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ADDED AIRWAY RESISTANCE AND ENDURANCE IN INTENSIVE EXERCISE

by

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Biomedical Laboratory

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The effect of added airway resistance on endurance in running on a treadmill at 7 mph was tested in US Army male volunteers. Various combinations of inspiratory and expiratory resistance were provided by the following respiratory conditions: (A) standard M17A1 protective mask, (B) modified M17 mask, (C) peripheral M9 mask, (D) M9 mask less filter, (E) mouthpiece and nose-clip, and (F) bareheaded control. In a pilot study, conditions (A) and (F) were compared at two grades on the treadmill. The decrement in endurance due to condition (A) was greater at the lower grade. In series 1 and 2, the six conditions were compared at a single grade for each of nine

20. ABSTRACT (Contd)

men, including duplicate tests on three of the men. Each man's grade was chosen to maximize the decrement due to added resistance. The average endurance times were: 338, 434, 490, 343, 392, and 545 seconds for conditions (A) through (F), respectively. The decrements in endurance were in the same order as the amount of the added resistance in conditions (C), (B), (E), and (D). However, the increase in inspiratory resistance from condition (D) to condition (A) had no additional effect on endurance. In series 3, conditions (C) and (F) were tested twice in 10 men, including 7 men from series 1 and 2. The difference between the two conditions was barely significant at the 0.05 level. The significance was no greater in series 3 than in series 1 and 2. The thermocouple attached to a nostril provided useful information concerning breathing frequency and the duration of phases of the respiratory cycle. The sensitivity of tests of the influence of added airway resistance on endurance in running can be improved by selecting a work rate commensurate with each man's ability. The results were consistent with the hypothesis that the decrement in endurance due to added airway resistance will be small at high and low work rates and will be maximal at some intermediate work rate. The small added airway resistance commonly found in equipment for making various respiratory measurements during exercise can cause a decrement in endurance in proportion to the size of the resistance. The results raised the question of whether, in the range of resistances of modern protective masks, the expiratory resistance is more critical than the inspiratory. It might be advantageous to open two ports for the outflow in order to reduce the peak flow through either port.

PREFACE

The work described in this report was authorized under Project/Task 1W762710AD2501, Medical Defense Against Chemical Agents, Biomedical Evaluation of Protective Material. The data were collected between August 1974 and December 1974. The experimental data are contained in notebook MN-2684.

The volunteers in these tests are US Army personnel. These tests are governed by the principles, policies, and rules for medical volunteers established in AR 70-25 and the Declaration of Helsinki.

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Acknowledgments

The authors are indebted to the US Army personnel who were subjects in these tests and to Carl A. Stearn who coordinated scheduling of these volunteers. The authors are grateful to John T. Moffitt and Charles R. Bulette for assistance and to Dr. E. G. Cummings for mask resistance measurements and for many constructive suggestions.

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ADDED AIRWAY RESISTANCE AND ENDURANCE IN INTENSIVE EXERCISE

I. INTRODUCTION.

Many private and governmental agencies have been interested in the relationship between physiological performance and the influence of respiratory protective devices. Ordinarily, a protective mask imposes few constraints upon the sedentary individual; but in certain stressful situations, such as firefighting or military combat, a requirement may exist simultaneously for physical exertion and the wearing of a mask. To study the effect of protective masks on physiological responses, men in this laboratory have engaged in walking, bicycling, and a number of other physical activities while wearing masks. Specific features of masks such as resistance to airflow, dead space, weight, limited visual field, discomfort, and covering of the face have also been of interest because of their potential effects on the efficiency of performance. Resistance to airflow has received the greatest attention because breathing is more difficult when masks are worn.

Although curtailment of performance by masked individuals is well documented,[1] the physiological responses are less well understood.[2] This is not surprising, for even in unmasked man it is not entirely clear how the physiological mechanisms limit endurance.[3]

In men engaged in exhausting work at the same rate with or without a mask or added resistance, the effect of the resistance can be expressed as the ratio of time to exhaustion with added resistance (TR2) to time to exhaustion without added resistance (TR1), or TR2/TR1. The decrement in performance due to the added resistance can be expressed as the fraction: (TR1-TR2)/TR1 or, when multiplied by 100, as a percentage of TR1. The size of the decrement would be expected to vary with the added resistance.[1]

The work rate also appears to be a critical factor. From recent studies, the hypothesis that the decrement will be small at high and low work rates and pass through a maximum at some intermediate work rate has emerged. The relationship is illustrated in figure A-1* in modified form in order to combine data from different individuals and conditions. Instead of the work rate, the independent variable is time to exhaustion with minimal added resistance.

A comparison of studies of mask resistance is complicated by the use of different reference or minimum resistance conditions. The bareheaded or no mask condition has the disadvantage of making no provision for measurements of breathing. The nose-clip and mouthpiece have been used with various valve systems. The protective mask has been modified by removal of the filter or the valves. One purpose of the present work is to determine the decrement under a variety of such conditions in comparisons with the bareheaded condition. A second is to test whether there are any residual effects from the faceblank and the head harness when the eyepieces, airways, and valves have been removed. A third purpose is to find out what respiratory measurements can be made in the bareheaded condition. In our experience, neither the volume pneumograph nor the impedance pneumograph has been reliable during exercise. A sensitive thermocouple attached to the nostril appeared to be capable of signaling the time of change in direction of airflow.

* All figures (A-1 through A-9) are in Appendix A.

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II. MATERIALS AND METHODS.

The six respiratory conditions, designated by capital letters, are depicted in figures A-2 through A-7.

Condition (A) is the standard M17A1 protective mask.

Condition (B) is the M17 mask modified to provide a single airway for both inspiration and expiration by removing the voicemitter and blocking the normal inspiratory and expiratory airways. A slight resistance was introduced by inserting a pneumotachometer screen in the airway. The M17 mask lacks the equipment for drinking and resuscitation found in the M17A1 mask. Condition (B) has been studied before under the designation R11[4] and modified M17.[5] In the work of Van Huss and Heusner,[6] condition (B) less the screen was designated MM. Condition (B) is to be distinguished from the E13 blank[7] and the M17A1 blank;[8,9] there the valves were retained and the filter pads were cut away to reduce the inspiratory resistance.

Condition (C) is the M9 mask with the area over the eyes and nose cutaway, and the expiratory valve removed; only the chin rest, periphery, and head harness are left. With restrictions on vision and breathing removed, this condition permits identification of any residual effects.

Condition (D) is the M9 mask with the filter replaced by pneumotachometer screen in its adapter. Condition (D) has been designated R23.[4] With the addition of an adapter and tubing leading to a mixing can for analysis of expired air, condition (D) has been designated R1E1.[1,2]

In condition (E), the nostrils were blocked by a swimmer's nose-clip and the airway was restricted to a mouthpiece leading to a special valve system.* This condition was intended to permit comparison with equipment commonly used in exercise physiology in place of a face mask. The internal dimensions of the mouthpiece (Collins P-530) were 40 X 23 mm at the mouth and 32 mm in diameter at the attachment to the valve. This is distinguished from the smaller mouthpiece used in basal metabolism equipment and in many older exercise studies. The weight of the valve system (mouthpiece and valve box) was 78 grams. The space enclosed was 94 ml. The corresponding figures for the valve box alone were 41 grams and 73 ml. The valves were of the type used in the protective mask nose cup; two were for inspiration and two were for expiration. The valve system was kept light in weight for easy carriage in the mouth without additional support; collection of gas was not intended.

In condition (F), nothing was placed on the face or head except for the clamp from an earring to hold the thermocouple in the nostril. Without this addition, condition (F) was designated ROO.[4] The bareheaded condition was included in other tests.[8-10]

The resistance to airflow of the conditions described above was measured by placing the equipment on a manikin headform through which air was drawn or blown by a vacuum cleaner. Steady rates of 60, 120, 180, and 240 liters per minute in either direction were used. The pressure within the equipment was measured on a water manometer. The results are listed in table B-1.** The pressure for the manikin alone is subtracted to obtain the net pressure added by the equipment.

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* Designed and fabricated in this laboratory by Mr. J. T. Moffitt.

** All tables (B-1 through B-9) are in appendix B.

The exhausting work consisted of a run to a voluntary end point on the treadmill at 7 mph for all subjects and at a grade selected for each subject. At the time of orientation and familiarization with the treadmill, each subject ran twice, generally at 3% slope in the morning and either at level or 6% slope in the afternoon. If the endurance was between 6 and 15 minutes at 3%, that slope was used in all the subject's tests. For those men with endurance of less than 6 minutes at 3%, a level treadmill was used. For those with endurance greater than 15 minutes at 3%, the 6% grade was used. The treadmill speed of 7 mph was chosen because Taylor *et al.*[11] reported that it was the slowest speed at which all their subjects were forced to maintain a running stride

Since a rapid means of obtaining a precise, reproducible treadmill belt speed was unavailable, a simple method for predetermined speed is described.* Reflected light pulses from the teeth of a gear mounted on the axle of the drive drum of the treadmill were detected by a photoelectric cell and counted on a model 521 ER Hewlett Packard Counter. Belt travel at various drive-motor speeds was timed with a stopwatch and converted into miles per hour. Counts were recorded simultaneously during calibration of belt speed. By establishment of the relationship between counts and belt travel, it was necessary only to adjust motor speed until the count for the required speed in miles per hour was displayed.

Three series of tests were performed with the volunteer subjects described in table B-2. In a pilot study on the first four subjects, endurance in conditions (A) and (F) was measured at two treadmill grades to examine the relationship between decrement and work rate.

Subjects 5 through 13 took part in two series of tests under all six conditions. Each man completed one series in 3 days: the schedule is given in table B-3. All subjects used the same set of equipment. Prior to each test they did not know which equipment would be worn next. In each test the men wore their own shorts, fatigue trousers, socks, and boots. Heart rates were obtained from EKG tracings recorded continuously with three chest electrodes. Two of the chest electrodes plus an impedance pneumograph were used to record respiratory frequency in the first series. In series 2, an alternate method was tried to record respiratory frequency. A copper constantan thermocouple of 36-gauge wire, positioned within one nostril, measured the temperature of air as it moved past. The change from heating to cooling indicated when inspiration began, and the change from cooling to heating indicated when expiration began. From these inflection points, the duration of the breath and the frequency could be read from the record of temperature. Absolute measurements of temperature were not made. The output of the thermocouple was fed into a Sanborn DC amplifier (250-2B) and a low-level preamplifier (350-1500A) and recorded with a sensitivity of about 5 mm of pen deflection per degree centigrade change in temperature.

A third series of tests with 10 subjects provided additional comparisons of conditions (C) and (F) (series 3, table B-3).

In series 1, 2, and 3, each test began with a 5-minute warmup walk on a 10% slope at 3 mph. The subject then stood for 3 minutes while the speed and slope were adjusted for the endurance run; he then ran until he could no longer maintain the pace. The running time was recorded to the nearest second with a stopwatch. Room temperature varied from 24° to 28°C.

*Technique developed by Mr. J. T. Moffitt of this laboratory.

III. RESULTS.

In the pilot study, repeated tests with the same subjects at different treadmill slopes showed larger differences in performance times between conditions (A) and (F) at lower slopes than at higher slopes (figure A-1 and table B-4).

In series 1, the six respiratory conditions were tested in six men in random order. In series 2, the conditions were tested again in three of the men used in series 1 and in three new men. since the other three were no longer available. Individual results for running time appear in table B-5. The average running time was shorter in condition (C) than in condition (F) although condition (C) had no added airway resistance. With added resistance in ascending order in conditions (B), (E), and (D), the running time decreased in order. As seen in figure A-8, this applies to both inspiratory and expiratory resistance. However, when the inspiratory resistance increased from (D) to (A) with no change in expiratory resistance, there was no further decrease in running time. The decrements were greater in series 1 than in series 2 except at condition (E). For the three men who took part in both series 1 and series 2, the decrements were smaller in series 2 at every condition. For this series of tests (1 and 2), as a whole, the differences between (F) and the other conditions were highly significant except for condition (C) (table B-6). The differences among the intermediate conditions are also described on table B-6. Both the heart rate and frequency of breathing counted during the last minute of the run increased from one condition to another with the increase in running time (figure A-9, tables B-7 and B-8). Note the sustained frequency of 80 breaths per minute in subject 11 (table B-8).

In order to test further the possibility of a difference between conditions (C) and (F), series 3 was performed with duplicate observations on 10 men, 7 from series 1 and 2 and 3 new men (table B-9). There was an average decrement in endurance of 11% that was significant at the 0.05 level of probability when the results for 2 days were averaged to make 10 comparisons. When the data were separated by day or by time of day, the times were very short on the first afternoon with condition (C); and, conversely, on the second morning, the times with (C) were not significantly different from those for condition (F) on either day in 10 comparisons. In 20 comparisons, the difference between (F) and (C) was barely significant at the 0.05 level by days, but not by time of day.

The short running time with condition (C) on the first afternoon was accompanied by an average heart rate equal to that on the first morning with condition (F). On the second morning, the heart rate was significantly lower for condition (C) in 20 comparisons at the same time of day, but not for the 10 pairs of afternoon runs.

The thermocouple was useful for obtaining breathing rates in exercising subjects. Since the sensor was so small and lightweight, its presence in the nose was unnoticed after a few moments and apparently did not influence breathing or exercise. The only problems encountered thus far have been a loss in sensitivity when the thermocouple made body contact or whenever nasal secretions coated the exposed portion of the sensor.

Several subjects commented on the difficulty of breathing when wearing masks and exercising on the treadmill. The most frequent complaint for masks (A) and (D) was an inability to "move air fast enough." Almost all subjects complained of a dry throat and a problem in swallowing when tested with the large-diameter mouthpiece (E). One subject undoubtedly had a reduced performance time as a result of gagging on saliva which drained into his throat from the valve. No complaints or comments were made by the subjects concerning the other conditions.

IV. DISCUSSION.

The results at different work rates in series 1 agreed well enough with the older data in figure A-1. They emphasize the importance of choosing the appropriate work rate if the maximum sensitivity to added resistance is to be observed. Further work is needed to determine how sensitivity is influenced by absolute work rate, by work rate as a fraction of that required to produce maximum oxygen uptake, and by work rate measured by the time to exhaustion, as in the present tests.

Although the conditions were chosen to provide comparisons with earlier control conditions such as E1R1,* as it turned out they provided a graded series of resistance. The results demonstrated a graded decrement in endurance to the resistances. Although the significance of the difference in decrement between adjacent conditions in figure A-8 was only 0.05 or not significant, the difference between alternate conditions, that is, (F) and (B), (C) and (E), and (B) and (D), was significant at better than the 0.01 level.

The resistance of the (B) condition (contributed by the pneumotachometer screen) had been considered by us to be negligible. While the possibility of a contribution to the decrement by the dead space has not been excluded, the position of (B) on the curve between (C) and (E) suggests an independent effect of resistance.

The position of (E) on the curve indicates that the resistance is the critical feature of the condition rather than the possible effects of the mouthpiece and the nose-clip. Also, the results with the mouthpiece and a set of valves intermediate between those available for physiological studies, of greater and lesser resistance, suggest that this type of equipment may prevent the achievement of the highest oxygen intake in tests of $\dot{V}O_2$ max. Possibly, a comparison with the helmet equipment of Webb[12] is indicated.

The close agreement in endurance between conditions (A) and (D) had not been anticipated in view of the substantial difference in inspiratory resistance. This raises the question of whether the expiratory resistance is critical in this range of inspiratory resistances, and whether it would be advantageous to reduce the expiratory resistance of the protective mask by dividing the outflow between two ports as has been done in the case of inspiratory flow in the M17A1 mask. However, the results with (A) and (D) agree closely with those of masks XM28 and XM28R3 (low),[9] with respect to the size of the decrement and the range of the inspiratory resistance. This can be seen when the data are recalculated to permit plotting (figure A-8).

*E1 = standard expiratory valve used in M9 and M17 masks, and the external tubing; R1 = pneumotachometer in place of the filter.

In view of the disappointing results when training was employed,[4] the improvement in endurance with conditions (A), (D), and (E) from series 1 to series 2 in subjects 5, 9, and 10 is worth noting. However, many more replications would be needed to substantiate it as a training effect. There was a difference in type of work: running in series 1 and 2 and grade walking in the earlier tests.

The well-known difficulty of dealing with a voluntary end point is seen in series 3, which did not clearly discriminate between conditions (A) and (C) The significance of the difference between (A) and (C) ranged from 0.01 to not significant, depending on which subgroups of data were compared.

It may be necessary to consider that condition (C) has an effect in conjunction with some as yet unidentified factor; for example, on the first day. The natural tendency is to suspect a failure of motivation for the second test of the day, but this seems to be ruled out here by the final heart rate, which was the same in the morning and afternoon tests. Condition (C) may have the effect of reducing the frequency of breathing, but the probability that the effect is not due to chance is no greater than it is for running time.

As shown in figure A-9, both the heart rate and the respiratory rate averaged over the final minute of the run in series 1 and 2 increased progressively with the average running time for each respiratory condition. Although the general problem of how resistance modified endurance is not dealt with in this report, a detailed analysis of series 2 data permits a tentative interpretation of the heart rate. In figure A-9, the heart rates for condition (F) are shown averaged over intervals of 15 seconds counting back from the end of the run. The heart rates for the final 15 seconds of the runs at the other conditions are plotted on the same time scale and appear to fall near the points for condition (F) at the corresponding times during the run. It would appear that the heart rate is increasing progressively during the run up to the point of exhaustion, that the time course is much the same for all conditions, that because of the resistance the run is interrupted at various times along this course, and that the heart rate before exhaustion is essentially independent of resistance. Possibly, the same argument would apply to breathing rate.

V. CONCLUSIONS.

The sensitivity of tests of the influence of added airway resistance on endurance in running can be improved by selecting a work rate commensurate with each man's ability. The results were consistent with the hypothesis that the decrement in endurance due to added airway resistance will be small at high and low work rates and will be maximal at some intermediate work rate.

The small added airway resistance commonly found in equipment for making various respiratory measurement during exercise can cause a decrement in endurance in proportion to the size of the resistance.

The results raised the question of whether, in the range of resistances of modern protective masks, the expiratory resistance is more critical than the inspiratory. It might be advantageous to open two ports for the outflow in order to reduce the peak flow through either port.

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APPENDIX A

FIGURES

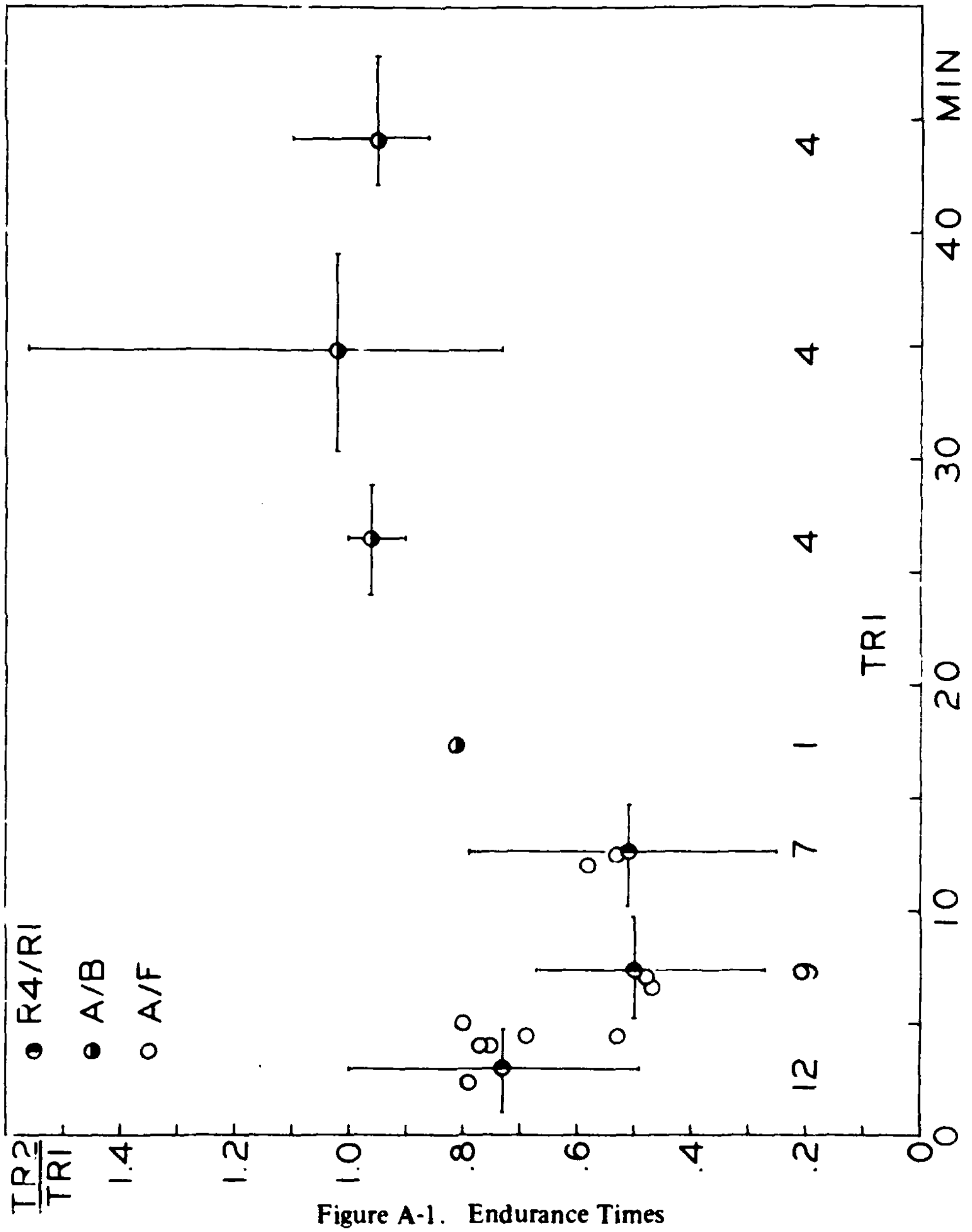

Figure A-1. Endurance Times

The ratio of endurance time at high resistance (TR2) to endurance time at low resistance (TR1) plotted against work rate where work rate is indicated by (TR1). R4/R1 refers to conditions R4E1 and R1E1 and data in table III in reference 2. A/B refers to conditions (A) and (B) described in the method section and data from reference 5. A/F refers to conditions (A) and (F) described in the method section and data from table B-3 in the present paper. The vertical and horizontal bars on the half-filled circle represent the extreme ranges for the number of paired experiments shown below each circle.

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Figure A-2. M17A1 Mask (A). (Front View)

Figure A-3. Modified M17A1 Mask (B). (Front View)

All ports are blocked except one in the front of the mask which has an adapter containing a pneumotachometer screen through which all inspired and expired air passes.

Figure A-4. Modified M9 Mask (C). (Front View)

An earring bearing a thermocouple is clipped to the nostril to record breathing rate.

Figure A-5. Modified M9 Mask (D). (Front View)

The canister of the mask has been replaced by an adapter containing a pneumotachometer screen through which inspired air is passed.

Figure A-6. Moffitt Valve (E). (Side View)

A swimmer's nose-clip is in position. The two expiratory valves are located closest to the lips with only one of the two inspiratory valves visible in the photo. A thermocouple is shown positioned in the airstream within the rubber mouthpiece.

Figure A-7. Unmasked Subject (F)

The earring clipped to the nostril positions the thermocouple for measurement of breathing rate.

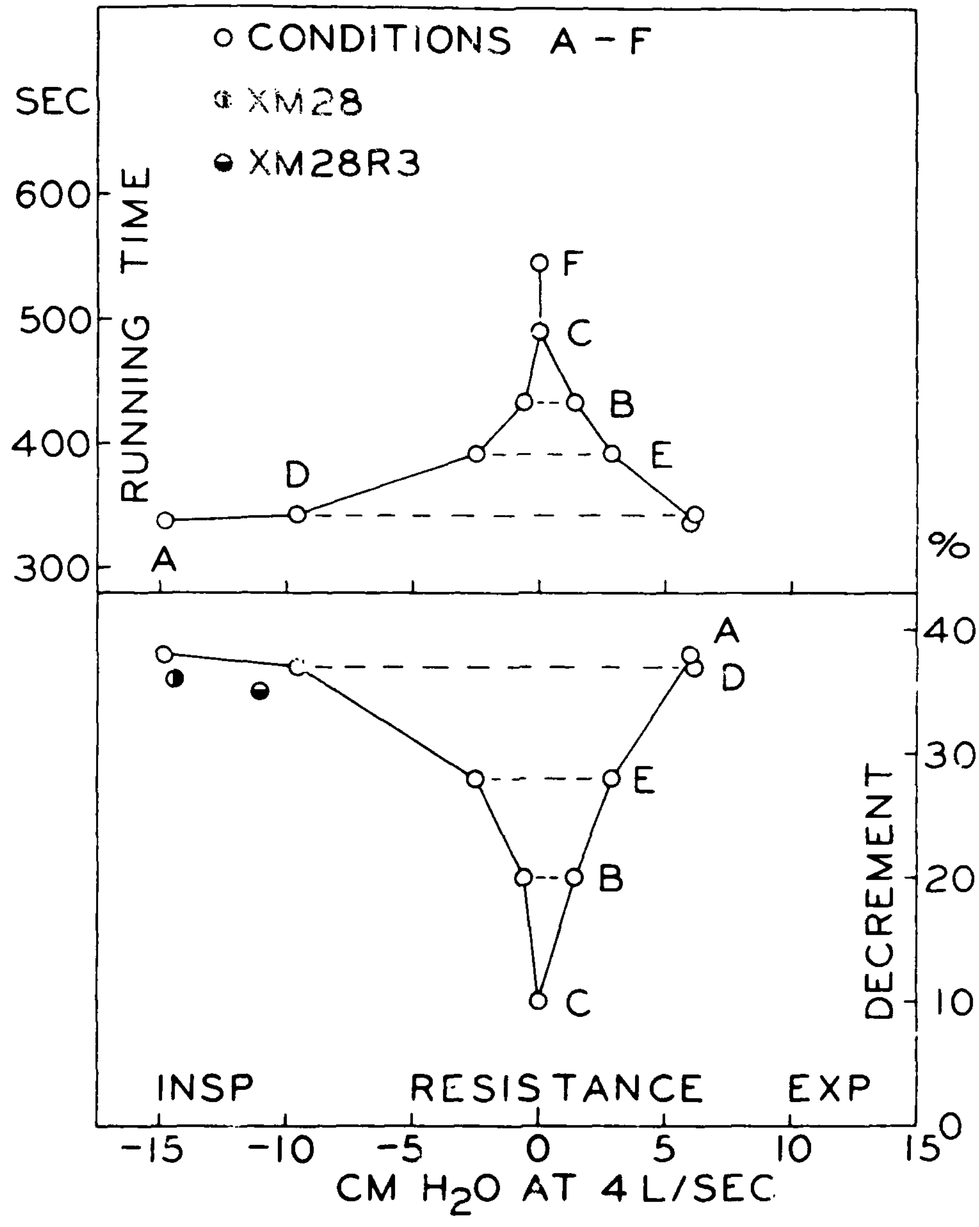

Figure A-8. Endurance and Resistance

Running time (upper panel) for conditions (A) through (F) or decrement with respect to condition (F) plotted against the inspiratory and expiratory resistance. The half-filled circles refer to masks XM28 and X5928R3 (low) and data from reference 9.

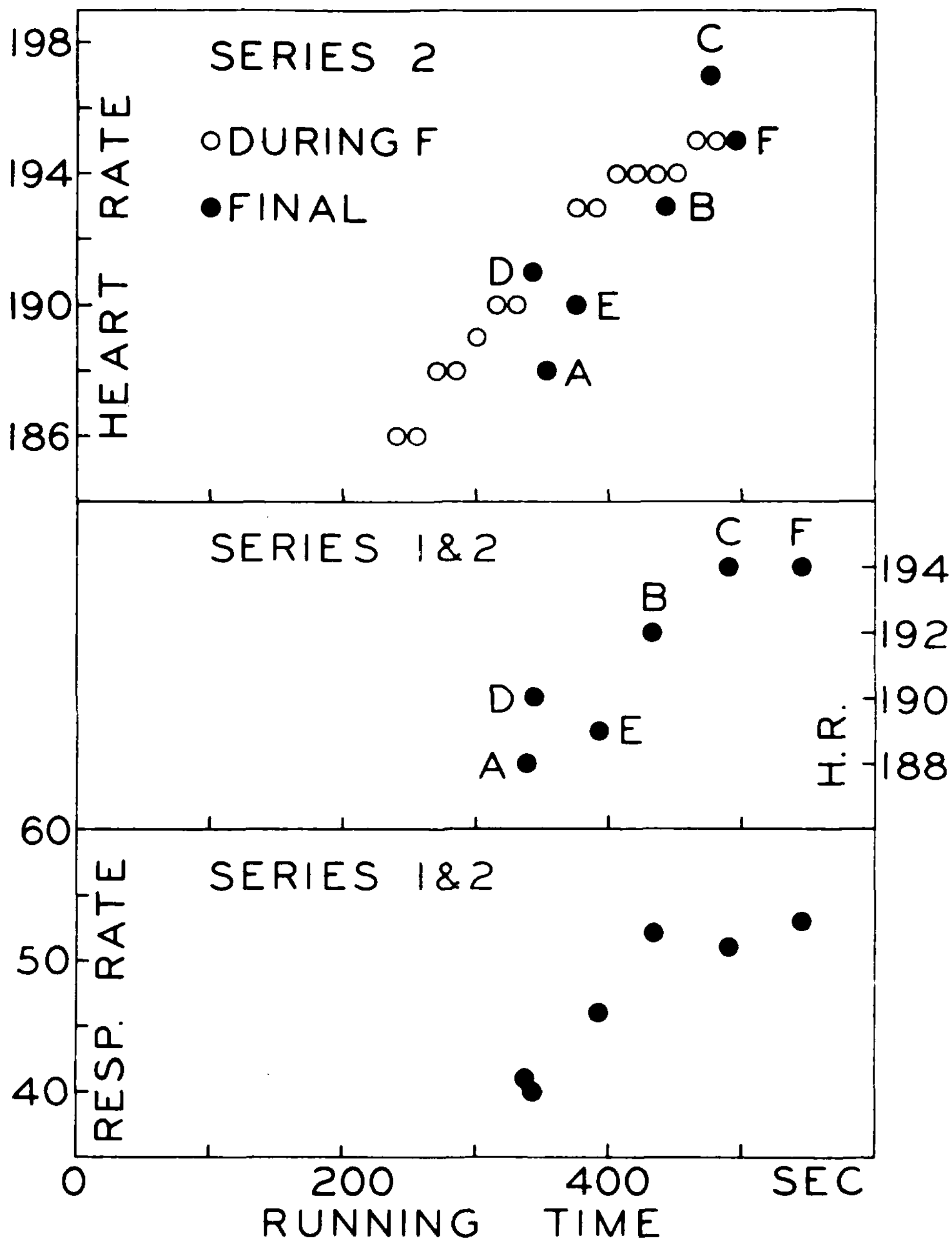

Figure A-9. Final Conditions in Series 1 and 2

The two lower panels show the heart rate and respiratory rate for the final minute at each condition plotted against the average running time for the conditions (A) through (F) averaged for series 1 and 2. In the top panel are shown the heart rate for the final 15 seconds in series 2 only (solid circles) and the heart rate in successive periods of 15 seconds in condition (F) (open circles).

APPENDIX B

TABLES

Table B-1. Resistance Measured on Head Form [a]

Condition	Inspiratory direction l/min				Expiratory direction l/min			
	60	120	180	240	60	120	180	240
	pressure (mm H_2O)							
Head form alone	0.2	1.5	5	10	0.2	1	1.5	4
(A)	30	67	110	158	13	28	47	64
(B)	2	6	10	16	2	7	12	18
(D)	7	24	52	106	13	30	40	66
(E)	10	18	24	35	2	10	20	33
R1E1 [b]	10	23	44	70	12	23	32	39
(D) [c]	4	20	43	90	10	19	28	34

[a] Measurements made by E. G. Cummings on 25 March 1975.

[b] R1E1 equal to (D) plus tubing and mixing can.

[c] (D) with pneumotachometer screen and expiratory valve removed.

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Table B-2. Subject Data

Volunteer No.	Race	Height	Weight	Age
		cm	kg	yr
1. 6850	Caucasian	175	73	21
2. 6794	Caucasian	171	60	20
3. 6802	Black	169	70	21
4. 6792	Black	180	70	22
5. 6833	Caucasian	170	72	24
6. 6832	Black	175	75	23
7. 6846	Black	175	66	24
8. 6820	Black	175	66	19
9. 6818	Caucasian	173	65	24
10. 6839	Black	178	70	18
11. 6850	Black	178	75	21
12. 6808	Caucasian	173	62	24
13. 6831	Caucasian	175	64	18
14. 6835	Black	183	82	21
15. 6834	Black	178	65	19
16. 6816	Caucasian	157	55	19

Table B-3. Test Schedules

Subject	Day 1		Day 2		Day 3		Slope
	am	pm	am	pm	am	pm	
							%
Series 1							
5	(C)	(E)	(A)	(B)	(F)	(D)	3
6	(D)	(E)	(A)	(C)	(B)	(F)	0
7	(E)	(C)	(A)	(D)	(B)	(F)	6
8	(A)	(E)	(D)	(C)	(B)	(F)	6
9	(F)	(C)	(D)	(B)	(E)	(A)	0
10	(D)	(E)	(B)	(F)	(A)	(C)	3
Series 2							
10	(A)	(B)	(C)	(D)	(E)	(F)	3
9	(B)	(C)	(D)	(E)	(F)	(A)	0
5	(C)	(D)	(E)	(F)	(A)	(B)	3
11	(D)	(E)	(F)	(A)	(B)	(C)	3
12	(E)	(F)	(A)	(B)	(C)	(D)	3
13	(F)	(A)	(B)	(C)	(D)	(E)	3
Series 3							
5	(F)	(C)	(C)	(F)			3
11	(F)	(C)	(C)	(F)			3
10	(F)	(C)	(C)	(F)			3
12	(F)	(C)	(C)	(F)			3
9	(F)	(C)	(C)	(F)			0
7	(F)	(C)	(C)	(F)			6
14	(F)	(C)	(C)	(F)			0
8	(F)	(C)	(C)	(F)			6
15	(F)	(C)	(C)	(F)			3
16	(F)	(C)	(C)	(F)			0

Table B-4. Pilot Study to Define Work Rate

Subject	Slope	Endurance at condition		(A/F)	Slope*	Endurance at condition		(A/F)
		(F)	(A)			(F)	(A)	
	%	sec			%	sec		
1	3	720 (1)	420 (3)	0.58	6	300 (4)	240 (2)	0.80
2	0	266 (4)	184 (2)	0.69	3	239 (1)	181 (3)	0.76
3	0	423 (4)	204 (2)	0.48	3	266 (1)	141 (3)	0.53
4	0	394 (4)	186 (2)	0.47	3	239 (1)	183 (3)	0.77
JTM**	0	250 (4)	133 (2)	0.53	3	180 (1)	143 (3)	0.79

Note: Figures in parentheses indicate order of test.

* Speed: 7 mph.

** Civilian employee: age 47 years, height 166 cm, weight 85 kg.

Table B-5. Performance Time, Series 1 and 2

Subject	Series	Slope	Performance time						Average (A-F)
			Condition						
			(A)	(B)	(C)	(D)	(E)	(F)	
			Inspiratory (top) and expiratory (bottom) pressures in mm H_2O at 4 liter/sec						
			-148 / 60	-6 / 14	0 / 0	-96 / 62	-25 / 29	0 / 0	
		%	sec						sec
5	1	3	363	447	656	469	442	840	536
	2	3	578	543	635	450	775	698	613
9	1	0	320	320	287	177	349	390	307
	2	0	276	354	396	256	312	393	331
10	1	3	259	241	420	202	263	377	293
	2	3	331	348	415	310	289	483	362
6	1	0	233	398	484	399	282	600	399
7	1	6	366	479	453	447	527	523	462
8	1	6	407	672	710	357	598	688	572
11	2	3	335	586	595	326	320	692	475
12	2	3	451	547	560	450	283	538	471
13	2	3	142	270	289	267	270	312	258
Mean	1 & 2		338	434	490	343	392	545	
	1		324	426	498	342	410	569	428
	2		352	441	481	343	374	519	418
5, 9, 10	1		314	336	454	282	351	535	
5, 9, 10	2		395	415	482	338	458	524	
Decrement, %									
	1 & 2		38	20	10	37	28		
	1		43	25	12	40	28		
	2		32	15	7	34	28		
5, 9, 10	1		41	37	15	47	34		
5, 9, 10	2		25	21	8	35	13		

Table B-6. Significance* of Difference in Mean Performance Times in Series 1 and 2

Mean, sec	338	434	490	343	392	545
Condition	(A)	(B)	(C)	(D)	(E)	(F)
(A)	X					
(B)	0.01	X				
(C)	0.001	0.05	X			
(D)	NS	0.01	0.001	X		
(E)	NS	NS	0.01	NS	X	
(F)	0.001	0.001	0.05	0.001	0.001	X

* Pairs for individuals and replicates in table 5 were reduced to ratios. The standard error for the mean ratio was calculated, and the significance of the difference between the mean ratio and unity was determined by the t test.

Note: NS = not significant.

Table B-7. Heart Rate During Final Minute of Exercise, Series 1 and 2

Subject	Heart rate					
	Condition					
	(A)	(B)	(C)	(D)	(E)	(F)
	beats/minute					
5	185	186	194	188	188	189
5	181	185	191	190	187	188
9	199	207	204	194	199	208
9	198	205	199	200	203	204
10	184	183	185	173	182	188
10	184	192	193	184	184	193
6	180	185	188	188	175	191
7	190	195	195	196	194	198
8	192	190	193	187	195	188
11	198	198	199	185	185	202
12	183	187	195	195	182	191
13	183	190	196	194	199	192
Mean	188	192	194	190	189	194

Table B-8. Respiratory Rate During Final Minute of Exercise, Series 1 and 2

Subject	Respiratory rate					
	Condition					
	(A)	(B)	(C)	(D)	(E)	(F)
5	46	50	52	45	44	52
5	45	49	49	43	55	53
9	39	47	43	32	47	44
9	38	45	46	35	43	45
10	39	35	37	32	33	39
10	34	38	39	35	40	39
6	38	56	59	47	47	66
7	45	57	58	46	55	61
8	40	70	55	48	37	70
11	46	81	80	39	60	65
12	44	45	45	45	40	48
13	39	51	52	37	46	53
Mean	41	52	51	40	46	53

Table B-9. Results for Series 3

Subject	Performance time				Heart rate (last minute)				Respiratory rate (last minute)			
	Day 1		Day 2		Day 1		Day 2		Day 1		Day 2	
	am (F)	pm (C)	am (C)	pm (F)	am (F)	pm (C)	am (C)	pm (F)	am (F)	pm (C)	am (C)	pm (F)
	sec				beats/minute				breaths/minute			
5	747	580	633	592	190	189	186	188	48	44	39	45
7	420	438	640	697	188	190	191	191	62	54	64	66
8	650	353	745	623	200	199	194	195	68	50	70	72
9	285	275	317	263	204	205	199	204	46	45	45	46
10	293	227	190	266	181	182	173	188	42	40	42	41
11	470	392	388	353	196	193	186	193	67	67	57	76
12	492	365	415	371	187	184	178	178	44	44	47	45
14	386	335	264	506	195	196	189	193	48	46	44	48
15	498	335	637	500	186	186	180	177	58	54	50	54
16	360	237	322	294	195	19[illegible]	191	191	58	51	53	49
Mean	460	354	455	447	192	192	187	190	54	50	51	54