THE EFFECT OF OXYGEN, ALTITUDE AND EXERCISE ON BREATH-HOLDING TIME

S. RODBARD

From the Cardiovascular Department, Research Institute, Michael Reese Hospital, Chicago, Ill.

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Until recently, the duration of voluntary apnea had been recorded in a variety of situations such as mountain climbing expeditions (1, 2), in certain diseases, particularly those of the pulmonary and cardiovascular systems (3), in evaluating physical fitness and anxiety states (4), and for instructional purposes (5). The second World War renewed interest in breath-holding and it was again tested for its utility in the evaluation of physical stamina (6), in the study of the effects of high altitude in the decompression chamber (7, 8, 9) and in testing for neurocirculatory asthenia (10, 11).

The second World War renewed interest in breath-holding since it appeared to have survival value in emergency situations in which oxygen tensions in the inspired air is low, or in the presence of fire or noxious gases. The studies outlined in this paper were directed at an evaluation of the utility of breath-holding in escape from aircraft at high altitudes. In order to analyze factors which might affect the time of the hold, we determined the effects of altitude, of certain oxygen tensions, of hyperventilation and of a short burst of work equivalent to an attempt to leave an airplane in flight.

METHODS. Fifteen hundred and eighty-one determinations of breath-holding time were made on 80 volunteers at the Altitude Training Unit, Kingman Army Air Field, Arizona (altitude 3400 ft.), and at the Aero Medical Laboratory, Wright Field, Dayton, Ohio (altitude 500 ft.) during November-December 1944. The subjects were told to take a single deep inspiration and to hold it as long as possible, but to exhale before extreme pain and discomfort occurred. When the subjects first attempted to hold the breath, unfamiliarity with the maneuver caused them to terminate the test after about 30 seconds. Confidence developed after a few trials, and the subjects became remarkably consistent in successive measurements. In an early series of 341 consecutive determinations while the subjects were at rest at ground level breathing air, the average hold was 70 seconds, ranging from 34 to 125 seconds. Since the responses to various procedures were proportional to the hold at rest while at ground level and breathing air, our results are expressed as percentages of this average hold of 70 seconds.

RESULTS. 1. The variability of the breath-holding time. The apparent great variability of the breath-holding time seen from subject to subject, and even in the same subject at various times has unquestionably deterred many workers from using this technique for the study of problems in respiration, work, fatigue and the like. Analysis of our data indicated that the hold is quite constant when only a few minutes intervenes between readings. There may be shifts of the
Breath-holding time. Usually an increase in breath-holding time occurs with repetition of
the test. Nevertheless, randomization of the control readings makes it clear
that useful data may be obtained. This is illustrated in the results of a typical
experiment on a volunteer lying at rest on a cot at ground level, breathing air
(table 1).

By taking 2 deep breaths and holding the second, 5 subjects increased their
breath-holding time an average of 16 per cent. This was increased but slightly
by taking three deep breaths and holding the third, or taking 5 deep breaths and
holding the fifth. After hyperventilating at ground level for 30 seconds the hold
was increased 45 per cent.

In 28 resting subjects who took either a single deep breath of oxygen, or
breathed oxygen for one or two minutes, the breath-holding time was increased
an average of 80 per cent over the control values.

<table>
<thead>
<tr>
<th>TIME P.M.</th>
<th>CONTROL HOLD</th>
<th>HYPERVENTILATED FOR 30 SECONDS WHILE</th>
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<tr>
<td></td>
<td>seconds</td>
<td>breathing air, hold</td>
</tr>
<tr>
<td></td>
<td></td>
<td>seconds</td>
</tr>
<tr>
<td>2:30</td>
<td>53</td>
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<tr>
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<td>88</td>
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<td>3:14</td>
<td>64</td>
<td>93</td>
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<td>3:27</td>
<td></td>
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<tr>
<td>3:32</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>62</td>
<td>93</td>
</tr>
</tbody>
</table>

2. The effect of altitude. The hold decreased progressively with increasing
altitude when the subject breathed ambient air (fig. 1).

The breath-holding time increased above normal when the subject breathed
pure oxygen at altitudes below 25,000 feet; above that altitude the hold was
less than normal and decreased progressively with decrease in atmospheric pres-
sure (fig. 1).

The demand oxygen regulator (type A-14) used by the Army Air Forces was
designed to deliver a mixture of oxygen and air calculated to maintain the normal
ground level alveolar oxygen tension. When the regulator delivered this mix-
ture, no significant change in the hold was noted until altitudes above 23,000
feet were reached. Above that altitude, the breath holding time decreased with
decreasing barometric pressure (fig. 1).

3. The effect of exercise. The effect on the hold of the moderate exercise in-
volved in 10 deep knee bends performed in 15 seconds was determined at several altitudes in 105 trials. The subjects took 10 deep knee bends, sat down, took a deep breath and held it as long as possible. This exercise was found to be equivalent to the performance on the bicycle ergometer of about 2250 foot pounds of work in 15 seconds.

The average breath-holding time after 10 knee bends was found to be about 30 seconds (40 per cent of control) at altitudes above 10,000 feet and did not appear to change significantly with greater altitudes up to 28,000 feet. Above 28,000 feet the breath-holding time after exercise appeared to be further reduced.

There was no significant difference between the group breathing pure oxygen during the exercise and the group using the oxygen-air mixture furnished by the regulator (fig. 2).

Short bursts of work lasting 15 seconds on the bicycle ergometer in 56 tests on 4 subjects at ground level showed clearly that the breath-holding time is reduced in proportion to the degree of exertion (fig. 3). After exercise, recovery of the resting ability to hold the breath begins at once on resumption of respiration and appears to be complete within 5 minutes.

The performance of 10 knee bends in 15 seconds caused a doubling in minute

Fig. 1. Effect of altitude on breath-holding time. Upper curve: obtained with subjects breathing pure oxygen prior to hold. Middle curve: obtained with subjects breathing "automixed" air and oxygen from a demand regulator (type A-14) as described in the text. Lower curve: obtained with subjects breathing ambient air. Each point represents an average of at least 7 determinations.
respiratory volume when no attempt was made to hold the breath in 10 subjects. The debit in respiratory ventilation volume resulting from breath-holding was quickly repaid by spontaneous hyperventilation occurring immediately after resumption of breathing. Most of the debit was repaid within the first minute after respiration was resumed. Substitution of 100 per cent oxygen for air did not affect the rate or degree of this recovery.

![Graph showing breath-holding time vs. altitude](image)

**Fig. 2.** The effect of 10 knee bends on breath-holding at altitudes up to 38,000 feet. Upper curve: this is the middle curve of figure 1, used as a line of reference. Solid line: breath-holding time at various altitudes while breathing oxygen-air mixture as described in text. Solid circles are individual determinations. Double line: average breath-holding times obtained when the subject breathed pure oxygen. Open circles are individual determinations.

4. *Escape from “spinning aircraft”*. Six subjects were tested for breath-holding ability in 16 trials while attempting to crawl through a hatch against the increased force of gravity, induced in the spinning centrifuge. They wore summer or winter flying clothes with a back-pack parachute weighing about 20 pounds. With 1.6 to 2.4 g (resultant between the lateral force induced by the spinning centrifuge and that of the downward pull of gravity) they were able to leave the hatch in 15 to 25 seconds. Breath-holding was begun at the beginning of the attempt to escape, and the hold under these conditions was found to be 18 to 28 seconds, averaging 23 seconds. The time to get through the hatch averaged 17 seconds. Thus the average breath-holding time after leaving the “aircraft” was 6 seconds.
5. The effect on the oxygen saturation of the blood. An indirect measure of oxygen saturation of the blood while holding the breath at several altitudes was obtained by means of the Millikan oximeter (12). The recording unit was placed on the ear and calibrated at 96 per cent when the subject breathed air at ground level. At 5, 10 and 15 thousand feet, the oximeter reading indicated a slight increase in oxygen saturation within a few seconds after the hold was commenced. As the hold continued the reading declined progressively until breathing was again resumed. Within a few seconds after respiration had begun again the oximeter reading fell sharply, and then began to return to the control reading, reaching this value in 20 to 30 seconds. Average data are indicated in table 2.

![Breath Holding Time vs. Oxygen Saturation](http://ajplegacy.physiology.org/)

Fig. 3. Effect of a sudden burst (15 sec.) of pedaling on the bicycle ergometer on the ability to hold the breath immediately after exercise. Each point is an average of at least 7 determinations.

When breathing 100 per cent oxygen at ground level no change in the oximeter reading was observed in four tests even though the subject held his breath for 140 to 166 seconds. At 15,000 feet there was a fall of only 2 points in subjects breathing 100 per cent O₂ and holding the breath for 130 seconds.

The results suggest that at the onset of breath-holding, the increased intrathoracic pressure resulting from the Valsalva maneuver increases the effective pressure in the lungs and thus causes a greater oxygenation of the blood. Conversely, at the end of the hold, the sudden release of intrathoracic pressure results in a similar fashion in a decreased oxygen tension of the blood. Such a mechanism would tend to raise the blood oxygen saturation somewhat during breath-holding. The increasing tonus of the diaphragm and the thoracic wall during
Breath-holding probably plays a large part in the production of the discomfort which finally causes an end of the hold.

In 10 tests, exercise (10 knee bends) had little or no effect on the oxygen saturation readings during the subsequent breath-holding period. On resumption of breathing a transient sharp fall of 8 to 10 points in the oximeter reading was usually observed. No difference was seen in the groups breathing air or oxygen.

Discussion. The effect of hyperventilation with air in increasing the hold probably may be due to the loss of blood carbon dioxide. The increase in the hold when the subjects were breathing pure oxygen can be ascribed only to the increase in oxygen tension in the alveoli and the blood. The fact that breathing of pure oxygen for 2 minutes was not of much more value than a single deep breath of oxygen re-emphasizes the fact that the ability of the body to store oxygen in the tissues is severely limited. This is also in accord with the findings of Ferris and his associates (13) that breath-holding time varies directly with the oxygen content of the blood, and that under conditions of rest, the factor precipitating the breaking point is dependent on O$_2$ lack. Hyperventilation while breathing pure oxygen combines the individual beneficial effects of increased oxygen tension and of lowered alveolar carbon dioxide tension. Our results suggest that under conditions of exercise, CO$_2$ excess precipitates the end of the breath-holding maneuver.

The reduction in breath-holding time seen with decreased atmospheric pressure when the subjects breathe ambient air is remarkably similar to the percentage reduction in the calculated oxygen tension of the alveoli. This effect is not appreciably disturbed by preliminary spontaneous hyperventilation and the associated loss of carbon dioxide. This is in accord with the observations of Flack (4), Schneider (5) and Ferris (8, 13). With prolonged exposure to high altitude changes are seen in the breath-holding time as a result of changes in the acid-base balance (1).

It was of interest to note that the breath-holding time furnished a "bioassay" of the air-oxygen mixing regulators produced for the Army Air Forces designed to maintain the alveolar oxygen at that obtaining at ground level. However, while the regulator is calculated to deliver such a mixture up to 33,000 feet, the

### Table 2

<table>
<thead>
<tr>
<th>NO. TRIALS</th>
<th>ALTITUDE feet</th>
<th>READING AT 10 SECOND INTERVALS DURING BREATH-HOLDING</th>
<th>AFTER RESUMPTION OF BREATHING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control 10 20 30 40 50 60 70 80 90 100 110 120</td>
<td>Minimal reading 10 20 30</td>
</tr>
<tr>
<td>6</td>
<td>500</td>
<td>96 97 96 96 96 95 93 90 88 86 81 77 73</td>
<td>71 85 92 93</td>
</tr>
<tr>
<td>4</td>
<td>5,000</td>
<td>96 98 98 96 96 96 92 84 85 82 79</td>
<td>76 90 96</td>
</tr>
<tr>
<td>5</td>
<td>10,000</td>
<td>92 93 92 89 84 81 77</td>
<td>72 84 93</td>
</tr>
<tr>
<td>2</td>
<td>15,000</td>
<td>87 89 89 84 79 74 71</td>
<td>66 75 84</td>
</tr>
</tbody>
</table>
breath-holding time was reduced at altitudes above 23,000 feet. This reduction could not be attributed to leakage around the oxygen mask, since the fit of the masks was carefully checked. This unexpected reduction of the breath-holding time between 23 and 33 thousand feet deserves further investigation.

The utility of the breath-holding time as a practical measure for use in escape at high altitude is obviously limited, as indicated in our centrifuge experiments. Such a maneuver would preserve the oxygen already present in the lungs during a free fall through the higher reaches of the atmosphere where serious anoxia might occur. However, it is apparent that the work attendant upon escaping from an airplane when dressed in heavy flying clothing, as well as the reduction brought on by the anxiety and excitement of the situation, would seriously limit the utility of the breath-holding maneuver. The ready availability of a supplementary oxygen supply is indicated.

It is apparent that the study of the breath-holding time furnishes a very useful technique for the study of the respiratory mechanism in normal man and under various conditions of physiological stress.

SUMMARY

1. Breath-holding time is increased by breathing oxygen, and after hyperventilation. It is decreased by reduced alveolar oxygen tension and by short bursts of exercise.

2. The usefulness of the breath-holding time in the study of practical and theoretical problems involving the function of the respiratory mechanism is discussed.

REFERENCES

(2) Henderson, Y. Adventures in respiration. Williams & Wilkins Co., 1938.