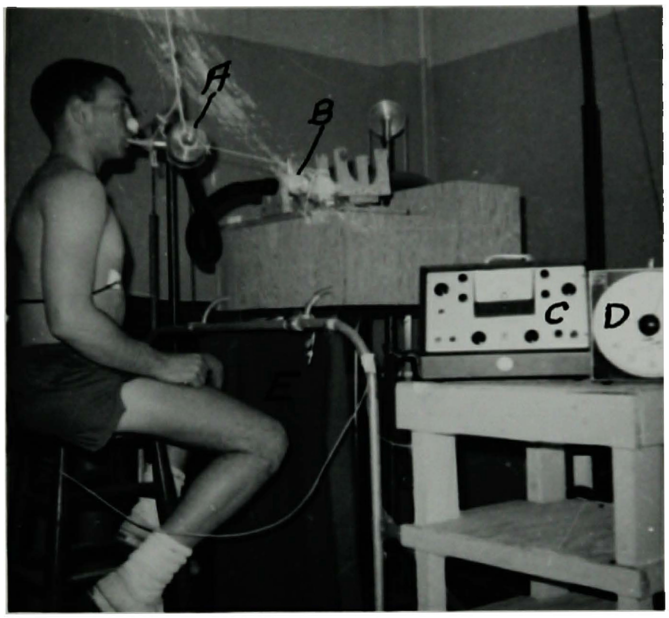

FIGURE IV

COLLECTING EXPIRED AIR

A. Automatic one-way breathing valve
B. Two-way valve to Douglas gas bag
C. Cardiotachometer
D. Electric timer
E. Douglas gas bag

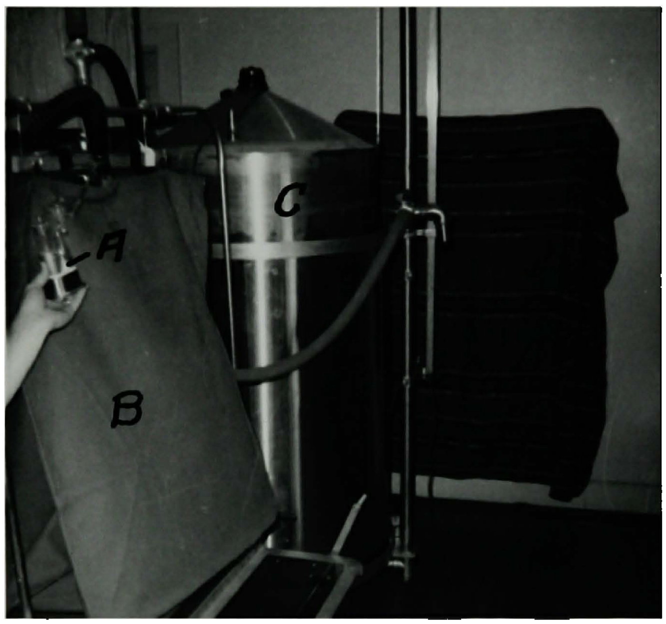

FIGURE V

COLLECTING GAS SAMPLE

A. Bailey bottle
B. Douglas gas bag
C. 600 liter chain compensated gasometer

from the gas in the Douglas gas bag over mercury into a Bailey bottle. This gas sample was analyzed within one hour after collection.

Measurement equipment. A 600 liter chain compensated gasometer was used to draw the subject's expired air out of the Douglas gas bag. A meter stick attached to the gasometer indicated the height that the gasometer bell rose when all the expired air had been drawn from the Douglas gas bag. The volume of the expired air was obtained by multiplying the rise in centimeters by the conversion factor of the gasometer, which was 5.158 liters per centimeter. The expired air was mixed by an electric fan located within the gasometer bell to stabilize the temperature of the gas. The temperature of the gas was obtained from a therometer located in the top of the gasometer bell.

Ventilation rate. The volume of gas collected from each subject was converted to standard temperature and pressure dry (STPD) by multiplying the volume obtained from the gasometer by a correction factor obtained from a chart prepared by Darling and reported by Consolazio, Johnson, and Pecora (3). The magnitude of the factor was dependent on the gas temperature and the barometric pressure of the atmosphere. The barometric pressure was recorded immediately after the gas was collected from an aneroid barometer located in the laboratory. The corrected volume of gas was then divided by the number of minutes of gas collection and the resulting volume was the ventilation rate of the subject and was recorded in liters per minutes.

Gas analysis. The Scholander method of gas analysis was used to determine the percentage of oxygen and carbon dioxide in the expired air samples. The procedure used for the gas analysis is described by Consolazio, Johnson, and Pecora (3).

Oxygen consumption. Oxygen consumption was computed by using the formulas provided by Consolazio, Johnson, and Pecora (3). Oxygen consumption was expressed as cubic centimeters per minute consumed. The true oxygen percentage was obtained from a chart prepared by Dill, et al. and reported by Consolazio, Johnson, and Pecora (3). This chart corrected for the difference in inspired and expired volumes as related to the percent of nitrogen in the expired air. The volume of oxygen consumed per minute was determined by the formula:

$$\text{Vol. L } O_2\text{/Min.} = \frac{\text{Vol. expired air/Min. x true } O_2\%}{100}$$

CHAPTER III

ANALYSIS AND DISCUSSION OF RESULTS

__Method of Analysis__. The analysis of variance as described by Garrett (5) was used to determine whether the mean changes in pulse rate, oxygen consumption, and ventilation rate resulting from the breathing of oxygen, compressed air, or atmospheric air were significant.

This method was chosen because the same group was tested in three different situations. The .05 and .01 level of significance were determined from Garrett's (5) table of "F" ratios.

Table I shows the means of pulse rate decrease, oxygen consumption, and ventilation rate for the three different testing situations, while Table II shows the means separated into the runners and non-runners.

TABLE I

MEANS OF PULSE DECREASE, POST EXERCISE OXYGEN CONSUMPTION AND VENTILATION RATE

Treatment	Pulse decrease	Post exercise O_2 Consumption	Post exercise Ventilation rate
Oxygen	55.00	1184.00 cc/min.	29.97 L/min.
Compressed air	54.17	1160.58 cc/min.	30.30 L/min.
Atmospheric air	52.25	1155.17 cc/min.	31.16 L/min.

TABLE II

MEANS OF PULSE DECREASE, POST EXERCISE OXYGEN CONSUMPTION AND VENTILATION RATE FOR THE RUNNERS AND THE NON-RUNNERS

	Treatment	Pulse decrease	Post exercise O_2 Consumption	Post exercise Ventilation rate
Runners	Oxygen	64.67	922.67	19.45
	Compressed air	65.00	839.17	18.65
	Atmospheric air	65.17	865.50	18.52
Non-Runners	Oxygen	45.33	1445.33	40.49
	Compressed air	43.33	1482.00	41.95
	Atmospheric air	39.33	1444.83	43.80

Analysis of Results. The analysis of variance of the pulse rate decrease from the end of the first five minute run to the end of the one minute rest period is shown in Table III.

TABLE III

PULSE DECREASE

Analysis of Variance

Source of variance	df	SS	Mean square Variance	F-ratio
Between trials	2	47.722	23.861	.288
Among subjects	11	6376 972	579.725	
Interaction	22	1818.945		

Level of significance .05 = 3.98 .01 = 7.20

Although the oxygen inhalation treatment resulted in the largest mean pulse decrease the "F" ratio obtained was not found to be significant. This indicated that the breathing of pure oxygen did not help lower the pulse rate of the subjects during the one minute rest between the two five minute runs.

Table IV shows the analysis of variance of the recovery oxygen consumption of the subjects.

Since Benedict, Lee and Strieck (2) had found that oxygen inhalation did not lower oxygen consumption during exercise, it was assumed that the breathing of high percentages of oxygen would not alter the steady state oxygen intake. Therefore, a three minute sample of expired air was collected following the second five minute run to reflect any differences in the time required to attain the steady state on the assumption that a hastened recovery due to breathing oxygen would result in a lower level of oxygen consumption at the beginning of the second run. This lower level at the outset of the second run would, in theory, show up as an elevated oxygen consumption during recovery.

The difference in the recovery oxygen consumption of the subject was not significant. It should be noted, however, that the minor differences in the mean recovery consumption (Table I) agree with the hypothesis.

TABLE IV

OXYGEN CONSUMPTION

Analysis of variance

Source of variance	df	SS	Mean square Variance	F-ratio
Between trials	2	5636.17	2818.09	.156
Among subjects	11	3987974.08	362543.10	
Interaction	22	397414.50	18064.30	

Level of significance .05 = 3.98 .01 = 7.20

Table V shows the analysis of variance of the recovery ventilation rate of the subjects.

Elbel and associates (4) found that the recovery ventilation rate decreased during the early part of recovery. Therefore, by measuring the subject's ventilation rate during the first three minutes of recovery, it was assumed that a lowered ventilation rate would be an indication of a shortened recovery period.

TABLE V

VENTILATION RATE

Analysis of variance

Source of variance	df	SS	Mean square Variance	F-ratio
Between trials	2	8.976	4.488	0.711
Among subjects	11	5906.273	536.934	
Interaction	22	138.939	6.315	

Level of significance .05 = 3.98 .01 = 7.20

The "F" ratio showed that there was no significant difference in the ventilation rates of the subjects at either level of confidence.

The differences in pulse rate, oxygen consumption, and ventilation rate that showed up in the raw data seem to be due to individual differences and not to any aid derived from the breathing of oxygen.

The differences between the runners and non-runners were seen most clearly in an analysis of the pulse rate decrease between oxygen inhalation and atmospheric air. The differences ranged from a minus eighteen beats per minute to a plus twenty-eight beats for the runners, with a mean of minus one-half beat per minute and from a minus thirteen to a plus sixteen beats per minute with a mean of plus six beats per minute for the non-runners. This data indicated that greater aid was generally derived by the group (non-runners) that was forced to near maximal exertion. The exertion was sub-maximal for the trained endurance runners.

Tables VI, VII, and VIII in the appendix give the raw data for heart rate decrease, oxygen consumption, and ventilation rate for each of the subjects while breathing oxygen, compressed air, and atmospheric air. Table IX contains all the data collected during the testing period.

CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary. The purpose of this study was to determine if breathing pure oxygen would aid the twelve subjects in recovery after exertion. This recovery was to be determined by heart rate recovery, recovery oxygen consumption, and recovery ventilation rate.

A review of literature indicated that the use of a high percentage of oxygen as an ergogenic aid was not a recent development in athletics. The breathing of a high percentage of oxygen has been used since the early 1900's. Because the review of literature showed a disagreement of conclusions, the investigator decided that additional research was needed.

Analysis of variance was the method employed to find the significant difference between the use of oxygen, compressed air, and atmospheric air. The "F" test was used to determine if the differences between the tests were real or due to chance.

Conclusion. On the basis of this study the following conclusion was made:

1. The breathing of a high percentage of oxygen is of no physiological help in aiding a person's recovery after exertion.

Recommendations. In view of the findings and conclusions of this study the following recommendations are made:

1. The work load of the cross-country runners should be increased to an amount that is closer to their maximum exertion. The data of this study and that collected by Rowell and associates (13) suggest that for recovery aid to be derived from the inhalation of oxygen, the subject should be a trained endurance runner performing in a maximal test of endurance. Only then would the hemoglobin saturation of oxygen be sufficiently low to require any post exercise supplement.
2. In future studies the expired air should be collected each minute throughout the exercise period. This would enable the investigator to note all changes in oxygen consumption and ventilation rate.

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APPENDIX

DAILY TESTING DATA SHEET

Name ______________________ Weight ________ Height ______

Oral Temp. ______ F° ____

Room Temp. ______ C° ____

Baro. Press. __________

Gas Temp. ______ C° ______

Corr. Factor ____________ (STPD)

Rest. Heart Rate _____, ______, ________, Mean ________

Exer. Heart rate

	20 sec.	40 sec.	60 sec.
1st. min.			
2nd. min.			
3rd. min.			
4th. min.			
5th. min.			
1 min rest			
6th. min.			
7th. min.			
8th. min.			
9th. min.			
10th. min.			

Recovery heart rate

30 sec.	60 sec.	90 sec.	120 sec.	150 sec.	180 sec.

Spirometer reading   Spirometer correction factor 5.158

________ - ________ x 5.158 x corr. factor - mins. = Vent
post   pre
rate L/min.

Gas analysis CO_2 __________, __________ Mean __________%

O_2 __________, __________ Mean __________%

TABLE VI

PULSE DECREASE

Subjects	Oxygen	Compressed air	Atmospheric air
G D B	58	56	63
R B H	67	75	39
P O D	59	56	66
B J G	73	76	76
M E U	64	55	82
F J F	67	72	65
D M G	36	31	20
R H H	42	37	39
B S P	62	58	47
D A Y	39	59	52
L L T	42	40	32
C J C	51	35	46
Total	660	650	617
Mean	55	54.17	52.25

TABLE VII

OXYGEN CONSUMPTION IN C.C./MINUTE

Subjects	Oxygen	Compressed air	Atmospheric air
G D B	712	698	845
R B H	946	892	1022
P O D	1058	849	838
B J G	734	767	745
M E U	1128	1092	908
F J F	958	737	935
D M G	1692	1306	1467
R H H	1397	1489	1753
B S P	1055	1506	1040
D A Y	1190	1158	1173
L L T	1735	1751	1623
C J C	1603	1682	1613
Total	14208	13927	13862
Mean	1184	1160.58	1155.17

TABLE VIII

VENTILATION RATE IN LITERS/MINUTE

Subjects	Oxygen	Compressed air	Atmospheric air
G D B	15.21	14.27	14.29
R B H	21.07	21.40	21.39
P O D	19.88	16.92	15.52
B J G	16.02	17.54	16.96
M E U	24.58	23.63	21.47
F J F	19.95	18.16	21.47
D M G	44.76	41.47	46.57
H H H	37.87	41.59	49.24
B S P	34.14	33.03	30.41
D A Y	31.49	31.73	35.76
L L T	49.02	53.21	50.09
C J C	45.68	50.65	50.72
Total	359.67	363.60	373.89
Mean	29.97	30.30	31.16

TABLE IX

RAW DATA

	Subj.	Heart Rate: Rest	Exercise Per/Min. 1	2	3	4	5	1 Min. Rest	Exercise Per/Min. 6	7	8	9	10
Oxygen	GDB	39	133	134	134	134	134	76	136	137	138	140	140
	RBH	65	146	151	155	157	158	90	156	159	160	162	164
	POD	52	140	144	145	148	150	89	140	149	151	154	155
	BJG	58	130	148	149	150	151	78	145	154	157	157	157
	MEU	55	141	145	148	152	150	86	139	145	145	145	145
	FJF	47	150	151	151	153	153	86	147	153	149	152	152
	DMG	88	170	181	182	188	193	155	189	197	201	203	206
	RHH	59	187	191	194	196	198	155	199	202	207	207	210
	BSP	62	151	169	174	178	181	118	165	185	188	189	192
	DAY	85	165	175	180	184	185	146	175	180	190	190	195
	LLT	77	166	176	181	184	187	144	180	190	193	194	196
	CJC	71	168	180	184	189	193	140	184	193	196	198	203
Compressed Air	GDB	38	140	140	140	135	140	80	137	139	139	139	139
	RBH	62	139	151	152	155	158	82	148	158	158	159	159
	POD	53	129	135	136	139	142	85	134	142	142	142	145
	BJG	60	144	151	154	157	160	82	154	159	160	162	162
	MEU	54	135	146	147	148	150	94	135	137	141	153	157
	FJF	47	136	137	140	143	143	70	140	143	146	146	145
	DMG	98	182	187	192	198	199	168	194	202	206	203	205
	RHH	66	181	187	191	196	197	160	200	203	207	210	212
	BSP	58	155	163	167	168	170	112	168	177	183	185	185
	DAY	71	165	172	179	184	190	129	172	181	187	197	205
	LLT	87	177	190	193	190	191	150	188	195	197	199	199
	CJC	65	157	165	178	182	187	150	179	187	191	192	198
Atmospheric Air	GDB	40	130	140	140	140	140	77	136	139	141	143	143
	RBH	65	147	155	158	160	160	120	153	163	163	163	163
	POD	65	142	147	148	149	153	86	144	151	153	153	155
	BJG	51	140	150	150	152	156	78	142	153	155	160	160
	MEU	66	135	153	153	156	156	74	145	155	159	163	163
	FJF	45	134	140	142	144	144	79	139	147	150	150	151
	DMG	91	180	185	190	195	195	175	195	202	205	210	210
	RHH	72	190	196	202	204	204	165	200	208	210	212	213
	BSP	65	161	170	178	178	183	135	172	182	186	187	190
	DAY	76	160	-	173	179	180	127	171	181	186	190	210
	LLT	79	174	186	189	191	193	160	190	198	203	204	204
	CJC	69	158	167	177	182	187	139	178	189	193	195	200

TABLE IX

RAW DATA

Condition	Subj.	Heart Rate Recovery Per/Min. 30	60	90	120	150	180	Gas Anal. in % CO_2	Gas Anal. in % O_2	True % CO_2	True % O_2	O_2 Cons. cc/min.
Oxygen	GDB	94	84	72	64	56	56	3.51	16.50	3.48	4.68	712
	RBH	-	104	96	92	84	80	3.68	16.62	3.65	4.49	946
	POD	120	87	87	85	80	85	4.30	15.84	4.27	5.32	1058
	BJG	128	92	88	80	76	76	3.90	16.50	3.87	4.58	734
	MEU	-	120	106	95	88	88	3.98	16.48	3.95	4.59	1128
	FJF	-	95	86	76	72	60	3.48	16.41	3.45	4.80	958
	DMG	180	160	144	132	128	123	3.07	18.08	3.04	3.78	1692
	RHH	-	144	128	116	112	112	3.58	17.27	3.55	3.69	1397
	BSP	148	120	104	92	88	88	3.38	17.79	3.35	3.09	1055
	DAY	165	135	130	125	124	115	3.18	17.28	3.15	3.78	1190
	LLT	164	140	124	120	116	112	3.89	17.32	3.86	3.54	1735
	CJC	176	160	148	136	128	120	3.90	17.34	3.87	3.51	1603
Compressed Air	GDB	96	88	84	76	76	69	3.63	16.32	3.60	4.89	698
	RBH	140	100	88	88	88	80	3.69	16.87	3.66	4.17	892
	POD	120	84	80	72	72	75	4.49	16.03	4.46	5.02	849
	BJG	120	84	84	80	80	72	3.70	16.70	3.67	4.37	767
	MEU	-	100	96	84	84	84	3.85	16.48	3.82	4.67	1092
	FJF	92	84	64	64	64	72	3.34	17.02	3.31	4.06	737
	DMG	185	170	151	144	140	132	3.24	17.76	3.21	3.15	1306
	RHH	168	144	132	116	112	114	3.69	17.33	3.66	3.58	1489
	BSP	155	120	112	96	96	96	3.12	17.67	3.09	4.56	1506
	DAY	-	132	130	112	108	108	3.89	17.24	3.86	3.65	1158
	LLT	185	175	145	128	121	114	3.15	17.68	3.12	3.29	1751
	CJC	-	160	140	136	132	124	3.82	17.51	3.79	3.32	1682
Atmospheric Air	GDB	100	88	84	80	76	69	3.88	16.25	3.85	5.91	845
	RBH	143	100	94	92	89	88	3.57	16.41	3.53	4.78	1022
	POD	116	88	84	84	84	84	4.61	15.72	4.58	5.40	838
	BJG	108	80	76	68	72	76	4.07	16.62	4.04	4.39	745
	MEU	140	100	92	88	88	84	3.92	16.77	3.89	4.23	908
	FJF	108	84	76	68	68	72	3.14	17.21	3.11	3.89	835
	DMG	200	185	165	162	157	150	2.73	17.88	2.70	3.15	1467
	RHH	185	155	135	125	125	125	3.15	17.45	3.13	3.56	1753
	BSP	188	132	116	104	104	99	3.48	17.50	3.45	3.42	1040
	DAY	140	132	124	116	108	112	3.47	17.61	3.44	3.28	1173
	LLT	180	148	132	120	116	108	3.64	17.61	3.61	3.24	1623
	CJC	176	156	140	128	120	116	3.90	17.52	3.87	3.18	1613

TABLE IX

RAW DATA

	Subj.	Resp. Rate L/min.	Gas Temp C°	Baro. Pres.	Conv. Fact.	Wt. Lbs.	Ht. In.	Body Temp. F°	Rel. Hum. %	Room Temp. C°
Oxygen	GDB	15.21	24	670	.790	138	67	94.0	14	25
	RBH	21.07	21	682	.817	149	70	97.0	21	22
	POD	19.88	22	682	.815	153	69	95.0	28	23
	BJG	16.02	22	679	.810	142	73	95.4	21	24
	MEU	24.58	21	681	.817	171	72	95.0	25	22
	FJF	19.95	20	681	.823	147	71	94.8	25	22
	DMG	44.76	19	683	.829	148	68	95.5	27	20
	RHH	37.87	20	685	.825	172	73	97.6	22	19
	BSP	34.14	20	682	.824	138	67	95.5	22	22
	DAY	31.49	22	673	.804	146	69	95.8	24	22
	LLT	49.02	21	676	.810	206	73	96.8	18	22
	CJC	45.68	22	679	.810	171	70	98.2	21	24
Compressed Air	GDB	14.27	23	678	.806	136	-	95.6	13	23
	RBH	21.40	22	685	.819	150	-	94.6	22	22
	POD	16.92	22	669	.800	155	-	92.7	24	23
	BJG	17.54	19	675	.816	145	-	96.4	19	21
	MEU	23.63	20	677	.818	167	-	96.6	32	21
	FJF	18.16	19	676	.819	148	-	98.2	32	21
	DMG	41.47	23	671	.796	149	-	96.8	14	20
	RHH	41.59	21	682	.820	172	-	95.4	21	22
	BSP	33.03	20	682	.821	143	-	97.0	28	20
	DAY	31.73	19	679	.824	144	-	97.6	21	21
	LLT	53.21	23	678	.806	205	-	95.8	13	22
	CJC	50.65	19	675	.816	165	-	97.1	19	20
Atmospheric Air	GDB	14.22	22	682	.815	138	-	96.0	21	22
	RBH	21.39	23	685	.814	152	-	95.0	26	23
	POD	15.52	22	674	.806	155	-	96.2	19	24
	BJG	16.96	20	682	.822	143	-	98.0	31	21
	MEU	21.47	21	675	.811	167	-	96.6	18	21
	FJF	21.47	19	675	.816	147	-	94.4	19	21
	DMG	46.57	22	692	.828	147	-	97.4	28	25
	RHH	49.24	23	685	.814	171	-	96.6	26	25
	BSP	30.41	22	674	.804	138	-	96.8	19	24
	DAY	35.76	20	682	.822	146	-	96.6	31	21
	LLT	50.09	19	675	.816	204	-	98.4	19	20
	CJC	50.72	19	679	.824	167	-	97.6	21	20

TABLE X

ORDER OF TREATMENTS

Subjects	Oxygen	Compressed air	Atmospheric air
G D B	2	3	1
R B H	3	1	2
P O D	1	2	3
B J G	2	1	3
M E U	1	3	2
F J F	1	3	2
D M G	3	1	2
R H H	2	1	3
B S P	2	3	1
D A Y	3	2	1
L L T	3	2	1
C J C	1	2	3

Number 1 - First testing period

Number 2 - Second testing period

Number 3 - Third testing period