THE INFLUENCE OF OXYGEN INHALATIONS ON MUSCULAR WORK. BY LEONARD HILL AND MARTIN FLACK.

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IN our last paper in this *Journal* (XXXVII. 1908, p. 77) we brought forward evidence which showed that the duration of the period in which the breath can be held depends on the relative partial pressures in the alveolar air of O_2 and CO_2.

Under ordinary conditions the 'breaking point' is reached when the CO_2 tension has risen to 6—7 % of an atmosphere and the O_2 tension fallen to 9—10 % of an atmosphere. On breathing the expired air in and out of a small bag, we found that the CO_2 tension rose to about 8 %, and the O_2 fell to about 8·5—4·5 % before the breaking point occurred.

We concluded from this that "holding the breath produces some mechanical obstruction to the circulation by the cessation of the respiratory pump."

The fact that the tension of CO_2 can be raised by breathing O_2, from 6—7 % to 8—10 % before the breaking point occurs, led us to try the effect of inhalations of oxygen both on the power to carry on muscular exercise on trained athletes and on untrained persons.

An account of results obtained has been published in several short papers. Experiments on short distance runners are described in the *Brit. Med. Journ.* Aug. 28, 1908. In the same *Journal*, Oct. 3, 1908, is an account of the effect of oxygen on Wolffe, a cross channel swimmer. We have described a number of experiments on the effect of inhalation of oxygen while running, boxing and stair-climbing (*Proc. Physiol. Soc.* Jan. 23. This *Journal*, XXXVIII. 1909). The experiments showed that oxygen inhaled before muscular exertion enables it to be carried out more easily, and inhaled after exercise diminishes the distress and the fatigue. Our conclusions were however contested by Douglas and

Haldane (*Proc. Physiol. Soc.* June 26. This *Journal,* XXXIX. 1909) who claimed that the effects of oxygen inhalation could be explained as a result of washing out CO_2 from the body by deep breathing. It has already been shown by one of us (Hill) and Mackenzie (*Proc. Physiol. Soc.* p. xxxiii. This *Journal,* XXXIX. 1909) that the explanation given by Douglas and Haldane is untenable. In this paper, we deal further with this view, and give some additional experiments bearing on the general question of the effects of oxygen inhalation on the body.

Effect of Forced Breathing.

Taking forcible breathing itself as a type of exertion we find that this if continued for long becomes very uncomfortable. There is a feeling of a band or bands being drawn tight round the head or neck, of pins and needles and numbness in the limbs. Most subjects who try it for the first time say the feeling is like going under nitrous oxide gas. If continued there arises lessened force in the breathing, and group breathing sometimes of a very marked character, audible to those around, but unnoticed by the subject himself, who is in a partly dazed mental state. Polygraph tracings show an acceleration and enfeeblement of the pulse during forced breathing, the pulse can be felt to become weak or even disappear with each inspiratory effort, to return with expiration. Readings of systolic blood pressure show a considerable fall synchronous with each inspiration.

Forcible breathing of oxygen is very different. The feelings of constriction and numbness are either not present, or may occur at the end of the first half minute to a slight degree and then vanish. The pulse keeps strong, while the systolic blood pressure, although falling with each inspiration, is maintained at a higher level. In subjects of middle age the forced breathing of oxygen was pleasant and could be continued indefinitely without any great effort, while the forced breathing of air was very unpleasant, and so much so that some of the subjects were unwilling to repeat it. On the other hand the young student, with great capacity of lung ventilation, could not continue forced breathing of oxygen indefinitely.

The middle aged men were able to breathe a considerably greater volume of O_2 per minute than of air; for example:

Deep breathing through the Zuntz meter.

A wide mouthpiece was used fitted with in- and out-valves. The oxygen was drawn from a bag and expelled through the meter air. The dead space was made as small as possible.

L. H. The numbers in this and the following protocols refer to litres in each successive 30 secs.

Air 3 mins.: 24·5, 28·5, 31, 26, 24, 21·5 = 155·5.

Face congested, tightness round head. Held breath afterwards 1 min. 47 secs.

O_2 3 mins.: 33, 36, 40, 38, 34, 32 = 213.

Comfortable. Held breath 6 mins. 2 secs. Heart throbbing then and sweating beginning, no distress, desire to breathe suddenly become imperative.

Air 3 mins: 25·5, 31·5, 33, 31, 28, 27 = 176.

Same symptoms as before. Held breath 1 min. 45 secs. Feeling of tightness of the chest and headache at the 'bursting point.'

M. F. Air 3 mins.: 30, 37, 34, 32, 29, 26 = 188.

Held breath 2 mins. 25 secs. The face was congested during the deep breathing. Tightness round head, lips cold and anæsthetic, pins and needles in left foot, hands felt cold and numb.

O_2 3 mins.: 40, 40, 41, 37, 37*, 30* = 225.

* Hampered by irritation from dryness of throat and swallowing movements.

Held breath 4 mins. 20 secs. Slight tickling sensation in back of scalp during the breathing. No other symptoms.

In the case of J. M., over 50 years of age, the forced breathing of air produced group breathing audible to every one in the room, and the symptoms of numbness of the limbs and the dazed mental state were so unpleasant, that he was very unwilling to repeat the experiment. Forced breathing of O_2 on the other hand was quite pleasant and produced no grouped breathing.

Prof. C. another middle-aged subject noted during forcible air breathing for 2 min., tightness round the head, aching in the forehead and inside the face, inability to associate ideas and blankness of mind, discomfort compelling him to stop. His blood pressure fell from 110 to 90 and even lower during the inspiratory gasps.

While breathing oxygen his mind was clear, and a slight aching in the head soon cleared off. His blood pressure did not fall below 100 mm. Hg.

R. A. R. Air 3 mins.: 32, 42, 36, 32, 30, 29 = 201.

Held breath 2 mins. 25 secs. Pressure feelings in head, darkness before eyes, pins and needles in hand and legs during the breathing.

O_2 3 mins.: 38, 40, 37, 36, 35*, 31* = 217.

* O_2 supply gave out before time was up.

Held breath 5 mins. 20 secs. Slight and evanescent symptoms.

P. Young student.

Air 3 mins.: 39, 43, 49, 47, 44, 46 = 268.

Held breath 1 min. 12 secs. Very congested in face, slight tightness of face. Blood-pressure fell from 120 to 90 during breathing.

O_2 3 mins.: 41, 46, 46, 46, 44, 50 = 273.

Held breath 1 min. 48 secs. Tightness in ears. Blood-pressure fell during respirations.

P. had extraordinary power of ventilation, and the fact that he only held his breath 1′ 48″ after oxygen was a new and striking one. It seemed to us that he had impeded his circulation by the violence of his inspiration pan-costal in type. To prove if this were so he breathed O_2 more moderately—91 litres in 2 min. His pulse remained strong and regular all through, and he then held his breath 4′ 37″.

On another day he carried out the following experiments.

		Held breath
(1)	Forced breathing, air, as hard as possible for 1 min. Pulse very irregular in force	70 secs.
(2)	Moderately forced breathing, air, pulse strong and regular ...	82 secs.
(3)	Forced breathing, O_2, as hard as possible, pulse irregular in force	133 secs.
(4)	Moderately forced breathing, O_2. Pulse very good and regular ...	230 secs.

A. O_2 5 mins. Very little sensation of numbness. Blood-pressure 100 during inspiration. Held breath 7 mins.

Air 4½ mins. Face very congested. Pins and needles very bad spreading up the legs. Dizzy feelings. 'Something rushing in head,' like going under gas. Blood-pressure fell to 70—80 during inspiration. Held breath 1 min. 20 secs.

R. A. R. Air 5 mins.: 39, 42, 37, 36, 33, 33, 31, 32, 31, 34 = 338.

Feeling of constriction round head very noticeable. Pins and needles in feet. Kept kicking legs because of their numbness. On holding the breath had tickling in throat and struggled to suppress a cough. After 2 mins. 30 secs. became intensely cyanosed, head thrown back, eyes set, general convulsive movements, consciousness lost. Quickly recovered on removal of nose clip after the first gasp of air.

O_2 5 mins. after 15 mins. rest after last experiment:

34, 33, 35, 36, 34, 33, 35, 30, 31, 32 = 333.

Breathed a smaller volume owing to fatigue of the respiratory muscles. Slight numbness in hands, pulse very good, 'felt grand.' Held breath 6 mins. 45 secs.

The student *A* with a great capacity for lung ventilation breathing air deeply and quickly as possible felt a buzzing in the head, as if going under gas, could not see or hear the movement of the polygraph recording his pulse tracing, in a half conscious state, his mental state being absorbed in the effort of maintaining the deep breathing. Deep breathing O_2 was nothing like so unpleasant, the buzzing in his head was slight, he felt he could go on deep breathing for any time, and could see and hear the polygraph.

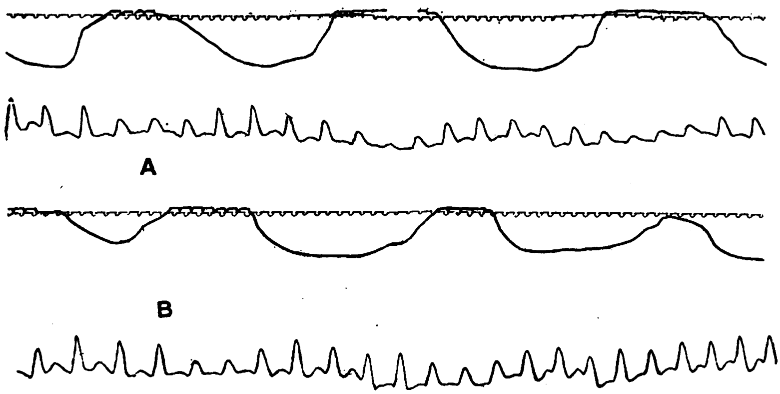

Fig. 1. Respiration and pulse tracings of P.

A. Forced breathing, air. B. Forced breathing, oxygen.
Inspiration = upstroke, duration not force of breath is indicated. Time $\frac{1}{5}$ sec.

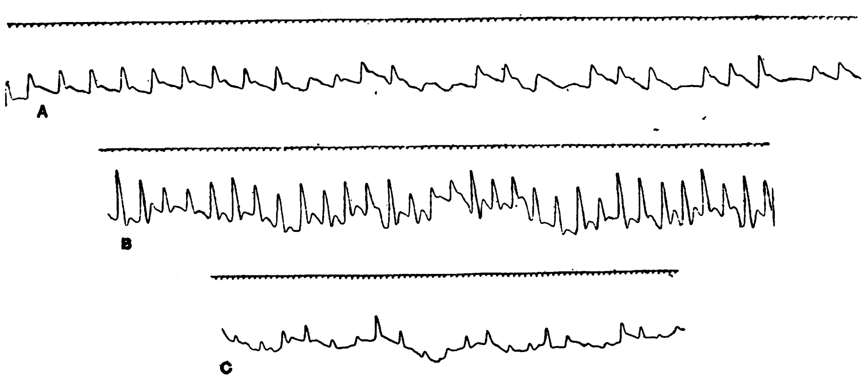

Fig. 2. Pulse tracings of R. A. R.

A. Forced breathing, air, standing up, at the start. B. At end of 2 mins.
C. In recumbent position.

Polygraph tracings of the radial pulse show a diminution almost to the vanishing point of the systolic wave during the inspiratory gasps. Finally the pulse may become like that of aortic regurgitation (Fig. 2 *B*). The amplitude is maintained better when O_2 is breathed.

On observing the heart with the Röntgen rays and screen it became evident to us that the heart shadow during each forced pan-thoracic inspiration becomes smaller. The curve of the left ventricle becomes flattened, the apex pulled in and the shadow less dense. While in the expirations following these it swells out, becomes larger and blacker.

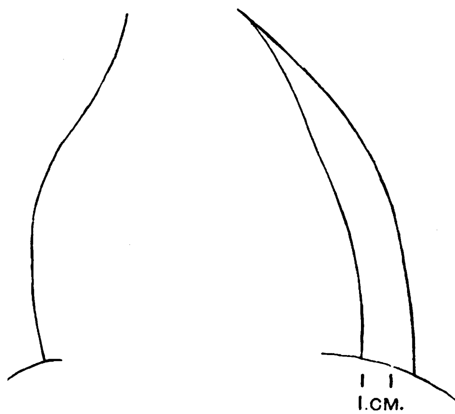

Fig. 3. Tracing of outline of heart of young man taken before and during forced breathing air. The tracing paper was laid on the screen with which the man's sternum was in apposition. The line of the shadow of the left ventricle moved in about 2 c.cm. both during forced inspiration and during the dyspnœa following severe exercise.

The screen shows us that the diaphragm descends well below the heart during the forced inspiration, while on inspection we see that the abdominal wall is pulled in below the epigastrum. In the rabbit or cat with opened thorax it is easy to see that the vena cava inferior is pulled taut by the violent descent of the diaphragm during the final asphyxial gasps, as it likewise is by the weight of the abdominal organs if the dying animal is hung in the vertical posture. It seems probable that the vena cava inferior is also pulled taut by the extreme pan-costal inspiration in our subjects, and so the flow of blood cut short from the abdominal organs to the heart. It also seems possible that the pericardium is pulled taut by the descent of the central tendon of the diaphragm and so impedes the filling of the auricles. It is possible that the vena cava inferior is compressed also between the liver drawn inwards by the abdominal wall and the crura of the diaphragm contracting and swelling forwards.

We have had taken Röntgen ray photographs of the heart with exposures of 1 to 2 sec. (cp. Figs. 4 and 5). We saw no sign of cardiac dilatation following exertion. The heart was smaller during the dyspnœic state, and did not become larger than normal after the dyspnœa had passed off. We are convinced that during forced thoracic breathing the circulation is impeded, and that the left ventricle is less well filled during each inspiration and gives a feeble or abortive beat.

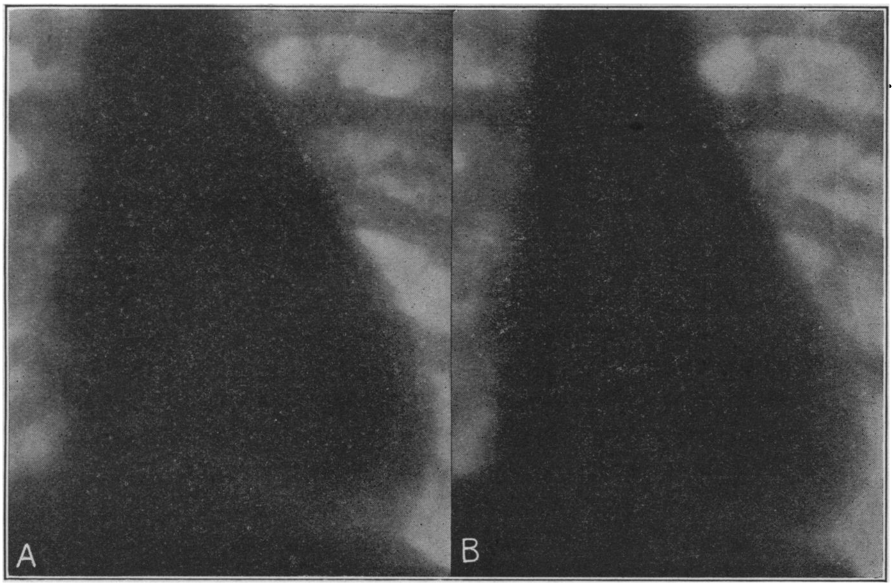

Fig. 4. *A* before and *B* after the severe exertion of jumping up and down on to a chair 18 inches high 70 times in as many seconds, *i.e.* about 18000 foot-pounds per min. The subject, a young man, stood in a frame in the same position in each case, and took up the position immediately after the exertion. His thorax was in apposition with the carrier holding the photographic plate. The Röntgen light was about four feet away. At the word the subject arrested his breathing in the full inspiratory position, raised a finger and the light was switched on for 1—2 seconds.

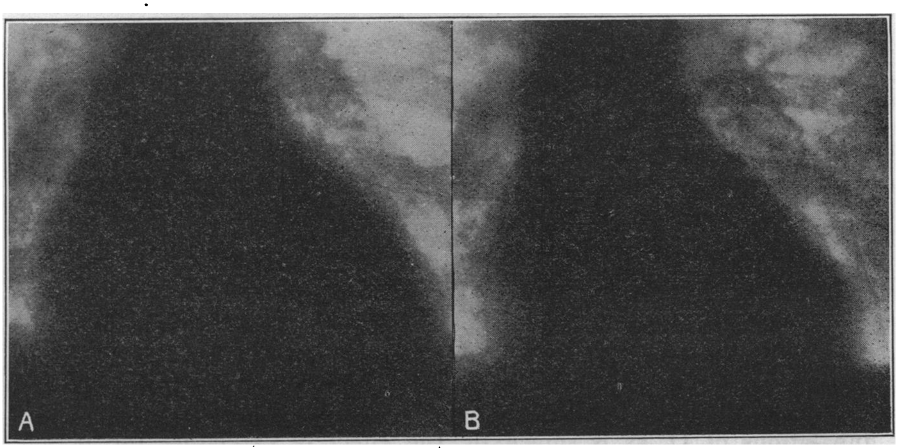

Fig. 5. *A* and *B* were taken from another subject, a powerful athlete, in the expiratory position before and after the exertion of lifting the body up and down from the floor by the arms (the toes resting on the ground) till exhausted.

The photographs show that in both cases the shadow is not enlarged but smaller immediately after the exertion. This is contrary to the opinion usually received.

To such an extent is this the case, that he who breathes moderately deeply can hold his breath much longer than if he breathes with extreme force, and a subject who breathes oxygen to the utmost cannot hold his breath more than a minute or two, which after breathing it by deep abdominal breaths he can hold his breath for six minutes. The blood is pooled in the abdominal veins and hence the thready radial pulse after great exertion. The high rectal temperatures noted by us—103—105° F. after a three mile race—may in part be due to this pooling of the blood. Second wind means the establishment of an abdominal type of breathing, and the adjustment of the rate of work to the ventilation and circulation capacity.

That the effects of deep breathing is largely due to interference with the circulation is shown by the different results we have obtained in the upright or recumbent postures. Haldane and Poulton citing an observation of C. J. Martin and Poulton's experience conclude that such breathing is not uncomfortable, and does not produce tingling sensations, etc. in the recumbent position. We are not able to confirm this conclusion, for deep breathing in students with great power of ventilation does in the recumbent posture produce all the usual symptoms; nevertheless the discomfort is less, and the breath on a full inspiration can be held afterwards much longer even after a less ample ventilation. In men with shallower power of breathing there occurs no discomfort in the recumbent posture. In the standing posture the influence of gravity increases the effect of the forced inspiration, and the blood pooled in the abdomen to a greater degree is thus less well aerated. In the lying down posture venous congestion of the face is evident, caused by the obstructive effect of the forced expirations. Two of our subjects noted a drowsy feeling as a result of the forced breathing in the recumbent position. Deep breathing is not so easily accomplished in the recumbent posture and the ventilation in consequence may be somewhat less ample.

Forced breathing for one minute usually produced less marked discomfort than the two minutes breathing.

The incoordination of the fine muscular movements produced by forced breathing is shown by the writing of the subjects before and immediately after the breathing. We give an example. (Fig. 6.)

The washing out of CO_2 has an unfavourable effect in long continued inhalations of O_2 as is shown by the effect of extending the period of moderately forced breathing.

Influence of posture on the effects of forced breathing.

Subject	Posture	Duration of forced breathing	No. of breaths	Total ventilation	Average volume of each breath	Time breath held after full inspiration	Remarks
H. B. W.	Recumbent	1 min.	27	67·5 l.	2·5 l.	1′ 35″	About 10 mins. interval allowed between these successive experiments.
	Standing	,,	26	66	2·54	55″	
	Sitting down	,,	38	79·7	2·99	35″	Breathing rapidly.
R. A. R.	Recumbent	,,	21	45·5	2·16	2′ 20″	Breathing less ample owing to attention being given to keeping hand quiet for pulse tracing.
	Standing	,,	30	70·4	2·34	1′ 13″	
	Recumbent	,,	30	61·2	2·04	2′ 3″	No pulse tracing taken.
	Sitting down	,,	30	64	2·13	1′ 18″	—
H. B. W.	Standing	,,	—	73	—	40″	After last forced expiration amount left in lungs probably varied considerably.
			23	63·6	2·76	15″	Very cyanosed in face at end of 15″.
	Sitting down	,,	19	69·5	3·65	60″	—
	Recumbent	,,	26	68·6	2·6	38″	—
R. A. R.	Sitting	,,	30	82·4	2·74	57″	—
	Standing	,,	30	78·3	2·61	50″	—
	Recumbent	,,	29	69·1	2·38	85″	—
H. B. W.	Standing	2 mins.	50	137	2·74	32″	Bands round head and aching, constriction round mouth and eyes, swaying towards end, dull epigastric pain, pale.
	Sitting	,,	47	124	2·64	23″	Slighter symptoms.
	Recumbent	,,	45	116	2·58	55″	In 2nd minute tingling, stiffness and tightness of neck muscles and wrists and hands, dimness of vision, constriction round mouth and eyes. While holding breath symptoms very evident and felt as if undergoing anæsthesia with N_2O_2.
R. A. R.	Standing	,,	65	149·4	2·3	73″	Darkness of vision, giddy, cyanosis of lips.
	Sitting	,,	69	158·5	2·3	48″	Bands round head, pins and needles in hands and feet, dimness of vision, no giddiness, lips very cyanosed at end of holding breath.
	Recumbent	,,	64	141	2·2	80″	Felt drowsy during forced breathing. Symptoms slight.
	Standing	,,	—	141·5	—	—	Symptoms most severe standing, least lying down.
	Sitting	,,	—	171·5	—	—	
	Recumbent	,,	—	156	—	—	
H. B. W.	Standing	,,	—	136·5	—	—	Same kind of symptoms in all postures, least severe when sitting and lying down.
	Sitting	,,	—	144	—	—	
	Recumbent	,,	—	116·1	—	—	
S.	Standing	,,	82	110·8	1·35	—	Rapid shallow breather. Symptoms of bands, tingling, tightness across chest.
	Sitting	,,	92	120·1	1·30	—	Comfortable.
	Recumbent	,,	88	117·2	1·33	—	Congestion of face, bands round face.
L. H.	Standing	,,	104	161·5	1·55	1′ 5″	Rapid shallow breather. Headache while breathing.
	Sitting	,,	120	145·5	1·20	1′ 4″	Little discomfort.
	Recumbent	,,	131	139	1·06	1′ 22″	Quite comfortable, could breathe more quickly, but less amply.

Subject	Duration of moderate deep breathing	Time breath held	CO_2 tension at breaking point	Vol. of air expired at breaking point
L. H.	60″	210″	7·54 %	—
,,	120	247	8·9	930 c.c.
,,	180	305	8·3	1450
M. F.	60	152	6·30	1500
,,	120	197	7·165	1425
,,	180	205	6·18	1500

The experiments were successive with short intervals of repose.

The figures, as far as they go, suggest that as the inhalations are lengthened the 'breaking point' occurs at first with a higher and then with a lower alveolar tension of CO_2.

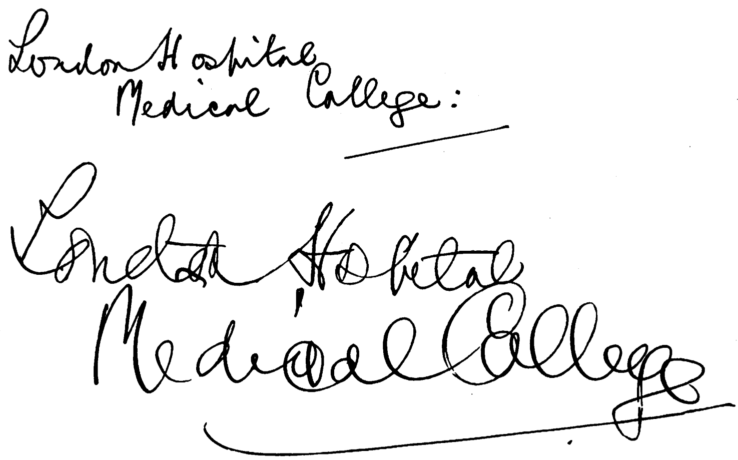

Fig. 6. The writing of R. A. R. before and after forced breathing of air for two minutes. × ⅔.

We have by a further series of experiments convinced ourselves that too prolonged forced breathing of oxygen does lessen the duration of the subsequent apnœa, also that while breathing O_2 maintains the power and increases the duration of the deep breathing, it does not continue to do this idefinitely at least in these with a great power of pulmonary ventilation. Oxygen breathing allows the subject to wash his CO_2 out to a level which cannot be reached by deep breathing of air alone.

The following experiments were carried out in the sitting posture:

Subject	Normal alveolar tensions	After deep breathing air for 4 mins.	After deep breathing O_2 for another 9 mins.
W. (Chinese student)	4·16 CO_2	2·68 CO_2	2·39 CO_2
	16·60 O_2	18·04 O_2	Excess O_2

While breathing air the subject felt as if a band were drawn round the head, and giddy and uncomfortable. On breathing O_2 he was at first more comfortable, but after 8 mins. complained of pins and needles in the limbs and showed slight periodic breathing. After 9 mins. did not want to breathe. After a slight rest breathed up to end of 11 mins., but the breathing was very shallow. This subject was not capable of any great pulmonary ventilation.

G. E. Moderate power of ventilation, deeply breathed O_2 (the gas was warmed and moistened), starting with a frequency of 50—54. After 3½ mins. he had 'pins and needles' in both hands. After 5 mins. felt 'twitching of the facial muscles' and a feeling of constriction round the face; periodic breathing began. At 6 mins. he looked very red in the face. At 7½ mins. he was not breathing so deeply, his fingers were getting cold and numb and his wrist and fingers were drawn into a semi-flexed position. Periodic breathing was marked. At 8 mins. he was breathing 48 times in the minute. The volume of pulse was still good. At 10 mins. breathing 44 to the minute, alveolar tension CO_2 2·9 %. At 10½ mins. he held his breath after a full inspiration of O_2. Marked tremor of the fingers. 1¼ mins. later signalled 'more comfortable,' tremor still marked. After holding breath for 3 mins. the pulse was strong and regular, the hands warm and showed no tremor or contracture. Apnœa lasted 5 mins. 20 secs.

A. Deeply breathed air. Capable of great pulmonary ventilation.

After 3 mins. felt constriction round chest, perspiring, 'pins and needles' in hand. At 4½ mins. alveolar tension CO_2 2·02 %. Began to breathe O_2, felt better after another 1½ mins. At 8 mins. was expiring each breath on the average 1¾ l. At 9—10 mins. felt 'pins and needles' again in limbs. At 13 mins. alveolar CO_2 tension 1·976 %. At 14 mins. O_2 supply ran short. On continuing to deep breathe air felt 'very queer.' Sample at 15½ mins. gave alveolar CO_2 tension **1·76**. Apnœa lasted 5 mins. 28 secs.

M. F. Deep breathing air. Great power of ventilation. Usual feelings of discomfort. Alveolar tension after 5 mins. 2·04 % CO_2. After 7 mins. 1·70 % CO_2. Oxygen then breathed, symptoms better and power to breathe much increased. At 11 mins. hands and fingers semi-flexed, cold and numb, like dead fingers. At 13 mins. numbness increasing, felt cold, pulse 88, small volume, regular. Alveolar tension CO_2 2·029. At 14½ mins. sensation of band round back of head. At 15 mins. pulse waxing and waning in force and volume, difficult to count. At 16 to 17 mins. hands felt cold, lips hot, average expiration 1·7 l. At 19 mins. pulse irregular, few beats reaching the wrist. **Alveolar tension CO_2 1·472.** Stopped deep breathing. Shivering, speech blurred, subjective sensation of face-twitching (nothing to be seen), mental state excited, but fully conscious. At 20½ mins. quiet breathing of air, felt quite composed, hands cold, still shivering, speech improving. At 21 mins. speech all right, pulse regular. At 25 mins. hands warming, 'pins and needles,' pulse of full volume and regular.

L. H. Deep breathing air. Pleuritic adhesions on left side have lessened vital capacity from 4½ to 3½ litres. After 1 min. 37 secs. alveolar CO_2 tension 3·15 %. Oxygen breathed, felt much more comfortable and could inspire more forcibly. After 6 mins. 35 secs. 2·36 % CO_2. Breathed air again, usual symptoms came on, after 8 mins. 40 secs. 3·06 % CO_2.

H. B. W. Deep breathed air, 35 per min. at start. Good power of ventilation. After 6 mins. 2·516 % CO_2, tightness round head, giddiness, mouth screwed up, difficult to take lips away from alveolar air tube, numbness of hands. Subject says he first noticed "a sensation of breathlessness similar to that felt after running hard." This grew more and more marked. 'Next a curious tingling was felt under the chin. This spread over the face until the facial muscles surrounding the eye and the orbicularis oris seemed affected. They seemed as if contracted up in concentric rings, the eyes were difficult to open fully, and the mouth was felt pursed up in the form of an O, so that speaking became difficult. At the same time a tightness was felt over the scalp and around the forehead, the legs and arms became heavy and numb. There was sweating towards the end." On breathing in and out of an empty bag relief came in 50 secs. The sensations passed off in the reverse order. The feeling of respiratory embarrassment disappeared first, the numbness in the limbs persisted longest.

On deep breathing O_2 (35 per min.), the tingling under the chin was noticed after 5—6 mins. At 6 mins. 50 secs. 2·55 % CO_2, did not feel half so queer. At 7½ mins. numbness of arms felt, at 9 mins. 30 secs. 1·87 % CO_2. "The various symptoms described before were felt in the same order, but took much longer to appear. They disappeared with great suddeness. The fingers of the left hand set themselves in a position of semi-flexion and could only be moved by a fairly considerable voluntary effort." On breathing in and out of the empty bag the symptoms quickly passed off except the numbness and incapacity for movement of the limbs, which was noticed on first standing up and attempting to write. The cutaneous vessels became very dilated after the experiment.

To test how quickly the return of the CO_2 tension, H. B. W. deeply breathed O_2 on another occasion. After 2 mins. 3·54 % CO_2, 4 mins. 2·54, 5 mins. 2·51, breath held, 15 secs. later 2·69, 30 secs. later 2·79, 45 secs. later 2·94. He inspired once after each sample was taken.

The subject then breathed oxygen again and ran up and down a flight of 26 stairs 7 times, and we obtained the following alveolar tensions.

Immediately after 6·17 % CO_2, 3 mins. later 4·09, 8 mins. later 3·78, 18 mins. later 4·37, 100 mins. later 4·55, normal next day 4·50.

The figures show that in spite of more than 5 min. oxygen breathing, there occurred asphyxia of the muscles during this excessive rate of work—about 11000 feet pounds per min.—and this was followed by a period of hyperpnœa and washing out of CO_2—just the same result as Haldane and Douglas obtained after deep breathing air for 1 min. and climbing 40 feet of stairs. The exercise was performed easily by the subject, and with little feeling of distress—the heart and brain had plenty of oxygen for the task, but not the muscles.

The effect after deep breathing of quickly raising the alveolar tension of CO_2 is shown by the following.

L. H. deeply breathed air. Uncomfortable after 2 mins. 31 secs., alveolar air 3·36 % CO_2. Breathed in and out of empty bag. Comfortable in 38 secs., alveolar air 4·88 % CO_2. Deeply breathed air again. At 7 mins. 43 secs. slightly uncomfortable, alveolar air 3·83 % CO_2. Breathed in and out bag, comfortable in 32 secs., alveolar air 4·32 % CO_2. Before the bag breathed 13½ l. in 22 breaths, after the bag breathed 17½ l. in 22 breaths.

On another occasion L. H. lowered the CO_2 tension to 3·12 % by deep breathing in 1 min. 23 secs., and after the bag had removed the discomfort lowered it to 2·84 %. The use of the bag restored the breathing power.

M. F. deeply breathed air. After 1 min. 45 secs. very uncomfortable, alveolar tension 2·11 % CO_2. Breathed in and out of bag, comfortable in 30 secs., alveolar tension 4·0 % CO_2. Deeply breathed air again, uncomfortable after 90 secs., alveolar tension 2·46 % CO_2. Breathed in and out of bag, comfortable in 35 secs., alveolar air 4·33 % CO_2.

In these experiments breathing oxygen in our opinion increased the ease of *inspiration*, while breathing air containing CO_2 increased the *expiratory* power. We would note here that the expiratory blast in deep breathing is made against a certain amount of resistance. The lips are partly closed so that the escape of the blast is retarded. Synchronous with this occurs a return in volume and force of the pulse. In a steady run when the 'second wind' is established, there occurs the same retardation, and the abdominal muscles come into play, and regulate the filling of the heart.

In the short-lasting intense exertion of a sprint, and in running up and down stairs we believe part of the blood returning from the limb is shunted into the abdominal venous cistern, the breathing is pan-thoracic and the heart is small in size, and rapid in action, circulating a small volume of well-aerated blood through the central nervous system and coronary arteries, the blood pressure being very high and the peripheral arteries contracted. The muscles havê to contract then in more or less an asphyxial state, and produce lactic acid as well as carbonic acid. Ryffel[1] found an increase of about 800 mgrms. lactic acid in the urine after running ⅔ of a mile with much dyspnœa. The carbon in 800 mgrms. lactic acid equals a production of 540 c.c. CO_2, say the amount excreted in 18 breaths of 1000 c.c. containing 3 % CO_2. The blood coming from the legs retained in the venous cistern of the abdomen, surcharged as it is with muscular waste products, is brought into circulation in the subsequent period of hyperpnœa after the exertion is over.

In a long continued cross-country run on steady exertion, the rate of oxygenation and of exertion keep pace together. The breathing is abdominal, the peripheral arteries are full, the frequency of the heart is less, the heart better filled. The respiratory pump and the cardiac pump are brought into rhythm, and one fills the other.

The favourable effect of moderate abdominal breathing—in comparison with forced thoracic—is shown by the following figures. With less ventilation the breath can be held longer, because the blood is circulated better, and so better ventilated by abdominal breathing.

[1] *Proc. Physiol. Soc.* p. xxix. This *Journal*, xxxix. 1910.

Effect of Type of Breathing.

Subject	Type	Ventilation	Time in secs.	Time breath held	Alveolar air at end
L. H.	Deep thoracic	As hard as possible	60	101	6·245 CO_2, 7·751 O_2.
L. H.	Deep abdominal	Steadily	60	159	6·544 CO_2, 7·78 O_2.
L. H.	Thoracic	49 l.	60	95	Last insp. 1100.
L. H.	Abdominal	18 l.	60	139	,, ,, 1600.
L. H.	,,	26 l.	60	119	,, ,, 1250.

The observations on the subject P. cited above prove the same point.

Our results confirm in part those of Yandell Henderson[1]. We thought at first that as forced ventilation disturbs the circulation mechanically, that O_2 want and not the washing out of CO_2 was the cause of the symptoms of shock which he produces. The fact that O_2 breathing prevented in the more elderly subjects unpleasant symptoms and allowed them to deep breathe indefinitely, supported us in this supposition, so did the evidence we obtained as to the mechanical interference with the circulation which deep thoracic breathing causes. The effects of continued forced breathing of O_2, in men capable of great pulmonary ventilation, have now convinced us that when the CO_2 is washed out to a low level, the pulse becomes feeble and irregular, the limbs numb, feelings of discomfort great, while a spastic state of the hands occurs. The peculiar point we have discovered is that high O_2 tension allows one to wash the CO_2 down, to the low figure, 1·5 % with impunity, and although the radial pulse becomes irregular and feeble, the dangerous symptoms of shock have not occurred which Yandell Henderson regards as inevitable.

The effect of the continued forced ventilation of animals when oxygen is used demands enquiry.

Yandell Henderson finds that 'shock' of the intestines is prevented by not exposing them to air, but to an atmosphere containing CO_2. After opening the abdomen, he covers the intestines with a sheet of celluloid, and conveys a current of CO_2 underneath this. The guts then remain free from congestion, and carry out active movements. His experiments indicate that the surgeon should use every method to prevent exposure of the tissues to the air, and that the anæsthetist should maintain the alveolar tension of CO_2 during the quick breathing excited by operative procedures, diminishing the ventilation. The fact

[1] *Amer. Journ. of Physiol.* XXI. p. 126. 1908; XXIII. p. 345. 1909; XXIV. p. 66. 1909; XXV. p. 385. 1910.

that the energy of the heart beat is weakened and the systolic output reduced by forced ventilation cannot be wholly ascribed to the washing out of CO_2, for the heart, treated as a surviving organ, beats well and for days if irrigated with a suitable and well oxygenated saline solution. The forced ventilation by its mechanical interference with the circulation lessens we believe the oxygenation, and then the low tension of CO_2 exerts its ill effect. Our experiments seem to show the remarkable fact that a high oxygen tension moderates the effect of both an abnormally low and high tension of CO_2.

To demonstrate the relative effect of deep breathing air or oxygen on capacity to do work, we have chosen the method of seeing how much work can be done while the breath is held up to the breaking point. This method puts a strain maximal in intensity, and in speed of onset, and so brings out unequivocal results. It is a method which we suggest may be used with advantage in determining the action of toxic agents such as alcohol and tobacco, on the power to do work.

The work performed has been (1) lifting a 60 lb. weight up a height of 18 ft. by means of a 'pile-driver' arrangement, the rope being attached to both a handle bar and a foot pedal, so that the two arms and a foot can be brought into play. (2) Running up and down the long laboratory, which affords us almost 30 yds. to the length. (3) Putting one foot on to a chair and lifting the body weight up to the level of the seat a number of times in succession.

Before performing the work either air or oxygen is breathed through a mouth piece provided with 'in' and 'out' valves, from a large bag. The gas is drawn from the bag and expelled into the atmosphere. The oxygen has been warmed and moistened on its way to the bag in some cases.

The work was always done with the air test first, and the oxygen test last, so that everything was against the oxygen test, as the periods for recovery allowed between the successive tests was only about 5 minutes.

The subjects were just told to go on as long as they could. They were not urged to work as quickly as possible. Nevertheless the 'pull' experiments show that in every case but one oxygen accelerated the rate of work as well as notably increasing the amount done and the duration of the effort.

Take the case of J. M., for example, who pulled 17 times in 23 sec. after ordinary breathing, 30 in 50 after 3 min. deeply breathing air, and 70 in 85 after 3 min. deeply breathing O_2. The analyses of alveolar air obtained at the end of the work at the breaking point shows that a much higher tension of CO_2 (up to 11 $^0/_0$) can be borne after deep breathing O_2.

In the case of the running experiments, the subjects ran as nearly as they could at the same pace: the turns at each end of the laboratory prevented any great pace.

By a series of tests we found very varying amounts were inspired if the subject was told to take a quiet inspiration just before holding his breath, so the work in each case was done on a full inspiration. The ventilation was recorded during the deep breathing. The figures show that the very striking results obtained cannot be inscribed to a greater ventilation and washing out of CO_2 in the case of the oxygen breathing experiments.

Take the case of R. A. R. He ran 113 yds. in $29\frac{3}{5}$ secs. after ordinary air, 150 yds. in $35\frac{2}{3}$ after deep air, 256 yards in $62\frac{3}{5}$ after deep oxygen. In every case both of 'pulling' and running the subjects pronounced on the greater ease with which the work was done, and absence of cardiac distress. The face becomes blanched and shrunken at the end of the effort after air, it remains of good colour after oxygen. The subject wants to bend or lie down after air tests and cannot speak, it is otherwise after oxygen.

The higher percentage of CO_2 in the alveolar air calls forth sweating and dilatation of the cutaneous vessels.

In the case of S. E., the laboratory attendant, who ran holding his breath after oxygen 470 yds. in 110 sec., we noticed that he 'wobbled' in his course and knocked his feet together in the last lap. We stopt him, or he would have gone on and fallen. Thinking he was faint we bent him double and told him to breathe. He took no notice. On removing the clip from his nose he took a stertorous breath. We laid him on the floor, and after about half a minute he got up on to a chair and looked round him in a dazed condition, and recovered his senses in about a minute. He had been unconscious of all that had happened during this time. His colour was good and there was no cyanosis. When on the floor his pulse was found to be good. From the colour of his face and the results of other analyses of alveolar air, there can be no doubt he still had plenty of oxygen in his lungs, and we conclude that his alveolar CO_2 tension had risen to such a point that he had become comatose and was running automatically.

In the case of L. H. the CO_2 tension rose to the high figure 10·715 $^0/_0$, and he did not push himself beyond the point of being able to collect

DEEP BREATHING AIR. DEEP BREATHING OXYGEN.

Table showing amount of work done upon Work Machine (raising 60 lbs. through 19 inches) with breath held.

Five minutes interval between the successive experiments.

Subject	(1) After normal inspiration: No. of pulls	Time in secs.	Amount of work done in ft.-lbs.	Work per sec. in ft.-lbs.	(2) After deep breathing Air: No. of pulls	Time in secs.	Amount of work done in ft.-lbs.	Work per sec. in ft.-lbs.	(3) After deep breathing Oxygen: No. of pulls	Time in secs.	Amount of work done in ft.-lbs.	Work per sec. in ft.-lbs.	Duration of deep breathing, in mins.	Remarks
L. H.	13	18	1235	68·61	33	43	3135	72·9	59	73	5605	76·78	3	Normal, on another occasion 12 in 19″.
M. F.	23	30	2185	72·83	60	70	5700	81·429	69	78	6555	84·038	2½	—
R. A. R.	11	17	1045	61·47	34	45	3230	71·77	49	60	4655	77·586	3	In (3) held breath 10 secs. before starting work.
J. M.	17	23	1615	70·217	30	50	2850	57·00	70	85	6650	78·235	3	Very marked group breathing during deep breathing air.
L. H.	15	16	1425	89·06	39	45	3705	82·53	65	68	6175	90·808	2	Working as hard as he could.
W. M. C.	20	40	1900	47·5	26	50	2470	49·4	36	65	3420	52·61	Air 2, O_2 1	Pulled at what he *believed* same rate in all three observations.

Similar Table giving analyses of Alveolar Air at the end of the Experiment.

Subject	(1) No. of pulls	Time in secs.	Amount of work done in ft.-lbs.	Work per sec. in ft.-lbs.	(2) No. of pulls	Time in secs.	Amount of work done in ft.-lbs.	Work per sec. in ft.-lbs.	(3) No. of pulls	Time in secs.	Amount of work done in ft.-lbs.	Work per sec. in ft.-lbs.	Duration of deep breathing, in mins.	Remarks
L. H.	19	23	1805	78·478	35	37	3325	89·86	57	59	5415	91·78	2	—
	(% CO_2 7·68, % O_2 8·31)				(% CO_2 7·37, % O_2 7·09)				(% CO_2 9·38, % O_2 about 50)					
R. A. R.	24	26	2280	87·69	44	48	4180	87·08	63	66	5985	90·682	2	Before (2) ventilated 133 litres, before (3) ventilated 134 litres.
	(% CO_2 7·807, % O_2 9·02)				(% CO_2 6·408, % O_2 5·203)				(% CO_2 8·885, % O_2 over 50)					
W. M. C.	27	35	2565	73·285	24	47	2280	48·51	50	70	4750	67·857	2	Before (2) *inspired* 75 litres through meter, hence poor result, before (3) *expired* 126 litres through meter.
	(% CO_2 6·43, % O_2 8·3)				(% CO_2 6·13, % O_2 6·37)				(% CO_2 8·0, % O_2 just over 50)					

the sample, and had run for only 48 sec. It seems possible that S. E. may have had something like 15 % of CO_2 in his alveolar air at the end of 110 sec.

Prof. W. M. C., a worker in experimental psychology, said that feelings of discomfort and a lessened clearness of mind came on early after breathing air, in the case of O_2 after running 245 yds. in 65 sec. he could have gone on running, but his consciousness seemed 'far away.' He omitted to properly take the sample of alveolar air owing to this 'far awayness.'

There is abundant evidence of athletes running themselves out till the field of vision becomes dark before them, till they cannot tell direction and wobble in their course, till they involuntarily evacuate fæces and urine. The effect of oxygen on the channel swimmer Wolffe showed us that oxygen want may be a cause of such symptoms. The difficulty of breathing in the choppy sea must contribute to this being the chief cause in the case of a swimmer. We have been told of a runner who was much refreshed by oxygen given near the end of a Marathon race. On the other hand in a 24 hours' walking race of the Blackheath Harriers, when many competitors walked over 100 (up to 126 miles), there was no evidence that oxygen want contributed to the fatigue. Ryffel found no lactic acid, and the administration of oxygen by one of us to one competitor who had given up seemed to have little, if any, restorative effect. We have to deal with causes of exhaustion here quite different to those of the runner. The sprinter really suffers from a temporary asphyxia and benefits from a full initial supply of O_2 and a washing out of CO_2. The long distance runner finally comes to a state of cardiac fatigue when oxygenation does not keep pace with the demands of the muscles. He is then benefited by a temporary inhalation of oxygen.

To further contravert the statement of Haldane and Douglas that quiet breathing of oxygen has no effect and that deep breathing of O_2 acts beneficially only by the washing out of CO_2, we give the following results. The work 'pulling' or 'running' was done on a full inspiration, after deeply breathing air or quietly breathing oxygen. It will be seen that 'quiet oxygen' gives much the best results and the highest CO_2 tensions.

In the case of J. B., running after quietly breathing O_2, the alveolar CO_2 went up to 11·18 %! Here we have the evidence that doing work enables one to stand a higher alveolar CO_2 percentage than in the case when one is sitting quiet and holding the breath. The movements of

DEEP BREATHING AIR. DEEP BREATHING OXYGEN.

Table showing amount of work done as Running with breath held.

Subject	(1) After full inspiration: No. of yards run	(1) Time in secs.	(2) After deep breathing Air, 2 mins.: No. of yards run	(2) Time in secs.	(2) Ventilation in litres during deep breathing	(3) After deep breathing Oxygen, 2 mins.: No. of yards run	(3) Time in secs.	(3) Ventilation in litres during deep breathing	Remarks
L. H.	98	$21\frac{2}{5}$	125	31	104	215	52	116	Went very blanched in (2).
C. W.	125	$23\frac{2}{5}$	159	$32\frac{2}{5}$	75	183	$38\frac{1}{5}$	65·5	Much easier on O_2.
J. M.	99	$21\frac{4}{5}$	155	28	111	192	$38\frac{3}{5}$	112·5	—
D. M.	133	$26\frac{3}{5}$	180	$36\frac{2}{5}$	99	210	$39\frac{4}{5}$	71·5	Association footballer in training.
S. E.	98	$21\frac{2}{5}$	—	—	—	420	110	92·5	In (1) went purple then very blanched. In (3) see text.
M. F.	101	$23\frac{2}{5}$	145	$34\frac{2}{5}$	136	235	56	143	—
A. W.	94	$24\frac{2}{5}$	180	55	98·5	210	59	93	In (3) ran much faster at start.
R. A. R.	113	$29\frac{3}{5}$	150	$35\frac{2}{5}$	122	256	$62\frac{3}{5}$	124	—
R. F. F.	120	$26\frac{1}{5}$	150	$32\frac{2}{5}$	70	240	53	87	—
W. M. C.	114	33	109	27	Moderate	245	65	Moderate	—
					Alveolar Air: % CO_2 / % O_2			Alveolar Air: % CO_2 / % O_2	
L. H.	85	23	113	32	6·990 / 4·03	189	48	10·715 / over 50	After (1) felt very bad. After (3) sweating—comfortable.
M. F.	100	28	129	$38\frac{1}{2}$	6·2 / 4·09	199	59	9·19 / over 60	In (2) felt heart very much. In (3) no heart symptoms.

The blood-pressure of A. W. fell to 90 during deep inspirations and rose to 120 during the expirations. After the deep-air run it was 140 and the frequency of the pulse 148, after the O_2 run 155 and 148. The pulse was irregular after the air and not after O_2 runs.

running may pump the blood from the abdominal venous cistern into the heart and so keep up better the oxygen tension in the centre, while the act of working takes off the attention from the discomfort. If it was not necessary to reserve some energy, enough to take the alveolar air sample, the CO_2 tensions, no doubt, could be driven to levels higher than our analyses show, before the breaking point came.

DEEP BREATHING AIR. QUIET BREATHING OXYGEN.

Table showing effect upon work measured by Work Machine.

Subject	(1) After normal inspiration			(2) After deep Air			(3) After quiet Oxygen		
	No. of pulls	Time in secs.	Work done in lbs.	No. of pulls	Time in secs.	Work done in lbs.	No. of pulls	Time in secs.	Work done in lbs.
L. H.	—	—	—	37	39	3330	57	56	5130
M. F.	—	—	—	37	46	3330	50	55	4500
S. E.	—	—	—	24	36	2160	34	42	3160
A. G. W.	14	22	1260	19	?	1710	25	32	2250
				(7·59 CO_2, 9·37 O_2)			(8·60 CO_2, excess O_2)		
J. B.	30	29	2700	31	29	2790	39	33	3510
				(8·30 CO_2, 5·84 O_2)			(9·49 CO_2, excess O_2)		
A. D. S.	25	24	2250	33	34	2970	55	53	4950
				(8·94 CO_2, 6·60 O_2)			(9·51 CO_2, excess O_2)		
P.	—	—	—	13	23½	1170	26	44	2340
				(7·61 CO_2, 10·51 O_2)			(8·88 CO_2, excess O_2)		

DEEP BREATHING AIR. QUIET BREATHING OXYGEN.

Table showing amount of work done as Running with breath held.

Subject	(1) After full inspiration				(2) After 1 min. deep Air				(3) After 1 min. quiet O_2			
	No. of yards	Time in secs.	°/₀ Alv. Air at end CO_2	O_2	No. of yards	Time in secs.	°/₀ Alv. Air at end CO_2	O_2	No. of yards	Time in secs.	°/₀ Alv. Air at end CO_2	O_2
R. C. P.	108	23	8·20	7·21	145	31	7·067	5·70	159	37	—	—
J. B.	113	25	8·09	6·09	151	34	—	—	174	38	11·18	50
A. D. S.	120	30	—	—	164	38	7·15	7·65	203	49*	—	—

* Obstructed in running.

The sprinter can and does run a 100 yds. without a breath. The limit we are told is about 120 yds. Our results seem to show that after deep breathing O_2 for a few minutes 220 or even 300 yds. might be run without a breath. The mechanical advantage of not breathing during a sprint is probably considerable.

To distinguish between the influence of the O_2 stored in the body fluids and in the lungs, we have deeply breathed O_2 for $1\frac{1}{2}$ minutes and then air for 30 sec., this is sufficient to clear the excess of O_2 out of the lungs. It removes of course much of the oxygen stored in the body, but not all as shown by the results.

The following table gives the analyses of the alveolar air after breathing O_2 for 1′ 30″, and air for 30″ and shows that the excess of oxygen in the lungs is washed out by breathing air for 30″.

Alveolar tensions.

	(1) After 2 min. deep Air		(2) After $1\frac{1}{2}$ mins. deep O_2, $\frac{1}{2}$ min. deep Air	
Subject	CO_2	O_2	CO_2	O_2
M. F.	2·43 %	18·77 %	2·24 %	19·00 %
C. H. M.	3·04	18·3	2·96	18·99
K. B.	3·37	18·41	4·14	18·56
H.	2·66	18·40	2·93	18·89

The next table shows that more work is done after this than after breathing air for 2′ 0″.

Work done.

	(1) After deep Air 2 mins.			(2) After deep O_2 $1\frac{1}{2}$ mins., deep Air $\frac{1}{2}$ min.			
Subject	No. of pulls	Time in secs.	Work done in ft.-lbs.	No. of pulls	Time in secs.	Work done in ft.-lbs.	Remarks
L. H.	36	32	3240	40	37	3600	Almost immediately after.
				41	38	3690	Later.
M.	52	60	4680	59	55	5310	—
M. G.	43	54	3870	49	68	4410	As far as possible in (1). In (2) did not push himself so far, stopped in better condition. Marked slowing in rate of work owing to fatigue of muscles. The weight was too much for his strength.

In the next table we give the durations of a succession of efforts to hold the breath, one breath being taken between each successive effort. The help given by O_2 is here again conclusively shown. The 'quiet O_2' results however are less than the 'deep air,' owing to the shallowness of the quiet breathing—only $4\frac{1}{2}$–5 l. per minute. The table on p. 369 gives the number of pulls or lifts and work done during a succession of efforts with the breath held, one breath being taken between each successive effort.

Successive periods of holding the breath with one breath between each period.

Subject	(1) Normal after full inspiration Time in secs.	(2) After 2 mins. deep Air Time in secs.	(3) After 2 mins. quiet O_2 Time in secs.	(4) After 1½ mins. deep O_2 ½ min. deep Air Time in secs.	(5) After 2 mins. deep O_2 Time in secs.	Remarks
M. F.	49 (one breath)	87 (two breaths)	120 (two breaths)	130 (two breaths)	185 (one breath)	Two breaths = small inspiration (sniff) followed by expiration and then a full inspiration.
	44 ,,	60 ,,	45 ,,	58 ,,	86 ,,	
	40 ,,	42 ,,	47 ,,	48 ,,	35 ,,	
	28 ,,	45 ,,	25 ,,	45 ,,	48 (two breaths)	One breath = full expiration followed by full inspiration.
	161	234	237	281	354	
Av.	84 (one breath)	119 (one breath)	109 (one breath)	150 (one breath)	381 (one breath)	In (3) breathed only 10 litres in 2 mins.!
	71 ,,	90 ,,	78 ,,	89 ,,	132 ,,	
	67 ,,	63 ,,	68 ,,	72 ,,	60 ,,	
	52 ,,	75 ,,	51 ,,	69 ,,	52 ,,	
	274	347	306	380	625	
H. H.	56 (one breath)	94 (one breath)	82 (one breath)	141 (one breath)	228 (one breath)	In (3) breathed only 9 litres !
	48 ,,	58 ,,	51 ,,	61 ,,	91 ,,	
	42 ,,	43 ,,	41 ,,	41 ,,	50 ,,	
	29 ,,	42 ,,	28 ,,	42 ,,	49 ,,	
	175	237	202	285	418	

The results show that the oxygen still left in the body after breathing O_2 for 1′ 30″ and then air for 30″, gives a notable increase to the working power. This increase is given in the first effort; the O_2 is almost but not quite expended by this first effort. In those experiments in which the lung is filled with O_2, the first effort is notably prolonged and the O_2 is so far expended in this effort, that little effect is left after the first breath has partly washed out the lungs.

	(1) 2 mins. deep Air		(2) 1½ mins. deep O_2, ½ min. Air		(3) 2 mins. deep O_2		
Subject	No. of times work done	Work in ft.-lbs.	No. of times work done	Work in ft.-lbs.	No. of times work done	Work in ft.-lbs.	Form of work
L. H.	20	—	30	—	49	—	Lifting 60 lb. wt.
	10	—	12	—	24	—	18 ins. on work
	2	—	1	—	13	—	machine.
	10	—	8	—	6	—	
	1	—	0	—	2	—	
	10	—	10	—	—	—	
	53 in 6	4770	61 in 6	5490	94 in 5	8550	
W. T.	32	—	37	—	57	—	As above.
	11	—	10	—	12	—	
	7	—	9	—	7	—	
	5	—	7	—	7	—	
	4	—	5	—	5	—	
	5	—	6	—	5	—	
	4	—	5	—	6	—	
	68	6120	79	7110	99	8910	
H. F.	20	Working	21	Working	32	Working	Lifting body from
weight	7	left leg	8	right leg	9	left leg	floor through 18
12 st. 11½ lbs.	6	—	6	at a	6	—	ins. Preferred to
	5	—	5	disad-	5	—	work left leg.
	5	—	5	vantage	5	—	At end of (3)
	4	—	5	—	4	—	CO_2 = 9·70.
	4	—	4	—	4	—	
	51	13·731¾	54	14·539½	65	17·501¼	

The experiments indicate that a preliminary breathing of oxygen will give help in the first part of race, and will be of more use in sprints such as the 100 yds., 220 yds. or the quarter and in the half-mile than in longer races. For if the athlete held his breath and run till his CO_2 tension reaches a high point, on taking the first breath or two and washing out the O_2 in his lungs, he may be at a disadvantage from the excess of CO_2 in his body. Mr Just ran the second lap of his record half-mile in 61⅕ sec., the first lap in 54 sec., thus demonstrating that the oxygen effect was mostly expended in the first lap. We have enabled two sprinters who could not last out the quarter to finish this distance. They ran the first 360 yds. very fast but staggered in over the last 70 yds. After 10 minutes' rest and more oxygen they ran 100 yds. in 10⅗ sec., a fast time for an unpaced trial after the punishing effect of a quarter. There is no doubt in the minds of all our subjects that oxygen not only makes the exertion easier, but leaves them less exhausted afterwards, and ready for a further exertion, and that if taken immediately after exertion it relieves the distress of the heart.

We have made a few experiments which seem to show that oxygen inhaled some 15 minutes before exertion has an effect on the amount of work done, although this effect is comparatively slight. The first hill in a bicycle ride is taken more easily.

It is of interest to consider the volume of oxygen in the body of man under normal conditions, and after breathing oxygen for some minutes until partly saturated. Suppose the body-weight is 70 kgm. and the capacity of the lungs after the deepest inspiration is 5000 c.c. That the blood is 5 % of the body-weight, say 3½ l.; the fat 15 % of the body-weight say 10½ l.; the body-water 64 % of the body-weight say 45 l. After breathing the oxygen and the deepest inspiration the lungs will contain say 4500 c.c. O_2. Supposing ⅓ of the blood is normally arterial and contains 18·5 % O_2, and the rest is venous with 10·5 % O_2, and that the whole of the blood is arterialised by the oxygen up to 18·5 % there will be in the blood, say 550 c.c. Fat dissolves from an atmosphere of O_2 about 5·5 %. If the fat were all saturated it would take up about 575 c.c. Suppose it is about half saturated, it will hold say 300 c.c., the body-water can dissolve about 2·5 %, and if saturated would take up about 1150 c.c. Suppose it is about half saturated, it will hold say 600 c.c. We have then 4500 c.c. in the lungs, 1450 c.c. in the body, a total of 5950 c.c. O_2, enough to last the resting man while holding his breath 20–30 minutes, if he were only able to store CO_2 (or absorb this gas) in his lungs. The time he can hold his breath is set by the period it takes for the CO_2 to reach 10 % or a little over. That oxygen stored in the lungs plays the largest part, our work experiments show.

Under ordinary conditions there would be in the lungs 3000 c.c. at 15 % O_2, 500 c.c. at 21 % O_2, total say about 550 c.c. O_2. For the blood about 350 c.c. O_2. The body fluids are as far as we know oxygen free, whether the fat is so is doubtful, so the total would be say about 900–1000 c.c.

We have made some observations which show that immersing the face in cold water shortens the period of holding the breath. The two uncomfortable sensations are summated. This agrees with some experiments on men diving in a cold swimming bath. Oxygen inhalation had far less effect in prolonging the duration under water in comparison with the time the breath can be held in the air. The longest time was 44 sec., and in one case when the water was very cold the duration (15 sec.) was not lengthened at all by oxygen. We have not yet had an opportunity of repeating the diving experiments in warm water, but from the experience of sponge and pearl divers and the following figures the difference is likely to be a striking one.

Effect of temperature on holding breath.

Face immersed in water at different temperatures.

	Temp.	Time breath held			Temp.	Time breath held	
L. H.	36	33	Consecutive observations	L. H.	5	25	Another day
	12·5	25			41	34	
	34	38			5	30	
	12·5	34			40	40	
M. F.	36·5	60	”	M. F.	5	25	”
	12·0	32			41	36	
	40·0	46			5	36	
	11·5	40			42	52	
L. H.	38	40	Later	W. M. C.	42	42	
	11·5	26			7	30	

A singer, Miss M., distinguished in her profession, asked us to try on her the effect of oxygen inhalations, to test her power to sustain a note or trills in a number of consecutive periods with one breath between each. After breathing oxygen with moderate depth she easily sustained half a dozen or more periods. For example (1) 23, (2) 27, (3) 24, (4) 21, (5) 30, (6) 28, (7) 19 sec. She found herself free from the sensations of cardiac distress, ‘thumping of the heart,’ and said that she would without the aid of oxygen have had to interpose short periods and get in two or three breaths between the long periods. Thus music, different in form to the usual, could be written for a singer who breathed oxygen.

SUMMARY.

1. The inhalation of oxygen lessens the discomfort of forced breathing. It enables young men with a great power of pulmonary ventilation to go on with forced breathing for as long as 19 minutes, and to wash the CO_2 out of the body till the alveolar tension sinks to as low as 1·47 %.

It enables older men with a smaller ventilation power to breathe forcibly in comfort as long as they like, and abolishes periodic breathing in them.

2. The ventilation power is much greater in the young student than in the middle aged.

3. Oxygen inhalation allows a man to stand a much lower as well as a higher tension of CO_2 than is normal. The lowest tension we have observed during forced breathing is 1·47 %. The highest during exertion with the breath held 11·18 %.

4. The discomfort of forced breathing is due to the washing out of CO_2, as is shown by the quick relief given by forced breathing in and out of a bag. Want of O_2 influences the onset of the discomfort, because forced thoracic breathing causes a mechanical interference with the circulation and increases the effect of washing out CO_2 by lowering the tension of O_2.

5. The left ventricle becomes smaller, the radial artery emptier, the blood pressure lower with each forced thoracic inspiration. The effect on the circulation and the discomfort of forced breathing are greatest in the standing and least in the horizontal position.

6. Oxygen inhalation enables the athlete to excel by making him able to stand a higher tension of CO_2. After deep breathing oxygen and filling his lungs with the gas he can run 200-300 yds. without breathing, and this gives him a mechanical advantage. The beneficial effect is due partly to the oxygen in the body, and chiefly to that in the lungs.

7. The effect of oxygen inhalation is almost entirely spent by the first period of exertion which follows the inhalation.