EFFICIENCY AT SORTING CARDS IN COMPRESSED AIR

BY

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At a site where compressed air was being used in the construction of a tunnel, 34 men sorted cards twice, once at normal atmospheric pressure and once at 3½, 2½, or 2 atmospheres absolute pressure. An additional six men sorted cards twice at normal atmospheric pressure.

When the task was carried out for the first time, all the groups of men performing at raised pressure were found to yield a reliably greater proportion of very slow responses than the group of men performing at normal pressure. There was reliably more variability in timing at 3½ and 2½ atmospheres absolute than at normal pressure. At 3½ atmospheres absolute the average performance was also reliably slower.

When the task was carried out for the second time, exposure to 3½ atmospheres absolute pressure had no reliable effect. Thus compressed air affected performance only while the task was being learnt; it had little effect after practice. No reliable differences were found related to age, to length of experience in compressed air, or to the duration of the exposure to compressed air, which was never less than 10 minutes at 3½ atmospheres absolute pressure.

Digging a tunnel near or beneath a river may mean that compressed air has to be used to prevent the works from becoming flooded. The pressure of air required to keep the tunnel dry will depend upon the nature of the ground through which it is being dug and the depth below the surface of the water in the river. Exposure to abnormally high pressure is also experienced by men when escaping from a submarine lying at the bottom of the sea, by divers working in the depths of the sea, and more recently by surgeons who are now beginning to operate in special compressed air operating theatres.

For the last 25 years the Americans have assumed that air at a pressure of 4 atmospheres absolute (100 feet of water or 45 lb. per square inch above atmospheric pressure) reduces mental efficiency. This was the conclusion of Shilling (1937) and more recently of Kiessling and Maag (1962), all of whom worked for the United States Navy. Research workers on this side of the Atlantic were unable to reproduce the American results except at pressures about twice as high (Case and Haldane, 1941; Miles and Mackay, 1959). However, recently there have been some experimental results reported by Barnard, Hempleman, and Trotter (1962), which tend to confirm the American viewpoint. The present experiment was designed to have another look at the problem, using pressures as low and lower than those previously investigated.

Method

Experimental Subjects.—Four of the five main groups comprised men collected at the site of the new Tilbury power station, mainly engineers and technical tradesmen, but also a few inspectors, miners, medical orderlies, and two medical officers. Their ages ranged from 19 to 52 years; their experience of working in compressed air ranged from nil to many years. The fifth group consisted of six men at Cambridge. They were aged between 17 and 24 years and were not exposed to compressed air.

Experimental Apparatus.—The Himalayan Card Sorter is a wooden box 22½ × 6½ × 13 in. tall (57-15 × 16·51 × 33·02 cm.). In the top are four rectangular holes 4 × 2 in. (10-16 × 5·08 cm.), each separated from the next by 3½ in. (8·89 cm.). The holes are labelled from left to right by a spade, a diamond, a club, and a heart taken from playing cards. When the box is set up on feet, the top stands 25 in. (63·5 cm.) above the floor.

A playing card dropped into one of the holes falls down a short chute, and in so doing interrupts a beam of
light pointing at a photosensitive transistor. This produces a short audible tone 'pip' from a small loud-speaker mounted in the box. The tone is lowest for spades on the left, and highest for hearts on the right. The signal can also be recorded on magnetic tape. A Ficord low-voltage tape recorder was used for this purpose. The card finally falls into a container corresponding to the hole through which it is dropped. The experimenter has a press-button switch which produces a tone of still higher pitch. It is used to indicate the start and end of the experimental period. Power for the card sorter can be taken from a 12-volt accumulator.

The main experiment was carried out in the medical lock at Tilbury, which was comfortably warm during the tests. The lock was cylindrical, having a diameter of 7 feet (2.13 m.) and a volume of 500 cu. ft. (14.15 m.³). It had benches standing 18 in. (45.72 cm.) from the floor running along each side, and good overhead illumination. The experimental subject and the experimenter sat on opposite benches with the card sorter standing between them. The additional control experiment was carried out in the laboratory at Cambridge under comparable conditions.

Experimental Design.—This is shown in the Table. Groups A, B, and C sorted cards in compressed air for 10 minutes before sorting for 10 minutes at normal atmospheric pressure. The pressure for group A was $3\frac{1}{2}$ atmospheres absolute, for group B $2\frac{1}{2}$, and for group C 2 atmospheres absolute. Group E sorted cards first at normal pressure and then at $3\frac{1}{2}$ atmospheres absolute. Group D sorted cards twice at normal pressure. Groups A and E were tested during January 1963, the men available being divided randomly between the two groups. Groups B and C were tested during June 1963, the first 10 men available being put into Group B.

Procedure.—The experiment was carried out as and when men were available. Before a test at pressure two thirds of the men had just come out of a tunnel where the pressure was $3\frac{1}{2}$ atmospheres absolute, and had been recompressed to this pressure as laid down in the standard schedule of decompression (Statutory Instruments, 1958). All the men were left at $3\frac{1}{2}$ atmospheres absolute for at least 10 minutes. At 4 atmospheres absolute this is a good deal longer than is necessary to produce the full effects of compressed air (Kiessling and Maag, 1962). For groups B and C the pressure was then reduced appropriately; this produces an almost immediate improvement in performance (Kiessling and Maag, 1962). The test at normal pressure was sometimes started during the final stages of decompression at a pressure of about 1-2 atmospheres absolute.

Before the first test there was always a practice lasting two minutes to check that the man knew what he was supposed to do. For groups B and C the practice was given just before the first test, when the man was at the appropriate pressure. Before the importance of doing this was realized, four men in group A had the practice at normal atmospheric pressure before going into the tunnel.

The man started each test with a pack of cards held face downwards in his hand. He was told to sort the cards as quickly as he could without making errors. If he noticed an error he was to say so, but to carry on. One or two packs were always to be found just to the man’s right on his bench. He was told that when he reached the end of a pack he was to pick up the next one at once and carry on. If he dropped any cards he was to let them lie; on no account was he to stop sorting. If, as occasionally happened, a card got stuck in one of the chutes of the card sorter, the experimenter pushed it through with a ruler.

Scoring and Calculations.—The occasional errors of classification were noted at the end of the test after the pressure had returned to normal. The time at which each card fell into a box, which was recorded automatically on magnetic tape, was later transferred to punched tape. This was fed into an electronic computer programmed to calculate the mean and the standard deviation (S.D.), and to print out a histogram of times grouped in intervals of 0-1 second.

The statistical tests involved ranking the men in the groups to be compared and computing Mann and Whitney’s U (Siegel, 1956). This method makes no

### Table

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Men</th>
<th>Mean Age</th>
<th>First Test</th>
<th>Second Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Absolute Pressure (atmospheres)</td>
<td>Mean Rate¹ (mean sec. per card)</td>
</tr>
<tr>
<td>A</td>
<td>7</td>
<td>33</td>
<td>$3\frac{1}{2}$</td>
<td>1.456</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>27</td>
<td>$2\frac{1}{2}$</td>
<td>1.467</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>29</td>
<td>2</td>
<td>1.389</td>
</tr>
<tr>
<td>D</td>
<td>13</td>
<td>27</td>
<td>(normal)</td>
<td>1.347</td>
</tr>
<tr>
<td>D+E</td>
<td>6 Cambridge</td>
<td>19</td>
<td>(normal)</td>
<td>1.361</td>
</tr>
<tr>
<td>E</td>
<td>7 Tilbury</td>
<td>34</td>
<td>(normal)</td>
<td>1.337</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ 1 atmosphere reliably different only from $3\frac{1}{2}$ atmospheres (P < 0-05)
² 1 atmosphere reliably different from $2\frac{1}{2}$ and $3\frac{1}{2}$ atmospheres
³ 1 atmosphere reliably different from 2, $2\frac{1}{2}$, and $3\frac{1}{2}$ atmospheres
⁴ No reliable differences between groups
assumptions about the parent distribution from which the samples examined are drawn, and is almost as powerful as the corresponding parametric test. Since the direction of any difference found between experimental and control conditions could be predicted from previous results at greater pressures, one-tailed tests have been used.

Results

The table shows three measures of performance for the first test but only the most sensitive of the three for the second test. This measure, the mean percentage of very slow responses, is based on a criterion of 2.5 seconds or longer, which is about two standard deviations (S.D.s) greater than the mean response time. In the first test, the two groups D and E, which performed at normal atmospheric pressure, gave almost identical results despite the differences between them in age and experience. The two sets of results for the first test, which are shown in the bottom two lines of the table, have therefore been combined in the line above.

Taking the combined group D + E as the baseline for the first test, group A sorting the cards at 3\(\frac{1}{2}\) atmospheres absolute took reliably longer per card [see footnote (1) of Table]. This means that an increase in mean time as large as that of group A over the combined group D + E would have occurred by chance less often than once in 20 experiments. When the criterion of performance is changed to the mean variability in timing, group B sorting at 2\(\frac{1}{2}\) atmospheres absolute was also reliably worse than the combined group D + E. And using the most sensitive criterion of the mean percentage of very slow responses, group C sorting cards at 2 atmospheres absolute was also reliably worse than the baseline group D + E. In contrast, in the second test the performance of group E, which sorted cards at 3\(\frac{1}{2}\) atmospheres absolute, was not reliably different from that of any of the other groups which worked at normal pressure.

A card was dropped into the wrong box on average rather less than twice per 10-minute test. A card (very occasionally a handful of cards) was dropped on the floor on average rather less than once per test. These two types of error were no more frequent in compressed air than at normal pressure.

Men who had spent 1.5 hours or more in compressed air at 3\(\frac{1}{2}\) atmospheres absolute just before their test at pressure did not do reliably worse than men who had spent only about 15 minutes at this pressure. Men who had had no previous experience in compressed air did not do reliably worse than the very experienced. The effect of compressed air was also unrelated to age.

Discussion

A Reliable Effect at 2 Atmospheres Absolute.—

The results show that sorting cards was affected by compressed air at a pressure as low as 2 atmospheres absolute. The practical implications of this are clear. Whenever a skill involving complex mental operations is undertaken after prolonged exposure to pressures of 2 atmospheres absolute or greater, it cannot necessarily be assumed that it will be carried out as adequately as it can be done at normal atmospheric pressure. This now applies to surgical operations in pressurized operating theatres as well as to surveying tunnels in compressed air and maintaining works under water.

In order to ensure that the brain was saturated with compressed air reasonably quickly, we adopted the procedure of leaving each man in groups B and C at 3\(\frac{1}{2}\) atmospheres absolute for at least 10 minutes before lowering the pressure to the level at which he was to be tested. This is because the rate at which compressed air diffuses into the brain appears to be proportional to the square of the difference in pressure (Bennett and Glass, 1961). Thus whereas about 10 minutes appears to have been adequate at 2\(\frac{1}{2}\) atmospheres above normal (3\(\frac{1}{2}\) atmospheres absolute), the corresponding duration for 1 atmosphere above normal (2 atmospheres absolute) would have been about one hour. This was longer than the men could spare. It should, however, be pointed out that for men working at only 2 atmospheres absolute, it may or may not be necessary to spend a full hour at this pressure before performance shows the full effect of compressed air. This is a point which has not yet been looked into.

The narcotic effects of compressed air wear off within a minute or two once the pressure is reduced (Kiessling and Maag, 1962). Thus by the time the men in groups B and C were ready to start the experiment, their level of performance was related to the pressure at which they were tested, not to the previous pressure of 3\(\frac{1}{2}\) atmospheres absolute.

A Sensitive Measure of Performance.—This is the first time that a statistically reliable effect of compressed air on performance has been reported at a pressure of less than 4 atmospheres absolute. To obtain an effect at 2 atmospheres absolute it was necessary to make the experiment as sensitive as possible. Unless experimental techniques can be refined still further, it appears unlikely that statistically reliable effects will be found at pressures much below this. Two atmospheres absolute is the lowest pressure at which type 1 'bends' are normally reported (Paton and Walder, 1954).

At these relatively low pressures compressed air
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affected the performance only of men sorting cards for the first time, when the task was unfamiliar and thus relatively difficult. Once the task had been well practised, and had thus become relatively easy, it was unaffected even by a pressure of 34 atmospheres absolute. When this interaction of compressed air with degree of practice became clear, it was decided to exploit it to the full by a change of procedure. Previously four men in group A had been given their initial instruction and two-minute practice as soon as they had agreed to serve in the experiment, before they entered the compressed air (see Procedure). They had thus been able to get the hang of the task at normal pressure. The procedure was changed to make the men undertake in compressed air the relatively complex mental operations of organizing the task and deciding how to carry it out. Thus any effect which the compressed air might have upon performance was augmented by any effect it might have upon the efficiency with which the men organized the task initially (see Welford, Brown, and Gabb, 1950).

Of the three measures of performance in the Table, the mean rate of sorting the cards was the least sensitive to differences in pressure. This was presumably because each man worked at his own speed. He was thus able to compensate to some extent for a slow response associated with a lapse of attention in compressed air by subsequently sorting a little more quickly. Alternating slow and quick responses do, however, increase the size of the standard deviation (S.D.), which was therefore more sensitive to differences in pressure. The mean percentage of very slow responses was a still more sensitive measure, because it was affected both by any reduction in the mean rate of responding and by any increase in variability.

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REFERENCES


THE APRIL (1964) ISSUE

The April (1964) issue contains the following papers:—

A Study of Byssinosis, Chronic Respiratory Symptoms, and Ventilatory Capacity in English and Dutch Cotton Workers, with Special Reference to Atmospheric Pollution. B. Lammers, R. S. F. Schilling, and Joan Walford.
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