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TRAINING TO IMPROVE ENDURANCE IN EXHAUSTING WORK OF MEN WEARING PROTECTIVE MASKS: A REVIEW AND SOME PRELIMINARY EXPERIMENTS

by

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July 1971

DEPARTMENT OF THE ARMY
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13. ABSTRACT

In order to identify some of the problems involved in protective mask training, small groups of medical volunteers were tested in exhausting work before and after 3 or 8 days of training. The men wore M9 and M17 masks with filters removed and with various inspiratory and expiratory resistances added. In training to improve endurance in exhausting work while wearing the protective mask, as few as from 3 to 8 practice sessions will probably be ineffective. Although endurance was not improved by a few practice sessions, the reduction in heart rate suggests a beginning was made in overcoming the psychological handicap of the mask and training situation. In addition to the resistance of the filter, the facepiece without the filter has a degrading effect on endurance. Available evidence indicates that physical fitness is a factor in endurance while wearing the protective mask. The longer one can work in the unmasked, the longer one can work in the masked. Thus, training for physical fitness should improve the endurance of masked men. In inexperienced men the ratio of endurance when masked to endurance when unmasked is not affected by fitness. Results with one experienced but unfit subject suggest there may be an experience factor as well as a fitness factor. Under the conditions of these experiments, small differences in expiratory resistance had no effect on endurance.

14. KEYWORDS

Inspiratory resistance	Respiratory frequency
Expiratory resistance	Inspiratory time
Respiratory minute volume	Expiratory time
Respiratory tidal volume	Heart rate

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FOREWORD

The work described in this report was authorized under Task 1B662710AD250104, Medical Defense Against Chemical Agents/Biomedical Evaluation of Protective Material/Analysis of Physical and Chemical Stresses on Men. The experimental work was started in July and completed in October 1970.

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

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DIGEST

In order to identify some of the problems involved in protective mask training, small groups of medical volunteers were tested in exhausting work before and after 3 or 8 days of training. The men wore M9 and M17 masks with filters removed and with various inspiratory and expiratory resistances added. A number of conclusions were drawn.

In training to improve endurance in exhausting work while wearing the protective mask, as few as from three to eight practice sessions will probably be ineffective. Although endurance was not improved by a few practice sessions, the reduction in heart rate suggests a beginning was made in overcoming the psychological handicap of the mask and training situation.

Even without the filter, the facepiece has a degrading effect on endurance.

Available evidence indicates that physical fitness is a factor in endurance while wearing the protective mask. The longer one can work unmasked, the longer one can work masked. Thus, training for physical fitness should improve the endurance of masked men.

In inexperienced men the ratio of endurance when masked to endurance when unmasked is not affected by fitness. Results with one experienced but unfit subject suggest there may be an experience factor as well as a fitness factor.

Under the conditions of these experiments, small differences in expiratory resistance had no effect on endurance.

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I. INTRODUCTION.

A. Background.

1. Mask Design Versus Training.

Over the last 50 years improvements in design have considerably reduced the resistance to breathing imposed by protective masks. Nevertheless, the degradation of physical performance, attributed to the respiratory burden of the mask, remains a serious problem. Two ways of overcoming the problem are by further reduction of resistance in the mask and by a greater effort in training. With regard to mask design, the objective is clear, and one can weigh the advantages and disadvantages of a further reduction in resistance. With regard to training, the basic information is scanty. Little is known about what can be expected of training, what kind of training is needed, how long it will take, and how long it will last. The need for training is indicated in FM21-48,[1] and the introduction to the CBR Training Guide[2] suggests that training may take from 4 to 6 months. The present authors' concern with training is to provide operating instructions to the user as a step in the human factors engineering phase of mask development.

2. Kinds of Work Affected by the Mask.

Before taking up the matter of training, we must identify the performance degraded by the mask. The impact of the resistance to breathing associated with the mask is on the intensive ventilation of the lungs required by severe physical exercise. Added respiratory resistance reduces the frequency of breathing and the total ventilation. A greater extraction of oxygen from the respired air compensates for the reduction in ventilation. Masked resistance need not interfere with the performance of work of moderate intensity when the environmental temperature is low enough to prevent the overheating arising from the thermal insulation of the "closed suit" permeable protective outfit.

For the present, we can assume that inspiratory resistance does not impair the performance of submaximal work in fit men. This assumption is based upon wartime experience with the mask, permeable protective clothing, and full packs in a 14-mile hike;[3,4] a recent study of ergometer work at 80% of maximal oxygen intake;[5] and a test in which masks were worn continuously for 24 hours[6] and almost continuously for 48 hours more. Cumulative fatigue in long-continued wear is a possibility, but not enough information is available to form a basis for consideration of this point.

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[1] FM 21-48. Chemical, Biological and Radiological (CBR) and Nuclear Defense Training Exercise. Headquarters, Department of the Army. September 1968.

[2] Pamphlet 8. CBR Training Guide. US Army Chemical Center and School. Fort McClellan, Alabama. September 1968.

[3] Beckwith, J. R., and Helm, J. D., Jr. MRL(EA) Report 27. Tolerance of Men to the Service Gas Mask Under Varying Conditions. 8 July 1944. UNCLASSIFIED Report.

[4] Helm, J. D., Jr. Miscellaneous Report 5033-8. Medical Division OC-CWS, Edgewood Arsenal. Tolerance of Soldiers in the Tropics to the Gas Mask. 22 May 1944. UNCLASSIFIED Report.

[5] Gee, J. B. L., Burton, G., Bassalo, C., and Gregg, J. Effects of External Airway Obstruction on Work Capacity and Pulmonary Gas Exchange. Amer. Rev. Resp. Dis. 98, 1003-1012 (1968).

[6] Cummings, E. G., Marrero, J., Bird, E., with psychological evaluation by Earl Davy. CRDLR 3097. Seventy-Two Hour Outdoor Wearing Trial of Individual CBR Protecting Clothing with M17 Mask and E33 Hood Under Simulated Combat Conditions. September 1961. UNCLASSIFIED Report.

The deleterious effects of the mask are best seen in hard work leading to exhaustion in less than about 30 minutes. Because exhaustion is subjective, carefully controlled experiments with well-motivated men are required if significant results are to be obtained. The types of work usually studied are running for speed over a fixed distance on the ground, walking or running on the treadmill at fixed speed and grade for endurance, and pedaling on the cycle ergometer for endurance. There appears to be a difference between running on the track and running on the treadmill at about the same average speed. Van Huss and Heusner[7] tested members of a track team with and without the M17 mask. For a distance of 1 mile, the running time was increased from 361 seconds (9.7 mph) unmasked to 389 seconds with the M17. This is a decrement of 5% in speed. For a run at 10 mph on the treadmill, the endurance was 393 seconds unmasked (a distance of 1.09 miles) and 300 seconds with the M17. This is a decrement in endurance of 24%.

The intensity of work is another variable, identified in a study of medical volunteers walking on an inclined treadmill at 3.5 mph and wearing the M9 facepiece with and without a large added inspiratory resistance.[8] In a number of men walking at various grades, the endurance without added resistance was, as would be expected, greater the lower the grade. The decrement in endurance caused by the added resistance, however, was less at the steeper than at the lower grades. That is, for grades leading to exhaustion in 1 to 5 minutes without added resistance, the decrement in endurance resulting from added resistance averaged 27%. For lower grades, leading to exhaustion in from 5 to 16 minutes without added resistance, the decrement was 50%. The added resistance in this instance was 220 mm H_2O at 85 liter/min or more than twice as great as that of the filter of the M9A1 mask or the older assault type.

In a different task–riding a cycle ergometer–a group of well-motivated soldiers during the World War II was able to work for an average of 11.7 minutes wearing an assault mask with the filter removed. When the filter, with a resistance of 65 mm H_2O at 85 liter/min, was added they were able to work for 10.5 minutes; that is, without a significant decrement in endurance. In a second comparison of resistances of 2, 53, 65, and 77 mm H_2O at 85 liter/min, the times were 12.2, 12.2, 12.0, 12.0, and 12.5 minutes respectively. The men had trained on the ergometer for 3 weeks in the mask without a filter.[9]

A variant of the treadmill task is to allow the men to work for a fixed period at a non-exhausting intensity and then increase the intensity and determine the time to exhaustion. In a test by Silverman et al.,[10] the soldiers carried a 50-pound load at 4.3 mph and 2.5% grade for 15 minutes. The speed then was increased to 5.6 mph. After this, the time to exhaustion was 195 seconds with the assault mask with filter removed and 150 seconds with filter added, a 23% decrement.

In a modification of this test, Blockley and Annis[11] had their civilian subjects walk for 1 or 2 hours on the level at 3.5 mph; then, after a 5-minute rest, the men walked to exhaustion at a grade of 15%. These authors indicate that (1) after the sensitizing walks, the endurance was reduced to about one-half by the M17 mask, and (2) they could discriminate the effects of resistances of

[7]Van Huss, W. D. and Heusner, W. W. Michigan State University. Final Report. Contract DA 18-035-AMC-257(A). The Respiratory Burden of the Field Protective Mask. September 1965. UNCLASSIFIED Report.

[8]Craig, F. N., Blevins, W. V., and Cummings, E. G. EATR 4478. Exhausting Work Limited by External Resistance and Inhalation of Carbon Dioxide. December 1970. UNCLASSIFIED Report.

[9]Dumke, P. R., Himmelfarb, S., and Whittenberger, J. L. MDR 9. The Effect of the Resistance to Inspiration Imposed by the Combat Gas Mask Canister on the Ability of Soldiers to do Exhaustive Work in Temperate and in Simulated Tropical Conditions. 27 November 1944. UNCLASSIFIED Report.

[10]Silverman, L., Lee, R. C., Lee, G., Brouha, L., Whittenberger, J. L., Stiff, J. F., Byrne, J. E., Jr., and Smith, D. P. Harvard School of Public Health. Contract OEMsr 306. Fundamental Factors in the Design of Protective Respiratory Equipment: Endpoint Breathing Rate Studies. 1 August 1944. UNCLASSIFIED Report.

[11]Blockley, W. V., and Annis, James. Webb Associates. Final Report. Subcontract A-815-3(A). Physiological Studies of Respiratory and Thermal Burden. August 1964. UNCLASSIFIED Report.

one-third and two-thirds the resistance of the M17 mask. Not enough data were reported to establish the reliability of these intermediate effects.

3. The Facepiece.

The soldier has only one choice to wear or not to wear a mask. Some of the foregoing experiments have dealt with these conditions. The problem for the designer, however, is not to eliminate the facepiece, but to evaluate the effect of a change in resistance. This has been dealt with in other of the foregoing experiments. Even with the filter removed, the valves and airways offer some resistance, and the dead space lowers the efficiency of gas exchange. It remains to ask whether the critical factor is the facepiece and not the filter. Cummings et al.[12] tested M9 masks with standard filters and with blank filters of the same weight in a half-mile run with soldiers from the medical volunteer program. The average running times for the unmasked condition, the M9 blank, and the M9 were 174, 184, and 193 seconds respectively. The two masked conditions were significantly different from the unmasked condition but not from each other.

Van Huss and Heusner[7] modified the M17 mask by blocking the normal ports and removing the voicemitter to provide unobstructed breathing through an opening at the front of the mask. The running times both on the track and on the treadmill with the modified mask were intermediate between the times for the unmasked and standard mask conditions, but the intermediate differences were not statistically significant. The intermediate differences were large enough to suggest the need for further investigation of the facepiece.

4. Training and Fitness.

Practice in wearing the mask is a feature of training for chemical operations that needs to be distinguished from physical training for the purpose of improving fitness for hard work. There is little evidence bearing on the relation between the two. In chemically untrained men asked to don the mask and perform hard work, the physically fit perform better than the unfit. Few of the soldiers encountered in our medical volunteer program are fit. For example, Cummings, Blevins, and Bulette[13] recorded an average voluntary endurance time of 291 seconds in a run at 8 mph on the treadmill, whereas track team members[7] ran at 10 mph on the treadmill for 449 seconds in series 1 and 384 seconds in series 2. These times are for the unmasked condition. When these men ran with the M17 mask on, the times were 187 seconds for the medical volunteers, 352 seconds for series 1, and 288 seconds for series 2. Thus, fitness as measured by endurance in running conferred an advantage when the mask was worn. On a fractional basis, however, the decrements of 26%, 22%, and 25% respectively were similar. From the standpoint of chemical training, the problem is how best to reduce these decrements.

There is a physiological basis for expecting an improvement in performance while wearing the mask to result from training for hard work. At a given work rate, the ventilation of the lungs varies among individuals. In general, athletes have a smaller minute volume.[14] Also, in men undergoing physical training with a cycle ergometer, ventilation decreases over a period of 2 months.[15]

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[12]Cummings, E. G., Blevins, W. V., Greenland, C. M., and Craig, F. N. CWLR 2254. The Effect of Protective Masks on the Soldier's Ability to Run a Half-Mile. October 1958. UNCLASSIFIED Report.

[13]Cummings, E. G., Blevins, W. V., and Bulette, C. R. EATR 4304. Physical Performance Comparison of Men Wearing M17, M22 and XM 28 Protective Masks in Hot Environments. June 1969. UNCLASSIFIED Report.

[14]Silverman, L., Lee, G., Yancy, A. R., Amory, L., Barney, L. J., and Lee, R. C Harvard School of Public Health. Contract OEMsr 306. Fundamental Factors in the Design of Protective Respiratory Equipment: A Study and an Evaluation of Inspiratory and Expiratory Resistances for Protective Respiratory Equipment. 1 May 1945. UNCLASSIFIED Report.

[15]Schneider, E. C., and Ring, G. C. The Influence of a Moderate Amount of Physical Training on the Respiratory Exchange and Breathing During Physical Exercise. Amer. J. Physiol. *91*, 103-114 (1929).

If the frequency and rate of instantaneous flow are less, a lower pressure is required to overcome inspiratory resistance so that the fit person should be better able to accommodate to the mask.

In a treadmill task at progressively increasing grade, a relation between breathing frequency and decrement in performance caused by added inspiratory resistance appeared in an unselected group of four volunteers.[16] In duplicate trials the frequencies at low resistance were 55, 67, 48, and 48 breaths per minute in two men and 38, 38, 25, and 30 breaths per minute in the other two. The corresponding decrements in performance were 17%, 35%, 31%, and 28% in the first two volunteers and 7%, 15%, 5%, and 7% in the second two.

Another variable is the relation between the rate of instantaneous flow and time during a single breath. For a given tidal volume, a square wave form is more efficient than a triangular wave form because with the former the peak rate of flow is less; hence, less work is required to overcome the resistance.[17] The only systematic application of these ideas to gas mask training that we have encountered has been made by Soloviev.[18] Unfortunately, he does not give data to demonstrate the effectiveness of his methods in the form of the progressive improvement of performance during a period of training.

Data of this sort appear in a report by Mercer.[19] His subjects included 16 men from the Army Student Training Program and 19 medical students, all from the University of Pennsylvania. The test was for speed on the track over a distance of 1/2 mile. Because the subjects had no track experience they were instructed in body mechanics, running form, and pace. They worked out for half an hour 3 days per week. In the 2d and 3d weeks they made four test runs. In the 4th week gas masks were issued with instructions on their construction, fitting, and care. The importance of deep, regular, slow breathing was emphasized. Two tests with the masks were run. In the 5th week, the men received further instruction and practice with the mask and ran one test without the mask. In the 6th week there were two tests, one with the mask and one without. The running time improved with practice with and without the mask. When first tried, the mask increased the time required to run the half-mile by about 14%; on the last trial with the mask the increase was about 5%. The major improvement came between the first and second runs with the mask. The 5% figure agrees with the results for the half-mile and 1-mile runs of Van Huss and Heusner.[7] Although Mercer stressed the importance of breathing, there were no observations on how the men breathed during the runs.

Given fit men, one would expect additional training in wearing the mask to reduce the decrement in performance from the unmasked to the masked condition. The only experimental evidence is negative. Two groups of track team members at Michigan State practiced on the track for 17 days: one group wore the M17 mask. In subsequent trials for speed over a distance of 1 mile, the mask-trained group had average times of 370 seconds unmasked and 389 seconds masked. The group that had trained previously without the mask also had average times of 370 seconds unmasked and 389 seconds masked.

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[16] Craig, F. N., Froehlich, H. L., and Blevins, W. V. EATR 4230. Inspiratory Resistance as a Limiting Factor in Exhausting Work. October 1968. UNCLASSIFIED Report.

[17] Silverman, L., Lee, R. C., Lee, G., Drinker, K. R., and Carpenter, T. M. Harvard School of Public Health. Contract OEMsr 306. Fundamental Factors in the Design of Protective Respiratory Equipment. Inspiratory Air Flow Measurements on Human Subjects With and Without Resistance. 1 January 1943. UNCLASSIFIED Report.

[18] Soloviev, V. K. CWL 550-R-247. Physiological Basis of the Training in Gas Masks. Translated by Claudius F. Mayer, M. D. December 1959. UNCLASSIFIED Report.

[19] Mercer, E. L. University of Pennsylvania. ETF 611-23. Gas Mask Testing Program. 22 July 1944. UNCLASSIFIED Report.

5. Expiratory Resistance.

The modification of the M17 mask to provide for drinking and for resuscitation (M17A1) involved the addition of a second expiratory valve in series with the first. The men described in the previous paragraph also ran a mile wearing the M17A1 mask.[7] The times were 387 seconds for the mask-trained group and 400 seconds for the other group. The difference, although small, was statistically significant.

B. Objectives.

Because the medical volunteers are available for only 5 weeks of testing, it was not expected that much change in physical fitness could be produced in an experimental training program. An experiment was planned with a small number of men to see whether the decrement in performance of hard work produced by added inspiratory resistance could be reduced by a few days of familiarization with the mask. A second objective was to compare the unmasked condition with a high and a low inspiratory resistance condition during exhausting work on the inclined treadmill. A third objective was to see whether the breathing pattern in unfit men could be altered in the direction of reduced frequency and ventilation. A fourth objective was to examine in unfit men the effect of small differences in expiratory resistance.

II. EXPERIMENTAL PLAN.

The various resistance conditions are described in table I. Condition R11 was selected to provide the least respiratory resistance consistent with obtaining measurements of air flow. The normal ports of the M17 mask were blocked, and the voicemitter was removed to provide an opening for the insertion of a screen pneumotachometer with an inside diameter of 41 mm. Thus, the subject breathed back and forth through the same opening. With R22, 23, and 24, the airways and inspiratory valve of the M9 mask were unchanged, but the filter was replaced by the pneumotachometer. In R32, 33, and 34, the largest resistance described earlier,[16] the R4, was added to the inspiratory resistance. In R23 and R33, the standard expiratory valve was used. An increase in expiratory resistance beyond that used in R24 and R34 would result in expired air being blown out around the face seal in heavy work.

All the work was done on the treadmill at room temperature (65° to 74°F) at 3.5 mph. The subjects wore socks, undershirts, shorts, and their own boots. The experimental plans for series I (May 1970) and series II (September and October 1970) appear in table II. The subjects are described in table III. They were enlisted men furnished by the Medical Volunteer Program and were used according to AR 70-25 with the exception of subject 6, who was a civilian employee. Subject 2 appeared to be moderately fit. Subjects 7 and 8 volunteered because they hoped to improve their fitness during the program.

III. RESULTS.

The times to exhaustion (endurance) and final heart rates in series I are listed in table IV. At 15% and 22% treadmill grades and R23 and R33, the performance was much as had been reported earlier.[8] Endurance improved slightly in the unmasked condition R00 from the 1st to the 3d week, but in the R33 condition endurance was less in the 3d than in the 1st week. In 19 out of 20 comparisons, endurance was less in the R23 than in the R00 conditions. Ventilation was not measured in series I, but the frequency of breathing at exhaustion was counted from the record of mask pressure (table V). The duration of inspiration and expiration were recorded also.

The results for the first 4 weeks of series II are given in tables VI and VII. Here again, endurance was less in the masked than in the unmasked condition after training. Subject 7 improved in endurance at 10% and 15% grades, but subject 8 deteriorated. In response to coaching during the

Table I. Resistance Conditions

Code	Facepiece	Added resistance			
		Inspiratory		Expiratory	
		Source	Amount	Source	Amount
			mm H_2O at 85 liters/min		*mm H_2O at 85 liters/min*
R00	None	-	-	-	
R11	M17	Pneumotachometer No valves	3	Pneumotachometer No valves	3
R22	M9	Pneumotachometer Standard inspiratory valve	3 6	Standard inspiratory valve	6
R23	M9	Pneumotachometer Standard inspiratory valve	3 6	Standard expiratory valve	16
R24	M9	Pneumotachometer Standard inspiratory valve	3 6	Two standard expiratory valves in series	37
R32	M9	R4* Pneumotachometer Standard inspiratory valve	220 3 6	Standard inspiratory valve	6
R33	M9	R4* Pneumotachometer Standard inspiratory valve	220 3 6	Standard expiratory valve	16
R34	M9	R4* Pneumotachometer Standard inspiratory valve	220 3 6	Two standard expiratory valves in series	37

*R4 consisted of a sandwich of wire mesh and unbleached muslin compressed between plastic rings with an inside diameter of 41 mm and mounted in a plastic adapter between the pneumotachometer and the inspiratory valve.

training period, subject 7 reduced his frequency of breathing, particularly at the 10% grade, but subject 8 was unable to change. The reduction in frequency in subject 7, however, was accomplished by introducing periods of zero flow between the inspiratory and expiratory phases of breathing. The times of inspiration and expiration shown in tables VI and VII represent the periods devoted to moving air. In subject 7 at exhaustion, an average respiratory cycle in R23 at 10% grade consisted of 1.25 seconds for inspiratory flow, 1.03 seconds for rest, 0.68 seconds for expiratory flow, and 0.98 seconds for rest before the next inspiration. With R33 and 10% grade, the corresponding figures were 2.67, 0.80, 0.63, and 0.73 seconds. With R11 and 10% grade, the corresponding figures were 0.97, 2.03, 0.67, and 1.50 seconds.

Table II. Experimental Plan

Series	Week	Item
I	1	Pretraining test: Work to exhaustion at 10% grade on successive days at R00, R23, and R33.
	2	Training: Work to exhaustion at both 15% and 22% grades on successive days at R00, R23, and R33.
	3	Posttraining test: Repeat program of week 1.
II	1	Pretraining test: Work to exhaustion at 10%, 15%, and 22% grades on successive days at R00, R11, R23, and R33.
	2	Training: Work for 6 periods of 10 minutes (masked), followed by work to exhaustion at 15% and 22%, all at R33.
	3	Training: Repeat program of week 2.
	4	Posttraining test: Repeat program of week 1.
	5	Expiratory resistance test: Work to exhaustion at 15% grade four times a day as follows: day 1 R11, R22, R24, R11; day 2 R11, R32, R34, R11; day 3 R11, R24, R22, R11; and day 4 R11, R34, R32, R11.

Table III. Subject Data

Man	Initials	Record No.	Age	Height	Wt	Respiratory data at exhaustion at 15% grade and R23			
						Time	V_I[a]	f[b]	V_T[c]
			yr	*cm*	*kg*	*min*	*liter/min*	*breaths/min*	*liter*
1	JWP	5870	20	183	87	9	87.0	41.0	2.12
2	PA	5881	19	176	81	13	79.5	38.9	2.04
3	TP	5873	23	183	73	9	59.4	31.6	1.88
4	GL	5886	22	176	87	6	116.8	51.2	2.27
5	ECZ	5883	21	183	75	9	72.5	41.0	1.77
6	FNC 7/18/68		57	172	59	10	58.0	28.3	2.05
	10/26/70[d]		59	172	59	5	68.1	32.4	2.11
7	JK	5939	24	178	75	7	72.0	43.9	1.64
8	FF	5941	24	177	92	5	95.5	46.1	2.07

[a] V_I = respiratory minute volume.

[b] f = frequency.

[c] V_T = tidal volume.

[d] R22.

Table IV. Series I, Endurance and Final Heart Rate

Week of test	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
Resistance	R00	R23	R33	R23/R00 × 100	R33/R23 × 100	R00	R23	R33	R23/R00 × 100	R33/R23 × 100	R00	R23	R33	R23/R00 × 100	R33/R23 × 100	R00	R23	R33	R23/R00 × 100	R33/R23 × 100
Treadmill grade, %	10	10	10	10	10	15	15	15	15	15	22	22	22	22	22	10	10	10	10	10
Endurance in min																				
Man 1	30.0	17.2	10.4	57	61	11.5	9.2	4.6	80	50	2.7	1.9	1.7	71	90	32.5	15.5	7.2	48	46
Man 2	120.0[a]	93.0	35.3	78	38	22.0	13.9	7.6	63	54	4.9	3.4	2.4	68	72	120.0[a]	97.1	25.0	81	26
Man 3	42.2	30.0	20.0	71	67	16.0	9.7	3.5	60	36	3.6	2.8	1.8	76	63	45.0	42.6	17.7	95	42
Man 4	32.3	41.9	16.1	129	38	9.6	8.4	7.8	90	93	2.4	2.1	2.0	87	97	54.0	25.6	12.9	47	50
Man 5	27.4	14.8	11.7	54	79	13.7	10.0	6.6	73	66	4.6	3.3	2.3	72	68	30.2	24.0	12.6	82	52
Man 6 (5 Jun 70)			(75.0)																	
Avg (1-5)	50.4	39.4	18.7	78	57	14.6	10.2	6.0	73	60	3.6	2.7	2.0	75	78	56.3	40.9	15.1	71	43
Table 3, ref 8[b]							12.6	6.4		51		3.0	2.2		73					
Heart rate, beats per min																				
Man 1	180	170	161			180	183	165			180	175	169			162	163	152		
Man 2	152	165	155			164	171	164			179	179	163			150	164	150		
Man 3	140	160	175			170	162	157			176	173	165			134	158	157		
Man 4	180	176	170			180	184	180			185	180	183			168	162	170		
Man 5	144	154	149			178	175	159			193	182	169			147	151	148		
Man 6			(163)																	
Avg (1-5)	159	165	162			174	175	165			182	177	169			152	160	155		

[a]Walk ended by observer, volunteer could have continued

[b]*From* Craig, F. N., Blevins, W. V., and Cummings, E. G. EATR 4478 Exhausting Work Limited by External Resistance and Inhalation of Carbon Dioxide. December 1970. UNCLASSIFIED Report.

Table V. Characteristics of Breathing at Exhaustion

Test	Frequency		Duration				Frequency		Duration				Frequency		Duration			
			Inspiration		Expiration				Inspiration		Expiration				Inspiration		Expiration	
	Breaths/min		*sec*				*breaths/min*		*sec*				*breaths/min*		*sec*			
Week of test	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2
Resistance	R23	R33	R23	R33	R23	R33	R23	R33	R23	R33	R23	R33	R23	R33	R23	R33	R23	R33
Treadmill grade, %	10	10	10	10	10	10	15	15	15	15	15	15	22	22	22	22	22	22
Man 1	28.1	21.9	1.14	1.93	0.99	0.86	40.0	28.2	0.81	1.46	0.67	0.68	44.0	37.2	0.72	1.08	0.64	0.53
Man 2	33.4*	28.9	0.89*	1.28	0.91*	0.80	47.0	28.7	0.53	1.34	0.63	0.76	39.0	32.4	0.81	1.22	0.69	0.63
Man 3	36.1	29.3	0.76	1.23	0.90	0.82	38.2	29.4	0.77	1.17	0.74	0.87	33.8	29.3	0.91	1.24	0.84	0.82
Man 4	39.0	31.9	0.75	1.16	0.79	0.72	54.2	45.6	0.52	0.69*	0.59	0.58	46.7	47.7	0.54	0.61	0.58	0.65
Man 5	31.9	28.4	0.81	1.09	1.07	1.02	40.0	33.8	0.67	1.01	0.82	0.74	40.3	33.7	0.69	0.99	0.75	0.56
Man 6 (5 Jun 70)		23.7		1.46		1.07												
Avg (N=5)	33.7	28.1	0.87	1.34	0.93	0.84	43.9	33.1	0.66	1.13	0.69	0.73	40.8	36.1	0.73	1.03	0.70	0.64

*Walk ended by observer; volunteer could have continued.

Table VI. Data for Subject 7, Series II, Training

Test	Sep							Oct								
	21	22	23	24	28	29	30	1	5	6	7	8	12	13	14	15
	R00	R11	R23	R33	R33	R33	R33	R33	R33	R33	R33	R33	R00	R11	R23	R33
10% Grade																
Walking time, min	67.8	31.8	31.4	20.6	60.0*	60.0	60.0	60.0	60.0	60.0	60.0	60.0	76.2	35.0	36.1	21.0
Final heart rate/min	159	150	146	150									141	142	146	149
Final min vol, liter		55	38	32	32	34	33	31	24	24	23	20		41	30	28
Final tidal vol, liter		1.4	1.0	1.4	1.7	1.7	1.6	1.8	1.5	1.7	1.7	2.0		3.4	2.0	2.2
Final frequency/min		40	37	23	19	19	20	18	16	14	14	10		12	15	13
Final insp time, sec		0.71	0.85	1.66										0.97	1.25	2.67
Final exp time, sec		0.76	0.79	0.82										0.67	0.68	0.63
15% Grade																
Walking time, min	10.2	6.1	7.3	5.4	5.1	6.0	4.0	6.1	6.0	5.9	5.1	5.5	12.4	15.0	10.0	6.0
Final heart rate/min	189	172	172	170									169	171	166	168
Final min vol, liter		92	72	36	42	48	52	47	32	48	32	28		62	52	44
Final tidal vol, liter		1.9	1.6	1.7	1.9	2.2	2.4	2.0	1.5	2.3	1.8	2.1		2.9	1.7	2.2
Final frequency/min		48	44	21	23	22	22	23	22	21	18	13		22	30	20
Final insp time, sec		0.60	0.86	1.83										1.31	1.03	2.10
Final exp time, sec		0.63	0.57	0.72										0.62	0.60	0.70
22% Grade																
Walking time, min	1.8	2.2	3.0	2.0	2.0	1.3	1.6	2.0	1.8	2.1	2.4	2.1	2.4	2.5	2.1	2.0
Final heart rate/min	181	180	181	170									173	175	168	166
Final min vol, liter		98	86	41	62	43	52	49	46	45	36	40		116	89	51
Final tidal vol, liter		2.1	2.2	1.9	1.9	1.7	1.9	1.8	2.1	1.8	1.9	1.9		2.3	1.8	2.5
Final frequency/min		47	39	22	33	26	27	27	22	25	20	22		50	49	20
Final insp time, sec		0.54	0.82	1.85										0.64	0.62	2.18
Final exp time, sec		0.55	0.68	0.75										0.57	0.54	0.77

*At 10% grade from Sep 28 to Oct 8, total walking time in six walks separated by rest periods of 10 minutes.

Table VII. Data for Subject 8, Series II, Training

Test	Sep 21	Sep 22	Sep 23	Sep 24	Sep 28	Sep 29	Sep 30	Oct 1	Oct 5	Oct 6	Oct 7	Oct 8	Oct 12	Oct 13	Oct 14	Oct 15
	R00	R11	R23	R33	R33	R33	R33	R33	R33	R33	R33	R33	R00	R11	R23	R33
10% Grade																
Walking time, min	30.2	20.1	23.1	8.3	52.7*	52.6	45.1	37.1		32.9	48.8	43.1	12.5	14.9	11.0	8.0
Final heart rate/min		201	200	178									192	190	192	
Final min vol, liter		106	86		49	49	46	54		48	45	42			97	
Final tidal vol, liter		2.3	2.0		2.2	2.5	2.4	1.9		1.7	2.2	1.9			2.6	
Final frequency/min		46	43	33	22	20	20	29		28	21	23			38	
Final insp time, sec		0.60	0.78	1.18											0.74	
Final exp time, sec		0.71	0.56	0.63											0.77	
15% Grade																
Walking time, min	6.1	4.3	5.1	4.1	3.0	3.3	3.0	3.0		2.8	3.0	3.3	3.8	3.8	4.0	3.2
Final heart rate/min	206	206	202	183										190	189	185
Final min vol, liter		108	96	50	53	63	56	68		51	50	50		128	88	70
Final tidal vol, liter		2.6	2.1	1.6	1.8	2.7	2.6	2.5		2.2	2.4	1.9		2.8	2.6	2.2
Final frequency/min		42	46	32	30	24	22	27		23	21	26		46	34	33
Final insp time, sec		0.65	0.65	1.14										0.59	0.82	1.09
Final exp time, sec		0.78	0.64	0.73										0.71	0.78	0.74
22% Grade																
Walking time, min	1.5	1.5	2.0	1.8	1.5	1.1	1.5	1.9	1.4	1.5	2.1	1.8	1.5	2.0	1.4	1.5
Final heart rate/min	191	189	198	175									190	195	188	190
Final min vol, liter		106	98	59	60	59	48	61	48	55	54	55		122	107	59
Final tidal vol, liter		2.6	2.1	1.6	2.1	1.9	2.1	2.2	2.0	2.2	1.7	2.1		2.8	2.7	2.5
Final frequency/min		50	46	34	28	32	23	28	24	25	32	27		44	40	24
Final insp time, sec		0.53	0.63	1.11										0.63	0.74	1.61
Final exp time, sec		0.63	0.61	0.63										0.71	0.74	0.90

*At 10% grade from Sep 28 to Oct 8, total walking time in six walks separated by rest periods of 16 minutes.

For the 5th week in series II, the data are given in table VIII, with a summary in table IX. Although the average endurance was slightly longer at R22 and R32 than at R24 and R34, the difference was not significant. In 11 of 12 comparisons, endurance was greater with R22 and R24 than with R32 and R34; in 12 of 12 comparisons, endurance was greater with R11 than with R32 and R34. However, the men did not discriminate between the low inspiratory resistance conditions, R11 and R22.

IV. DISCUSSION.

A. Training.

When standard tests were made before and after 3 (series I) or 8 (series II) days of practice in hard work with high inspiratory resistance, there was no appreciable reduction in the decrements in performance associated with the R11, R23, and R33 conditions. In an earlier series[8] when the same tasks were repeated on 3 successive days, the ratios of time in seconds for conditions R33/R23 were 120/180, 120/300, and 180/360 for subject BR; 206/254, 242/268, and 215/281 for subject FR; and 482/607, 521/633, and 488/971 for subject WL. In these three men, endurance improved more with the low than the high resistance condition so that the decrement increased. The problem appears to be more difficult than the experience of Dumke, Himmelfarb, and Whittenberger[9] and Mercer[19] had led us to believe. The former were able to overcome the decrement in performance exhibited by 4 of 20 subjects by additional sessions on the cycle ergometer of 5 to 10 minutes daily for 3 to 5 days with the filter present in the mask. However, these sessions were in addition to the 3 weeks of training in the mask with filter removed, before the initial comparisons in which the decrements were observed. Dumke, Himmelfarb, and Whittenberger[9] attributed the difficulty experienced by these four men to psychological factors and stated, "The soldiers who do have difficulty will, in the course of several short intense training periods, be able to perform as well as without the mask." They did not report results of any tests without the mask.

In the present series I and II, the training was accompanied by decreases in heart rate of up to 20 beats per minute. This suggests that the training was overcoming some of the psychological strain of the experimental situation. Perhaps this is a phase that must be completed before endurance will improve. In some subjects this may be more than a phase. For example, the persistence for a year of hyperventilation and tachycardia in standing before a treadmill test in one experienced subject has been described.[20]

B. Facepiece.

The preponderance of values less than 1 in the R23/R00 ratios in series I and the R11/R00 ratios in series II substantiates the findings of Van Huss and Heusner[7] and Cummings et al.[12] mentioned in the introduction. It may be that the mask with filter removed presents a handicap that should be eliminated before training to handle the resistance of the filter is begun. Conditions R11 and R23 still present a dead space, but our experience with inhalation of various mixtures of carbon dioxide suggests that this is not the most stressful feature of the facepiece.

C. Breathing Pattern.

Subject 7 in series II was able to follow instructions to the extent of reducing his minute volume and frequency of breathing during the training period at the 10% and 15% grades. This reduction may be taken as evidence of reserve ventilatory capacity. However, perhaps because he did not take advantage of the opportunity to reduce the average rate of instantaneous flow, he did not improve his endurance. Evidently at 22% grade and in all the grades tested by subject 8, the

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[20]Craig, F. N., Cummings, E. G., and Blevins, W. V. Regulation of Breathing at Beginning of Exercise. J. Appl. Physiol. *18*, 1183-1187 (1963).

Table VIII. Comparison of Resistances in Walks to Exhaustion at 15% Grade

Test	Day 1				Day 2				Day 3				Day 4			
	R11	R22	R24	R11	R11	R32	R34	R11	R11	R22	R24	R11	R11	R32	R34	R11
Subject 7																
Walking time, min	8.2	10.0	10.1	5.1	10.1	6.1	6.1	8.2	8.0	7.2	6.5	6.2	8.3	5.1	5.2	6.3
Final heart rate/min	159	169	171	165	164	169	168	164	160	162	161	161	159	162	162	158
Final min vol, liter	50	54	50	49	39	38	45	60	57	60	69	67	70	44	46	63
Final tidal vol, liter	2.8	2.6	2.8	2.0	2.1	2.0	2.1	2.3	2.2	2.5	2.6	2.2	2.0	2.0	2.1	1.9
Final frequency/min	18	21	18	24	18	19	21	26	26	24	27	31	34	22	22	32
Final insp time, sec	2.36	1.56	1.82	1.33	2.14	2.26	2.00	1.28	1.24	1.50	1.40	1.05	0.80	2.01	1.96	0.88
Final exp time, sec	1.00	0.62	1.04	0.85	1.12	0.38	0.75	0.91	0.95	0.75	0.84	0.76	0.91	0.67	0.73	0.80
Subject 8																
Walking time, min	3.2	2.7	2.2	3.1	3.3	2.6	2.4	4.1	3.5	4.1	3.4	3.1	3.2	2.7	2.4	4.1
Final heart rate/min	187	188	189	192	191	178	182	192	186	196	192	193	180	175	174	191
Final min vol, liter	111	63	81	68	101	55	57	129	103	88	96	107	105	58	54	112
Final tidal vol, liter	3.4	2.8	3.9	2.7	2.7	2.4	2.6	3.4	3.1	3.2	2.9	3.1	2.9	2.6	2.8	3.4
Final frequency/min	33	34	30	36	37	23	22	37	33	27	33	35	36	23	19	33
Final insp time, sec	0.80	0.88	0.92	0.77	0.75	1.63	1.75	0.92	0.82	1.08	0.85	0.78	0.76	1.63	1.63	0.76
Final exp time, sec	0.84	0.91	1.02	0.83	0.85	1.00	0.98	0.66	0.90	0.98	0.88	0.86	0.88	1.03	0.88	0.87
Subject 6																
Walking time, min	3.9	4.8	4.1	4.3	4.7	3.1	3.0	5.1	5.5	5.5	5.6	5.3	5.1	2.7	2.7	5.3
Final heart rate/min	174	178	178	180	172	165	169	180	178	183	181	185	174	160	167	177
Final min vol, liter	93	68	69	69	71	41	40	97	76	68	71	84	72	43	48	
Final tidal vol, liter	2.4	2.1	2.2	2.0	1.8	1.8	1.6	2.5	1.8	2.0	2.0	2.1	1.7	1.4	1.6	
Final frequency/min	38	32	33	34	38	23	25	38	41	36	34	41	43	33	27	43
Final insp time, sec	0.79	1.01	0.90	0.88	0.80	1.63	1.62	0.79	0.74	0.83	0.93	0.77	0.72	1.22	1.51	0.72
Final exp time, sec	0.77	0.83	0.90	0.88	0.74	0.98	0.81	0.77	0.71	0.80	0.86	0.73	0.65	0.61	0.70	0.66

Table IX. Averages For Three Men Shown in Table VIII

Test	N=12; R11	N=6; R22	N=6; R24	N=6; R32	N=6; R34	N=12; R11
Walking time, min	5.58	5.71	5.31	3.71	3.63	5.01
Final heart rate/min	173.6	179.3	178.6	168.1	170.3	178.1
Final min vol, liter	79.0	66.8	72.6	46.5	48.3	82.2
Final tidal vol, liter	2.40	2.53	2.73	2.03	2.13	2.50
Final frequency/min	32.9	29.0	29.1	23.8	22.6	34.1
Final insp time, sec	1.060	1.143	1.136	1.730	1.745	0.911
Final exp time, sec	0.860	0.815	0.923	0.778	0.808	0.798

respiratory drive was too great to permit a voluntary reduction in ventilation. Although there were wide differences in ventilation and frequency among the subjects in series I, these features were not related to endurance.

Another feature of the respiratory pattern is the time devoted to the expiratory phase of the respiratory cycle. In series I the average duration of expiration at exhaustion at grades of 10%, 15%, and 22% was 0.84, 0.73, and 0.64 seconds respectively with condition R33 and 0.93, 0.69, and 0.70 with condition R23. This was contrary to the finding earlier[8] that the final expiratory time was nearly the same for all the conditions studied. Apparently the expiratory time, which was decreasing during the exhausting work as the frequency of breathing increased, had reached a minimal value at the time of exhaustion. The results in series I suggest that the men were not making as great an effort at the 10% grade as they did at the higher grades.

D. Expiratory Resistance.

The average walking times were slightly less and the final expiratory times were slightly longer for the R24 and R34 conditions than for the R22 and R32 conditions, but the differences were not significant. Under these conditions the effect of the difference in expiratory resistance was not important. Thus, these men appeared to resemble the mask-trained men of Van Huss and Heusner.[7] The total experience of subjects 7 and 8 in the first 4 weeks before the tests of expiratroy resistance was 16 days. The subjects of Van Huss and Heusner had 17 days of training. The earlier report[8] called attention to the critical nature of the final expiratory time. Because the change in expiratory resistance did not affect the final expiratory time, perhaps a change in endurance should not be expected.

E. Fitness.

The metabolic cost of walking at 3.5 mph up a 10% grade is about 8.9 Cal/min and equals the cost of a field march with heavy pack.[21] A 1-hour walk under these conditions has been used as a standard test of nonexhausting work.[22] The civilian subjects of Robinson et al. [23] could walk for 1 hour at 3.3 mph and 10% grade wearing the M9 mask and arctic clothing. Taylor et al.[24] described an increase in endurance at 3.5 mph and 10% grade from 1 to 4 hours

[21] Passmore, R., and Durnin, J. V. G. Human Energy Expenditure. Physiol. Rev. *35,* 801-840 (1955).

[22] Henschel, A., Taylor, H. L., and Keys, A. Performance Capacity in Acute Starvation with Hard Work. J. Appl. Physiol. *6,* 624-633 (1954).

[23] Robinson, S., Kunz, A. L., Maletich, R. T., Robinson, W. S., and Thomas, J. R., Jr. Indiana University. Final Report. Contract DA 18-108-CML-5764. The M9 Gas Mask in Cold Environments. November 1955. UNCLASSIFIED Report.

[24] Taylor, H. L., Henschel, A., Brozek, J., and Keys, A. Effects of Bed Rest on Cardiovascular Function and Work Performance. J. Appl. Physiol. *2,* 223-239 (1949).

per day during a training period of 6 weeks in conscientious objectors. A subsequent period of 3 weeks of bed rest reduced the endurance to 1 hour. Accordingly, the failure of the present subjects, with the exception of subject 2, to walk at least an hour in the unmasked condition is evidence of a poor state of fitness.

The present results agree with those cited in the introduction to show that the longer one can work unmasked, the longer he can work in the masked condition. Thus, in group I subject 2 outperformed the others, and in group II subject 7 outperformed subject 8 under all conditions. The fractional decrement in performance, however, was no greater for the fitter than for the less fit men, as was also seen previously (paragraph I.A.4). On the basis of the performance of subjects wearing the M9 mask (Robinson et al.[23]), one might have expected subject 2 to do better in the R23 condition. Whether the stress of the R23 condition for this subject was physiological or psychological is not known, but the final heart rate was 13 and 14 beats per minute greater in the R23 condition than in the unmasked condition in the two tests at 10% grade.

Physical fitness may not be the only factor influencing the performance of masked men. Subject 6 was able to walk for 75 minutes at 10% grade in the R33 condition. He was no more fit than the others, measured by performance at the 15% grade. The shape of the pneumotachogram was more triangular than square, and the frequency and minute volume are not low enough to give an advantage. Aside from his smaller weight, he differed from the others in having a long experience with masks under laboratory conditions. Thus there is no immediately obvious physiological explanation for the performance of this subject.

According to the evidence considered in this report, training for physical fitness is the only proved method of overcoming the handicap of the protective mask. A suggestion offered for trial is to begin training with a dummy low resistance filter. Whether there is some trick to be learned about breathing through a mask like learning to ride a bicycle remains to be seen. It would be interesting to test other experienced civilians employed at Edgewood Arsenal in an attempt to duplicate the results obtained with subject 6. If an experience factor could be identified in these subjects, it might simplify the training of troops to work in the mask.

V. CONCLUSIONS.

In training to improve endurance in exhausting work while wearing the protective mask, as few as from 3 to 8 practice sessions will probably be ineffective. Although endurance was not improved by a few practice sessions, the reduction in heart rate suggests a beginning was made in overcoming the psychological handicap of the mask and training situation.

Even without the filter, the facepiece has a degrading effect on endurance.

Available evidence indicates that physical fitness is a factor in endurance while wearing the protective mask. The longer one can work unmasked, the longer one can work masked. Thus, training for physical fitness should improve the endurance of masked men.

In inexperienced men the ratio of endurance when masked to endurance when unmasked is not affected by fitness. Results with one experienced but unfit subject suggest there may be an experience factor as well as a fitness factor.

Under the conditions of these experiments, small differences in expiratory resistance had no effect on endurance.

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