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PROGRESSIVE DETERIORATION IN SHORT TERM MEMORY WHILE BREATHING PURE OXYGEN AT NORMAL ATMOSPHERIC PRESSURE

by
E. C. Poulton

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SUMMARY

Twelve men performed a step tracking task involving short term memory while breathing pure oxygen from a demand-type oxygen mask, while breathing air from the mask, and in a control condition without the mask. A reliable progressive deterioration over 8 minutes was found while breathing oxygen, but not in the other 2 conditions. The progressive deterioration was particularly marked in the most difficult short term memory condition. It suggests that men should not breathe 100% oxygen at normal atmospheric pressure for periods longer than a few minutes if they must remain fully efficient.

CONTENTS

INTRODUCTION

1. The following experiment was carried out in 1952 in the context of escape from a submarine stranded at the bottom of the sea. The results received only a limited circulation at the time (Poulton, 1953). It is believed that they are sufficiently important and relevant today to receive a wider circulation.

2. By the end of World War II sophisticated submarines had a special escape compartment. The submariner put on a portable breathing apparatus, which supplied him with pure oxygen. He entered the escape compartment, and carried out a sequence of actions which flooded the compartment with sea water. He then opened a hatch to the outside, and climbed out into the water.

3. Reports of emergency escapes indicated that the procedure did not work well. One possibility was that the man forgot where he was in his overlearnt escape procedure. He omitted some crucial detail, or he carried out the correct actions, but in the wrong order. It seems possible that breathing pure oxygen may increase the chances of a failure of short term memory. The following experiment was performed to check on this. The task was selected because it provides a very precise measure of short term forgetting, under conditions which range from easy to extremely difficult. It is therefore likely to be sensitive to relatively small changes in efficiency.

4. A somewhat similar situation faces the pilot of an unpressurized high performance aircraft who breathes pure oxygen while he is performing his cockpit checks before take off. Starting to breathe oxygen before take off prevents the risk of oxygen deficiency during a rapid climb, which may not be detected by the pilot once his thinking has been impaired. Breathing oxygen for 60 minutes before take off eliminates almost half the free nitrogen in the body. It thus reduces the chances of decompression sickness during prolonged flying at height in an unpressurized aircraft (Morgan, Cook, Chapanis and Lund, 1963). However the results of the following experiment indicate that breathing pure oxygen at normal pressure may adversely affect the pilot's short term memory.

METHOD

5. Twelve young naval enlisted men served in the experiment. They were aged between 18 and 23 years. None were submariners, nor had any of them previously performed an experiment of this nature, although all had received gas drill using the usual service filter-type gas mask.

6. A track consisting of 3 sine waves was drawn on a moving paper tape. The frequencies were 13, 10.5 and 5.2 cycles per minute. The sine wave of 13 cycles per minute had an amplitude 2.5 times greater than either of the 2 lower frequency sine waves. The resulting track moved alternately from one side of the paper tape to the other. It reversed direction about once every 2.3 seconds. The side to side distance between 2 consecutive reversals varied irregularly. It never exceeded 4.5 cm.

7. The moving paper tape which carried the track could be seen through a slit 1.5 mm wide. The slit lay across the paper tape at right angles to it. The man had to watch the track in the slit, and to note the positions at which it stopped as it reversed direction. These positions had to be copied at lags ranging from 0 to 3, using a wire pointer attached to a ball point pen. The pen moved in a parallel slit, which was screened by a mask also attached to the pen.

8. At lag O the man had to mark the resting position of the track as it came to rest. At lag 1 he had to mark the previous resting position on one side, as the track came

to rest on the other side. By marking the previous position before noting the new position, only 1 position had to be remembered at a time.

9. At lag 2 the man had to mark the previous resting position on one side, as the track came to rest on the same side again. By marking the previous position before noting the new position, only 2 positions had to be remembered at a time, one on each side.

10. At lag 3 the man had to mark the one from previous resting position on one side, as the track came to rest on the other side. Thus 3 positions had to be remembered at a time, 2 on one side and 1 on the other. It was particularly difficult to remember the 2 positions on the same side. The man could become confused, and mark the more recent position on that side, instead of the previous position. Lag 3 thus provides a stringent test of the efficiency of short term memory storage.

11. Each man received a practice period on a day preceding the experiment. In this he learnt the procedures with the four lags. He then performed at each lag while wearing a demand-type oxygen mask supplied with oxygen from a bottle. A one-way valve fitted in the mask removed the expired air. He was told to try to breathe normally while wearing the mask. The mean respiration rate was not found to have been affected by it. Immediately before the experiment the man received a short practice without the mask at each lag.

12. The experiment itself was divided into three parts, with a 5 minute interval between each. In one part the man performed wearing the mask and supplied with oxygen. In a second part he wore the mask but was supplied with air from a bottle similar to the oxygen bottle. In the third part he performed without the mask. Each part started with a 1 minute period during which the flow of oxygen or air was regulated if a mask was worn. This was followed by four 1 minute experimental periods, one at each of the four lags. These periods were separated from each other by 1 minute rest periods, during which the man's last performance was examined by the experimenter and man together. When the mask was worn in any part, it was kept on throughout the part, for a period of altogether 8 minutes. Thus each man breathed oxygen continuously for 8 minutes.

13. The order of the three parts, and the order of lags within each part, was determined by a latin square. The man was told that the mask was supplied with air, and that the aim of the experiment was to determine the effect of wearing a mask. No mention of oxygen was made, and the air and oxygen bottles were covered in order to conceal their real contents. From the spontaneous remarks made, it seemed clear that none of the men guessed the real aim of the experiment.

14. For each man under each condition the modulus error of alignment was measured in mm for ten consecutive responses, always selected from a similar part of the track. All statistical tests are 2 tailed, using the null hypothesis that breathing oxygen should neither improve nor degrade performance.

RESULTS

15. The analysis of variance in Table 1 shows that both the differences between men and the differences between lags have a highly reliable effect upon the modulus mean error. The overall differences between gas conditions, and the interaction between lags and gas conditions, are not reliable. There is also no reliable effect of the order of the gas conditions, nor of the order of lags within gas conditions. However there is a reliable interaction between the gas conditions and the order of lags within gas

conditions. This is illustrated in Figure 1.

16. Figure 1 shows that when breathing oxygen, the average error increases from the start of the gas condition to the end. The difference between the first and last test periods is reliable on Fisher's t test. When breathing air with the mask, and in the control condition, the differences between the first and last test periods are not reliable. If anything performance improves slightly when breathing air through the mask, and deteriorates slightly in the control condition.

17. Figure 2 shows that most of the increase in the average error while breathing oxygen occurs during the difficult lag 3 condition. Here the man has 3 previous resting positions to remember (see METHOD). The 3 men who perform this condition at the end of the period of oxygen breathing, all have larger average errors than the 3 men who perform this condition at the start of the period of oxygen breathing. The difference is reliable on a Mann-Whitney U test.

DISCUSSION

18. The results indicate that when a sufficiently sensitive task is used, breathing pure oxygen at normal atmospheric pressure for as little as 8 minutes is found to produce a progressive reliable deterioration in short term memory. The task uses a very precise measure of short term forgetting, the accuracy with which memorized positions can subsequently be reproduced. Also the task provides various levels of difficulty. Figure 2 shows that at lag O, which simply involves direct copying, no progressive deterioration is apparent. Whereas at lag 3, which involves remembering 2 positions on the one side and one position on the other side, the progressive deterioration is large and reliable.

19. Breathing pure oxygen at normal atmospheric pressure reduces the flow of blood through the brain, presumably as a result of vasoconstriction. However the consumption of oxygen by the brain remains approximately constant (Womack, 1961). Also there may be a reliable increase in the partial pressure of carbon dioxide in the reduced amount of blood entering the internal jugular vein (Lambertson, Kough, Cooper, Emmel, Loeschcke and Schmidt, 1953). This suggests that the increased saturation of the blood with oxygen does not grossly alter the metabolism of the brain. It leaves unexplained the progressive impairment of short term memory reported here, while breathing pure oxygen at normal atmospheric pressure.

20. In the 1930s an artificial atmosphere of almost pure oxygen appeared so promising to physiologically minded physicians (Campbell and Poulton, 1934). Educated in this tradition, it was difficult for the present author to believe in 1952 that breathing pure oxygen at atmospheric pressure could do other than improve performance. However experience during and since World War II has demonstrated the toxic effects of breathing a high concentration of oxygen for long periods at atmospheric pressure. Toxic effects have been reported both on the lungs of adults (Comroe, Dripps, Dumke and Deming, 1945), and on the eyes of premature infants and dogs (Beehler, Newton, Culver and Tredici, 1963). The present experiment supplies yet another piece of evidence of the toxic effects of breathing pure oxygen at atmospheric pressure, this time on human short term memory.

ACKNOWLEDGMENTS

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TABLE I

Analysis of Variance for Modulus Mean Error

Variable	Degrees of freedom		Mean square
Men	11		994**
Gas conditions	2)		18
Lags	3)	11	18632**
Gas x Lags	6)		63
Order of Gas	2)		153
Order within Gas	3)	11	419
Order: Gas x within	6)		400*
Residual	1[illegible]		166

* Reliable

** Highly reliable

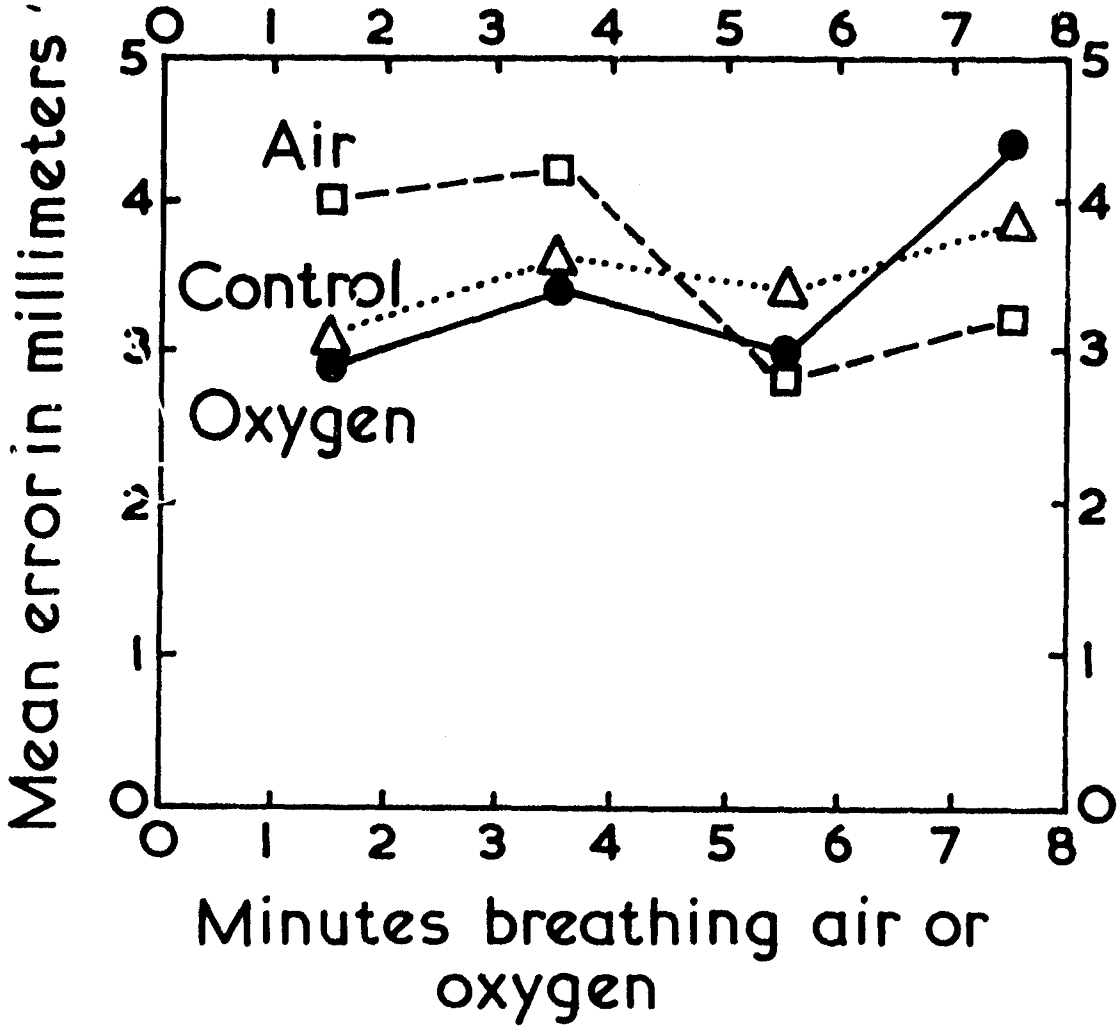

Fig 1. Average error of memory in the 3 gas conditions, plotted against the duration of the condition. Each point represents the average performance of all 12 men.

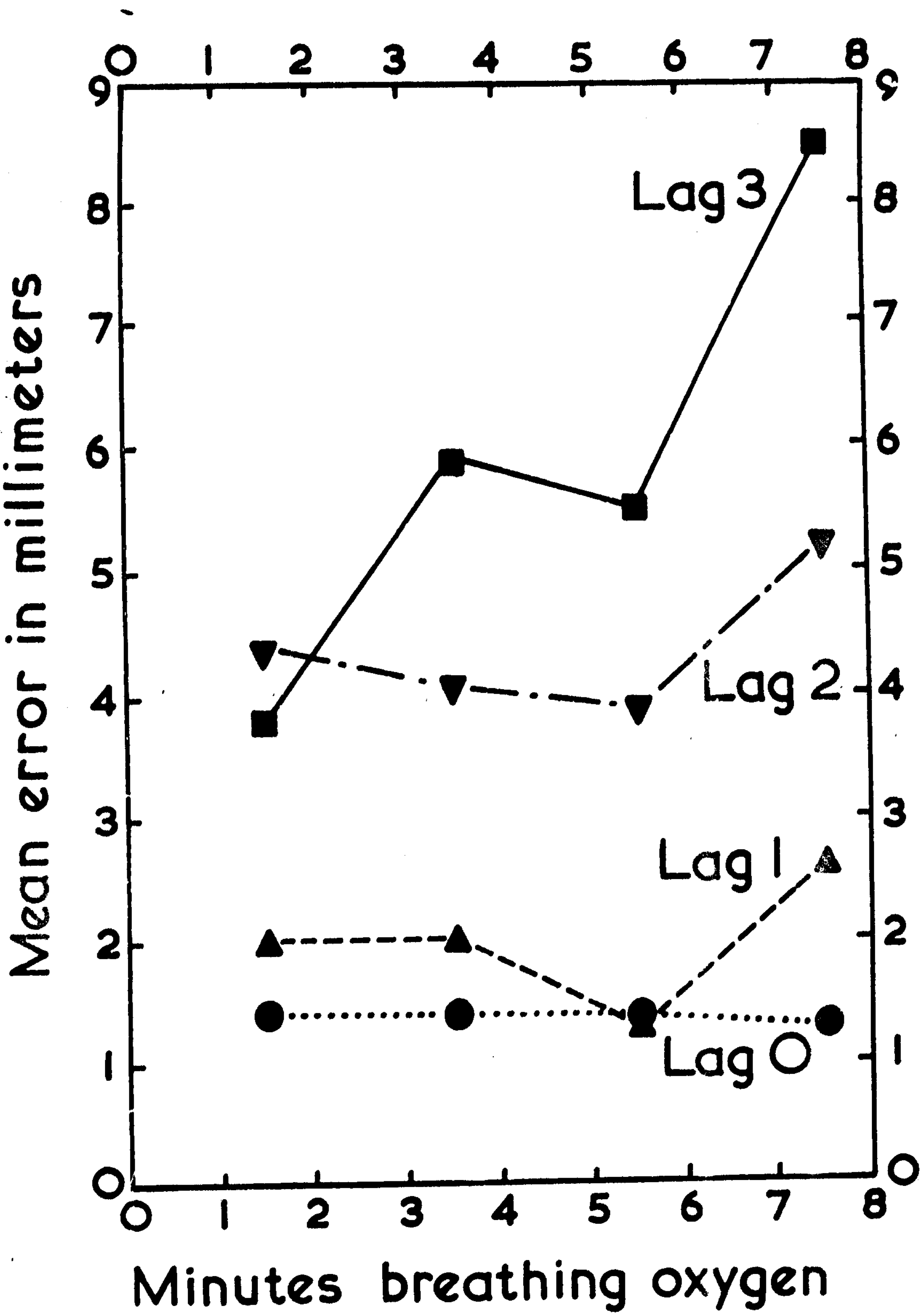

Fig 2. Average error of memory at each lag, plotted against the time during which oxygen has been breathed. Each point represents the average performance of 3 men.