SYMPTOMS OF OXYGEN POISONING AND LIMITS OF TOLERANCE AT REST AND AT WORK

O. D. Yarbrough, et al

Navy Experimental Diving Unit
Washington, D. C.

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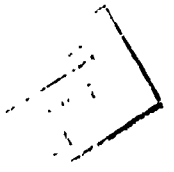

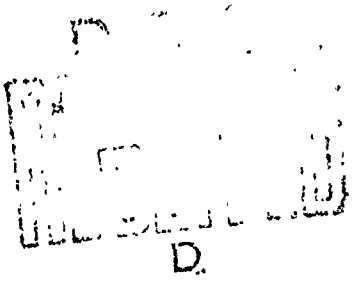

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O. D. Yarbrough
W. Welham
E. S. Brinton
A. R. Behnke

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13. ABSTRACT

U.S. Navy divers were exposed to increased pressures while breathirg 99.6 per cent oxygen. Observations were made with the subjects at rest and at work in both wet and dry environments. The following conclusions were drawn from these tests:

(a) Oxygen can be breathed by the quiescent individual in the dry chamber for periods of at least 2 hours at a simulated depth of 60 feet;
(b) In the wet chamber at 60 feet oxygen inhalation for a period of 10 minutes is consistent with safety;
(c) For underwater work the safe inhalation of pure oxygen is limited to a depth of 30 feet; and
(d) At a depth of 60 feet (at rest) some individuals are susceptible while others are consistently resistant to the toxic action of oxygen.

I

14	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Oxygen Toxicity Diving Hyperbaric Oxygenation						

II

EXPERIMENTAL DIVING UNIT

NAVAL GUN FACTORY

Washington, D. C.

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SYMPTOMS OF OXYGEN POISONING AND LIMITS OF TOLERANCE AT REAST AND AT WORK

PROJECT X-337 (Sub. No. 62) Report No. 1.

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IV

OBJECT

To determine the effect of breathing 99.6 per cent oxygen under increased pressure while at rest and at work and the maximal depth for the safe use of the self contained oxygen apparatus.

SUMMARY AND CONCLUSIONS

1. Oxygen is the most economical gas to use in underwater breathing equipment. In a closed system all of the oxygen supplied can be utilized by the tissues of the body and an individual may remain submerged for prolonged periods of time independent of surface help and his location may be concealed by the absence of bubbles escaping from the self contained equipment.

2. Oxygen, however, is toxic at high pressures, acting chiefly on the central nervous system. Before symptoms occur, however, there is a latent period of well being that renders the use of oxygen practical. Since the tolerance time for oxygen has been previously determined for men at rest in carefully controlled chamber tests, it was the purpose of this study primarily to ascertain the maximal pressure for oxygen inhalation when work was performed.

3. In corroboration of previous work, it was found that in 20 exposures in the dry chamber at rest at a simulated depth of 60 feet, symptoms did not occur during a period of two hours. However, at the same depth under-water, at rest, 32 out of 107 exposures were terminated prior to 60 minutes. The average time of termination was 32 minutes, range 8 to 58 minutes. Two convulsive seizures occurred, one at 13 minutes and the other at 24 minutes.

4. At a depth of 80 feet, 74 out of 99 exposures were terminated prior to 60 minutes; at a depth of 100 feet, 43 out of 46 exposures were terminated prior to 60 minutes.

5. Moderate work can be undertaken safely at depths of 30 feet or less. At this depth, in 35 exposures, symptoms were manifest in two individuals at 87 and 111 minutes, respectively. At a depth of 40 feet, symptoms occurred in and terminated 19 out of 71 exposures prior to two hours. At 50 feet, symptoms occurred in 3 out of 5 exposures.

6. Symptoms that terminated 168 quiescent exposures in the dry and wet chambers at 60, 80, and 100 feet in order of frequency were: nausea (40 per cent); twitching (21 per cent); vertigo (17 per cent); visual disturbances (6 per cent); restlessness, irritability (6 per cent); numbness (6 per cent); and convulsive seizures (4 per cent). With the exception of stupor, headache, and drowsiness persisting for several hours following seizures, symptoms rapidly disappeared when air was substituted for oxygen. Some individuals were consistently susceptible to symptoms while others were relatively resistant. Variability in time of onset of

symptoms in the same individual does not permit the setting of precise time limits for depths in excess of 30 feet when work is performed.

7. Some increase (119 mgm. to 129 mgm.) in blood sugar following injection of 25 grams of glucose was noted at the end of the first hour of oxygen inhalation only in exposures attended by symptoms. During such exposures the blood sugar returned to a level of 113 mgm. at the end of the second hour.

8. The following conclusions may be drawn from these tests:

   (a) Oxygen can be breathed by the quiescent individual in the dry chamber for periods of at least 2 hours at a simulated depth of 60 feet;
   (b) In the wet chamber at 60 feet oxygen inhalation for a period of 10 minutes is consistent with safety;
   (c) For underwater work the safe inhalation of pure oxygen is limited to a depth of 30 feet; and
   (d) At a depth of 60 feet (at rest) some individuals are susceptible while others are consistently resistant to the toxic action of oxygen.

INTRODUCTION

Paul Bert (1) was the first to observe symptoms of oxygen poisoning in the lungs and nervous system of lower animals. Prolonged exposures in excess of 24 hours at atmospheric pressure are usually required to produce the characteristic pulmonary edema. The safe concentration for continuous oxygen administration is about 70 per cent of one atmosphere.

At pressures of 3 atmospheres (66-foot diving depth) and higher, symptoms in lower animals and man are chiefly indicative of involvement of the nervous system. The convulsive seizure simulating an epileptic attack (2) is the most striking manifestation of oxygen toxicity. Nausea recurring periodically is the symptom most frequently encountered.

The two known factors that decrease tolerance for oxygen at high pressures are elevated alveolar (3) and tissue carbon dioxide levels, and exercise (4,5). Unless these factors are controlled, great variability in individual susceptibility to the toxic action of oxygen is to be anticipated. The comprehensive review of Stadie (6) summarizes our knowledge as to the etiology of oxygen poisoning.

The fact that the symptoms, notably the convulsive seizure, are followed by apparently complete recovery and the fact that a latent period precedes the onset of incapacitating symptoms make possible the inhalation of oxygen at pressures higher than 1 atmosphere for limited periods. In the U. S. Navy, oxygen has been successfully used for the prevention and treatment of compressed air illness, i.e., it has been administered to individuals in the inactive state for 2 or more hours in dry chambers at 60 feet and to divers during decompression for 10 minutes at 60 feet,

and at 50 feet for periods of two or more hours (7,8).

The primary purpose of this study was to learn the tolerance time for the inhalation of oxygen at various depths during underwater work.

EXPERIMENTAL PROCEDURE

Oxygen was administered by means of a mask in both the open and the closed circuit. In the open circuit, a "demand" system was used for dry chamber dives and constant flow for wet tank dives: in the closed circuit, Browne or Lambertson underwater respirators, containing baralyme as the carbon dioxide absorbent, were employed.

Standard naval dry and wet chambers were the means for simulating diving depths. The temperature of the water was about 90°F. In some dry chamber experiments, the subject stood immersed in water up to the neck.

The subjects were rugged, young divers in good physical condition. Their average age was 24 years (range 17 to 30), their average weight was 168 pounds of which about 12 per cent was fat (average specific gravity of the whole body, 1.077). In the rest exposures, the individuals remained seated in the dry chamber or semi-upright in the wet chamber. In the work exposures, the subjects lifted and lowered a weight (70 lb. in air, 58 lb. in water) to a platform 26 inches high at a rate of 5 times a minute. The energy output was approximately equivalent to 1200 foot pounds of work per minute. These exposures were of two hours duration.

Blood pressure and pulse rate readings were taken at 15 minute intervals at the various simulated depths in the dry chamber.

To measure glucose tolerance a sample of blood was withdrawn from a fasting individual in the morning and again at one and at two hour intervals after the injection of 25 grams of glucose administered intravenously just prior to dives to 60 feet in the wet tank.

EXPERIMENTAL DATA

Divers at rest (Table 1)

(a) Dry chamber.-At a depth of 60 feet all of the exposures (20) were tolerated for the two hour period. At a depth of 80 feet, 10 of 46 exposures were tolerated for the full two hour period and 10 were tolerated for more than one hour. At a depth of 100 feet, none were tolerated for the two hour period and only 3 were tolerated for one hour.

(b) Dry chamber - subjects immersed to neck. The tolerance times were similar to those obtained in the dry exposures. Apparently surrounding the body in water does not impose a stress equivalent to a wet chamber exposure.

(c) Wet chamber.-Of 107 dives to 60 feet, 75 reached or exceeded 60 minutes duration. In the 32 dives terminated by symptoms before one hour, the average time was 32 minutes, range 8 to 58 minutes. Two convulsive seizures occurred in exposures of 13 and 24 minutes duration.

Of 53 dives to 80 feet, 5 reached or exceeded 60 minutes. Of 20 dives to 100 feet only one continued longer than 60 minutes.

Divers at work (Table 2) - At a depth of 30 feet, only two out of 35 exposures were terminated prior to the completion of the hour work period. At a depth of 40 feet, 19 out of 71 exposures were terminated prior to two hours. At 50 feet, 3 out of 5 exposures had to be terminated.

Symptomatology. - In the dry chamber at simulated depths of 60, 80, and 100 feet, marked palor of the skin was consistently observed. A feeling of anxiety, especially at the greater depths described as "inward trembling" or as a sensation similar to that which usually follows an injection of adrenalin.

Of the symptoms terminating 168 exposures, nausea and vertigo comprised 57 per cent. Twitching (21 per cent) visual disturbances (6 per cent) restlessness and irritability (6 per cent) paresthesia, affecting particularly the tips of the fingers and toes and the circumoral area of the face (6 per cent) and convulsive seizures (4 per cent) comprised the remaining symptoms.

The characteristic feature of nausea was its periodic occurrence with intervals of complete freedom from distress. Vomiting was occasionally precipitated by the attacks of nausea. The visual disturbances were usually a loss of or restriction in peripheral field vision associated with pulillary dilatation. Convulsive seizure was often preceded by warning signs or symptoms such as auditory or other aura and closely simulated the epileptic convulsion and was followed by stupor, drowsiness, disorientation and headache.

There are individuals who appear to be highly susceptible and others who are relatively resistant to the symptoms of oxygen poisoning, expecially as observed at the 60 foot level (Table 4). For a given individual a high degree of variability in the time of onset of symptoms, especially at depths in excess of 60 feet, is observed.

Pulse rates and blood pressures (Table 5). - Pulse rates decreases during oxygen inhalation. Prior to the onset of symptoms, however, pulse rates frequently increased. The blood pressure values were not significantly altered for the periods recorded. Readings immediately preceding the onset of symptoms were seldom obtained.

Blood sugar levels following injection of glucose (Table 6). - The blood sugar level increased at the end of the first hour when symptoms occurred and subsequently decreased below the control level at the end of the second hour. There were no appreciable alterations in the blood sugar level of control exposures when air was breathed nor in exposures free from symptoms.

COMMENTS

The findings reported upon serve to emphasize the important consideration that activity sharply restricts the routine employment of oxygen to a depth of 30 feet. It has been unfortunate that the observations on oxygen tolerance referable to the resting state and its rational application in the therapy of decompression sickness have been construed to be applic-

able to men at work. Chamber tests (5) have demonstrated that although oxygen could be inhaled for two or more hours in the resting state at 60 feet, moderate exercise, sufficient to increase metabolic rate three-fold, served to restrict the period of useful work to a range between 10 and 20 minutes.

The decreased tolerance time of wet as compared with dry exposures may be due to some increase in metabolism and possible apprehension under-water. The explanation for the difference is not entirely clear, however, Some mask leakage could have diluted the oxygen in the dry dives and because of the difference of position of the subject, the wet dives may actually have been several feet deeper.

The variation in response of the same individual from day to day is perhaps the most disturbing feature attending the inhalation of oxygen at high pressures at this time. In view of the relationship of carbon dioxide and the acid-base balance to the toxicity of oxygen, wide variation in the response to oxygen can be anticipated unless some care is taken to regulate the variables which govern carbon dioxide production in the body. The 60 foot level for dry chamber exposures is safe for at least two hours for healthy naval personnel and this consideration has for some years governed the successful employment of oxygen at the Experimental Diving Unit. Attention should be directed, however, to avoidance of exposure to high oxygen pressure of those individuals who are, or may be, rendered "sensitive" to the inhalation of oxygen at diving depths.

O. D. YARBROUGH
Captain (MC) USN

W. WELHAM
Commander (MC) USN

E. S. BRINTON
Lieutenant (MC) USN

A. R. BEHNKE
Captain (MC) USN

APPROVED:

O. K. O'DANIEL
Captain, USN
Officer-in-Charge

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Table 1. Oxygen Tolerance time of divers at simulated depths of 60, 80, and 100 feet in exposures up to two hours in a dry chamber and a wet tank (water temp. about 90°F).

DEPTH	NUMBER of DIVES	WET OR DRY		DURATION COMPLETED 60" WET	DRY	120" WET	DRY	TERMINATED Before 60" WET	DRY	After 60" WET	DRY
60'	127	107	20	60	--	11	20	32	0	4	--
80'	99	53	46	--	--	0	10	48	26	5	10
100'	46	20	26	--	3	0	0	19	23	1	--

Table 2. - Work dives utilizing both closed and open circuits for oxygen inhalation for two-hour exposures in the wet chamber.

	DEPTH (ft)	No. of Exposures	No. Terminated	Time before onset of symptoms (min)	Average % Nitrogen	Average CO_2 Concentration
Closed Circuit	30	17	1	87	9	0.91%
	40	48	11	44	14	0.91%
	50	5	3	32	5	0.40%
Open Circuit	30	18	1	111	1	0.00
	40	23	8	69	1	0.00

Table 3. - Symptoms of oxygen poisoning in 272 exposures at depths of 60, 80, and 100 feet in the dry chamber and wet tank. Symptoms terminated 148 exposures within the first hour and 20 exposures during the second hour of oxygen inhalation.

			PERCENTAGE FREQUENCY OF VARIOUS SYMPTOMS						
DEPTH	NO. OF DIVES	PERCENTAGE SYMPTOMLESS	NAUSEA	TWITCHING	VERTIGO	NUMBNESS	RESTLESSNESS "SHAKES" IRRITABILITY	CONVULSIONS	VISUAL DISTURBANCES
60	127	71	49	27	5	11	4	4	0
80	99	11	41	22	17	6	4	1	9
100	46	6	32	15	30	0	8	8	7

Table 4. - Individual variation in tolerance time* and symptoms** during quiescent exposures in the wet chamber, depth 60 feet, during successive tests conducted at intervals of one or more weeks. Exposures were usually terminated at the end of 60 min.

PAC	MON	PLE	SKI	GIL	POR	MAD	COL	HAM	HFL
60	13-5	15-1,3	57-3	60	60	60	60	60	36-1
44-6	19-3	11-1	11-1	60	28-1	58-1	40-1,3	40-1	29-1,3
8-4	41-1	22-1,2	20-1	25-3	50-1	39-6	60-1	45-6	44-1,3
25-3,6		44-1	60	60	60-1	60-1	116-3	60	60-1
77			60	113-1,2	120	60-1		35-3	55-1,6

CUN	BUN	ALL	PAU	COL	SCH	HEN	WHI	JOH	ATI
60	60	52-6	60	60	60	60	60	60	60
60	60	60	60	60	60	60	60	60	60
60	60	60	60	24-5	60	32-1,3	60	60	60
60	60	60	60	15-3	60	60	60	60	60
120			60	60	60	60	60	120	120
				23-3	120	120	120		
					120				

* in minutes

** designated by the numerals following the dash which refer to the following symptoms: 1-nausea, 2-vertigo, 3-muscular twitching, 4-tremors or restlessness, 5-convulsions, 6-numbness.

Table 5. - Pulse rates and blood pressures recorded at 15-minute intervals during the course of oxygen inhalation at simulated depths of 40, 60, and 80 feet in the dry chamber.

DEPTH	NO. OF RUNS	AV.PULSE RATE FIRST 15 MIN. OF RUNS	AV.PULSE RATE FOR ENTIRE RUN	AV.PULSE RATE AFTER SYMPTOMS OCCURRED	AV.PULSE RATE WITHOUT SYMPTOMS	AV.BLOOD PRESSURE FIRST 15 MIN. OF RUN	AV.BLOOD PRESSURE FOR ENTIRE RUN	AV.BLOOD PRESSURE AFTER SYMPTOMS OCCURRED	AV.BLOOD PRESSURE SYMPTOMS FOR ENTIRE RUN
40	26	73	62			121/77	119/77		
60	34	68	58			120/77	118/78		
80	34	66	65	67	58	117/78	117/83	120/83	114/81

Table 6. - Blood sugar values following the injection of 25 grams of glucose. All exposures were of one hour duration at a depth of 60 feet in the wet chamber. Samples were withdrawn before and at one and two hour intervals after the start of air or oxygen inhalation.

	NUMBER OF DIVES	AVERAGE BLOOD SUGAR (mgm/cc)
OXYGEN DIVES		
Before dive (fasting)	41	119
1 hour		
with symptoms	13	129
without symptoms	28	118
2 hours		
with symptoms	13	113
without symptoms	28	120
AIR DIVES		
Before dive (fasting)	20	115
1 hour	20	110
2 hours	20	114