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George L. Engel, … , Joseph P. Webb, Charles D. Stevens

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Research Article

VOLUNTARY BREATHHOLDING. II. THE RELATION OF THE MAXIMUM TIME OF BREATHHOLDING TO THE OXYGEN TENSION OF THE INSPIRED AIR [1]

By GEORGE L. ENGEL, EUGENE B. FERRIS, JOSEPH P. WEBB, AND CHARLES D. STEVENS

(From the Departments of Internal Medicine and Psychiatry, University of Cincinnati, College of Medicine)

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The striking effect of 100 per cent oxygen in lengthening the period of voluntary breathholding became apparent to us during experiments concerned with underwater weighing, in which it was desirable for the subjects to remain immersed as long as possible. Although a few observers (1, 2) have noted this effect of oxygen previously, it has received very little attention in the literature since World War I; and some, notably Schneider (3), concluded that oxygen had a relatively insignificant influence upon the breathholding time.

The studies reported herewith were originally presented (4) as a method for demonstrating objective physiological effects of relatively small changes in altitude (pO_2, oxygen tension). This seemed important, because most functional tests of anoxemia do not reveal changes until altitudes of 12,000 to 16,000 feet are reached. These studies show conclusively that a close relation does exist between variations in maximum voluntary breathholding time and those of the pO_2 of inspired air. This relationship is of interest, because it offers a simple quantitative functional test which is sensitive to relatively slight changes in pO_2 of inspired air, and also because it throws considerable light on the interrelation of oxygen and CO_2 as stimulants which force the subject to start breathing after a period of breathholding.

METHODS

The subjects used in these studies were 40 normal, healthy males, all medical students, with the exception of 4 members of the laboratory team; the mean age of the group was 24 years. The breathholding tests were run on 3 groups of subjects under the following conditions: *(1)* Ground (746 mm. Hg), 7,000 feet (586 mm. Hg), 10,000 feet (523 mm. Hg), 13,000 feet (464 mm. Hg), and 16,000 feet (412 mm. Hg) breathing ambient air; (2) 16,000 feet (412 mm. Hg), 35,000 feet (179 mm. Hg), 39,000 feet (148 mm. Hg), and 42,500 feet (125 mm. Hg) breathing commercial oxygen (99.3 to 99.7 per cent oxygen) via A–14 demand masks adapted for constant flow; and *(3)* Ground, breathing compressed air, and oxygen-nitrogen mixtures containing 9.75 per cent, 20.95 per cent, 34.6 per cent, 77.9 per cent and 99.5 per cent oxygen, respectively, as determined by analysis in the Haldane apparatus with mixtures containing less than 50 per cent oxygen, and in the Van Slyke-Neill apparatus with mixtures containing more than 50 per cent oxygen.

The first 2 groups of runs were carried out in the decompression chamber, which was constantly and vigorously ventilated in order to prevent accumulation of CO_2 or oxygen. On all runs the technic of breathholding was as follows: the subjects, in the sitting position, were instructed to make a maximum exhalation, followed by a maximum inhalation, and then to hold the breath as long as possible. Time was started at the end of inspiration, and ended at the beginning of forced breathing. As far as possible, the subjects were kept in ignorance of the prevailing conditions; during the chamber runs the altimeter was covered so that, although aware of changes in altitude in an upward or downward direction, they did not know the exact altitude. In the ground level runs, the tanks containing the gas mixtures were so situated that their labels could not be read by the subject. At least 5 minutes of preliminary breathing was carried out for each exposure. The replicate determinations were never consecutive, and the order of testing was randomized. Duplicate determinations were carried out for each condition tested. There was some tendency on the part of the individual subjects to improve their breathholding ability during the course of the runs. The effect of this was partially offset by giving the subjects several preliminary trials on the ground in order to bring them to their maximum performance, and further controlled by the randomization of the order of testing. With these controlling factors, namely, randomization of testing, it can be assumed that the amount of gas held in the lungs by the individual subject was relatively constant on each test, and that the average value for a number of subjects gave a measure of the maximum breathholding time for a given amount of gas of given composition in the lungs.

[1] The work described in this paper was done under a contract, recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and the University of Cincinnati.

RESULTS

The results are shown in Tables I to III. As expected, there was considerable individual variation in breathholding time; *i.e.*, from 61 to 167 seconds with air at ground level, from 128 to 266 seconds with 100 per cent oxygen at ground level, and from 27 to 83 seconds with air at 16,000 feet. However, each individual yielded surprisingly consistent results, once having achieved proficiency in the procedure.

The duration of breathholding varied directly with the pO_2 of inspired air (corrected for saturation with water vapor at 37° C.) although there were occasional individual inconsistencies; *i.e.*, where a subject did better at 10,000 feet than at 7000 feet. Such instances were remarkably few in number. When the average breathholding times, expressed in percentage of values obtained after breathing ground air, are plotted against the percentage of change in the pO_2 of the saturated inspired air from ground value, the result is a straight line with a nearly 1:1 relationship when the atmospheric pO_2 is normal (*i.e.*, ground) or less than normal, using air up to 16,000 feet and, using 100 per cent oxygen at altitudes of 35,000 (179 mm.

TABLE I

Breathholding time at different altitudes breathing ambient air

Altitude in feet Altitude in mm.Hg pO_2 of inspired air	Ground 746 157	7,000 586 123	10,000 523 110	13,000 464 97	16,000 412 87
	Average to nearest second of 2 trials at each altitude				
FE	120	103	93	78	62
E	93	73	64	62	57
FR	97	78	72	63	57
GE	80	67	53	41	39
CL	87	58	61	42	41
SCHU	74	61	58	43	47
RU	125	92	105	78	70
SL	80	61	65	50	41
Mc	67	53	48	52	39
BEC	82	71	66	59	52
SC	72	62	56	51	39
SP	108	87	93	75	49
HU	91	68	60	60	54
RO	85		59		43
SCH	100		75		58
Breathholding time: average in seconds	91	72	66	57	50
Breathholding time; percentage of ground	100	79	73	63	55
pO_2 of inspired air; percentage of ground	100	79	70	63	55
Calculated pO_2 of inspired air after saturation with water vapor at 37°C; percentage of ground	100	77	68	60	52

TABLE II

*Breathholding time at different altitudes**

Altitude in thousands of feet Altitude mm. Hg pO_2 of inspired air	Ground 746 157	35 179 179	10 523 110	39 148 148	16 412 87	42.5 125 125	16 O_2 412 412
	Average to nearest second of 2 trials at each altitude						
SC	94	61	75	46	51	33	94
RE	76	70	61	61	48	43	90
BE	66	53	46	42	38	39	90
D	88	78	72	67	53	47	136
P	116	84	74	61	48	48	137
G	96	77	91	61	65	52	162
MO	97	118	75	83	60	43	125
HU	120	98	91	70	60	50	160
BR	105	90		80	55	65	145
RY	61	53	36	47	27	32	84
SCHU	63	65	56	60	46	50	113
MOR	90	73	60	55	50	39	121
SCHI	80	84	58	73	50	44	72
SW	160	118	108	103	83	93	210
BL	167	123	110	103	90	60	210
FL	137	90	90	75	80	62	135
FI	108	67	72	68	48	59	125
BEC	106	115	84	90	63	60	171
Breathholding time; average in seconds	103	88	76	71	58	54	136
Breathholding time; percentage of ground	100	85	74	69	56	52	132
Calculated pO_2 of inspired air after saturation with water vapor at 37°C; percentage of ground	100	90	68	69	52	53	248

* At ground, 10,000 feet and 16,000 feet, subjects breathed ambient air. At the higher altitudes, and at 16,000 feet, as indicated in the last column, they breathed 100 per cent oxygen.

TABLE III

Breathholding time breathing different oxygen-nitrogen mixtures by mask

Percentage oxygen content inspired air pO_2 of inspired air	100 746	78 582	49 366	35 261	25 187	21* 157	21† 157	10 75
	Average to nearest second of 2 trials with each							
ST	230	209	200	167		116	129	76
WE	142	137	122	114		70	83	43
SC	128	125	114	112		96	97	50
L	226	205	192	169		132	129	75
HU	191	153	158	138		92	102	65
FI	187	163	142	134		102	96	49
FL	210	159	154	123		117	108	58
D	266	240	239	228		154	120	92
BL	186	196	160	152		79	102	34
RE	167	118	122	112		105	105	45
BE	181	125	153	128		81	56	44
SCHN	186	165	157	132		97	80	47
WO	171	136	134	108	114	97	107	41
WI	161	143	124	117	110	99	108	44
Z	151	138	132	103	72	69	93	34
SE	172	171	166	162	157	148	140	58
G	148	137	132	129	116	91	107	33
STO	166	154	137	131	112	81	77	40
STU	183	171	198		130	100	94	52
C	162	148	140		119	113	100	21
K	281	233	219		150	129	125	51
MO	144	146	141	163	124	100	119	55
DR	182	176	142	174	113	91	100	41
Breathholding time; average in seconds	179	163	155	140	120	103	103	50
Breathholding time; percentage of ground	174	158	150	136	117	100	100	49
pO_2 of inspired air; percentage of ground	476	373	234	167	119	100	100	48
Calculated pO_2 of inspired air after saturation with water vapor at 37°C; percentage of ground	476	372	233	167	119	100	100	48

* From compressed air tank. † Room air, no mask used.

Hg), 39,000 feet (148 mm. Hg) and 42,500 feet (125 mm. Hg) (Figure 1). However, with pO_2 higher than normal, increasing the pO_2 of inspired air has progressively less effect in increasing the breathholding time; for example, with 100 per cent oxygen (atmospheric pO_2 475 per cent of ground) the breathholding time is increased only to 174 per cent of the ground value. This is illustrated by the loss of the straight line relationship between average breathholding times (expressed as percentage of values of ground air) and percentage of change in pO_2 of saturated inspired air, when the latter is above normal (Figure 2).

DISCUSSION

The data indicate that the effect of the pO_2 of inspired air on the maximum time of breathholding is most striking. Although there are some discrepancies in this relation in certain individuals, it is quite evident that, in this small group, a significant decrease in breathholding time as compared to that on the ground can be detected at altitudes as low as 7000 feet. In view of the simplicity of this test, and the short time required to indoctrinate subjects for it and to carry it out, it appears to have value as a method for demonstrating physiological alterations to relatively small changes in the pO_2 of inspired air. Its usefulness in the indoctrination of aviation candidates has already been pointed out (2).

Of more interest is the relation of the change in breathholding time to change in pO_2 at levels less than ground. Here, for every increment of pO_2 change, there is an equal change of increment in the breathholding time. In the case of inspired pO_2 greater than ground values, the effect of the increased tension in lengthening the breathholding time becomes less and less as the pO_2 increases.

This would indicate that at pO_2 of ground level or less, the pO_2 of the inspired air appears to be of

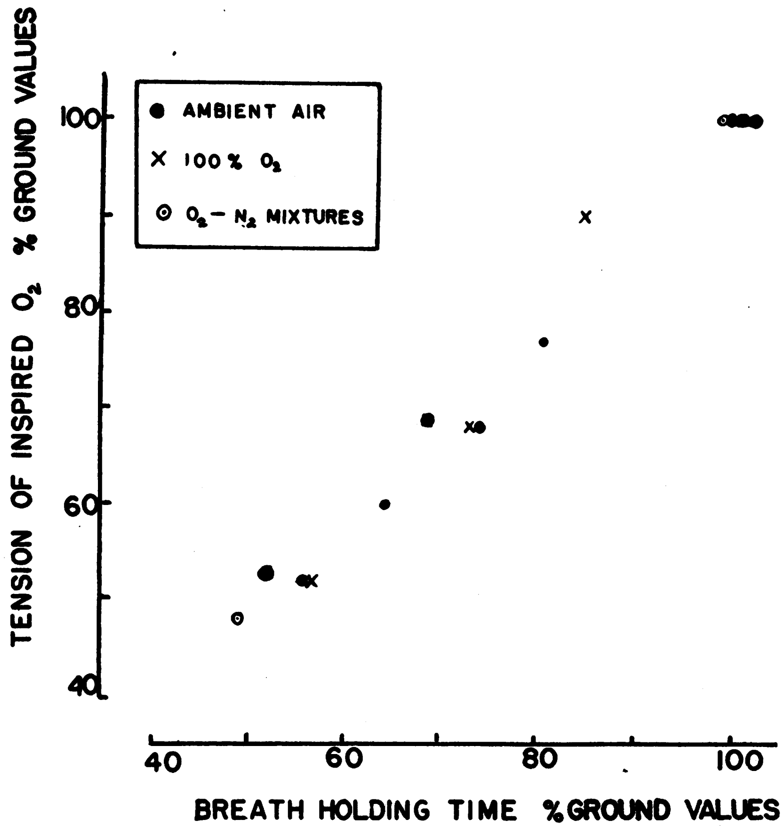

FIG. 1. THE RELATION OF THE pO_2 OF INSPIRED AIR TO THE MEAN BREATH-HOLDING TIMES OF THE SUBJECTS, IN PERCENTAGE OF "GROUND" VALUES

All conditions in which the pO_2 of inspired air was normal, or below normal are included.

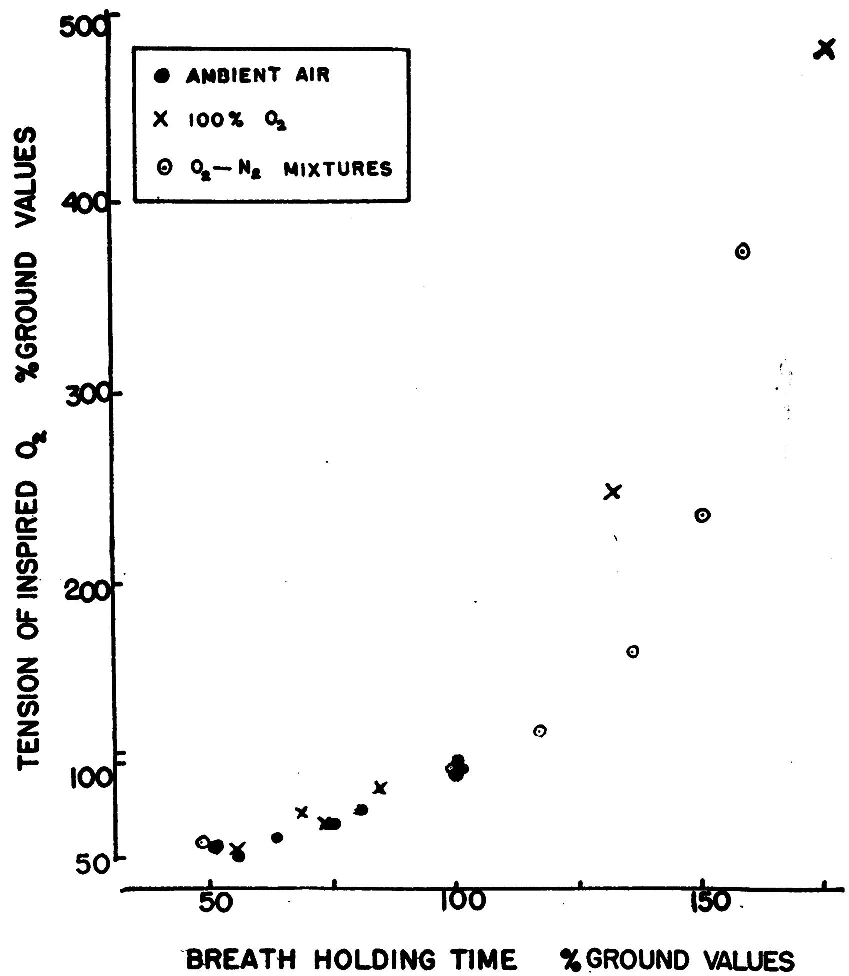

FIG. 2. THE RELATION OF THE pO_2 OF INSPIRED AIR TO THE MEAN BREATHHOLDING TIMES OF THE SUBJECTS IN PERCENTAGE OF "GROUND VALUES"

The pO_2's range from 75 to 746 mm. Hg.

major importance in determining when the subject shall breathe after maximum breathholding. At pO_2 greater than that on the ground (160 mm. Hg), oxygen, although still influencing the stimulus to breathe, becomes less effective as its tension rises, while another factor (presumably pCO_2 of the blood) becomes more effective as a respiratory stimulant.

It is evident, then, that oxygen lack takes on considerable importance as a respiratory stimulant under certain conditions, and that the relative roles of oxygen and CO_2 in influencing respiration are variable with respect to the oxygen tension of the inspired air.

SUMMARY

From ground levels to altitudes up to 16,000 feet the maximum breathholding time varies in direct proportion to the change in atmospheric pressure (pO_2 of inspired air). Identical changes are noted on the ground when equivalent gas mixtures are inspired by mask. Breathing of oxygen mixtures from 21 to 100 per cent progressively increases the breathholding time, but the effect becomes less and less as the pO_2 approaches 760 mm. Hg.

The breathholding technic offers a simple method for objective demonstration of physiologic changes at relatively low altitudes. A decrease in breathholding time occurred at 7000 feet in all individuals tested.

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