A REVIEW OF THE EFFECTS OF TRACE CONCENTRATIONS OF ANAESTHETICS ON PERFORMANCE

G. SMITH AND A. W. SHIRLEY

The professional performance of the anaesthetist is a subject of enormous importance which has been subjected to very little scientific scrutiny. From a questionnaire sent to junior hospital doctors of all specialties, Wilkinson, Tyler and Varey (1975) elicited that more than one-third of medical staff below the grade of registrar believed they suffered an impairment of working efficiency as a result of fatigue. Symptoms which were reported included irritability, inability to speak, tiredness and slowing of thought processes. Junior anaesthetists also believed that breathing anaesthetic waste gases contributed to fatigue and impaired working efficiency.

It is now generally accepted that working in the operating theatre environment is associated with an increase in health hazards. Although the direct cause of this problem has not been established, complaints of headaches by anaesthetists working with un-scavenged anaesthetic circuits, data demonstrating ill-effects in laboratory animals induced by low concentrations of anaesthetic agents, and laboratory studies demonstrating impaired psychomotor performance in human volunteers breathing trace concentrations of anaesthetics have led to pollution of the theatre environment with waste anaesthetic gases being incriminated as a possible aetiological factor. The National Institute of Occupational Safety and Hygiene (NIOSH, 1977) has laid down criteria for the permissible concentrations of gases in the environment of medical workers. These are a concentration of nitrous oxide of 25 p.p.m. (when used as the sole agent) and a concentration of halogenated anaesthetic of 2 p.p.m. These suggested limits are based to a large extent on the results of psychomotor performance tests carried out by Bruce and his colleagues (Bruce and Bach, 1976).

However, there are a very large number of factors which may affect performance (fig. 1). It is the purpose of this paper to review in detail only those data relating to the effect of trace concentrations of anaesthetic agents on performance. By trace concentrations, we imply those concentrations of anaesthetic agents likely to be found in the general atmosphere of the operating theatre as contaminants (Smith, 1976). Studies on higher, subanaesthetic concentrations of anaesthetic drugs will be mentioned in that they have a bearing on the threshold concentrations which affect performance. Performance following recovery from clinical doses of anaesthetic agents has been discussed recently in an excellent, comprehensive review by Drummond (1975) and this aspect will not be considered here.

It is now generally accepted that working in the operating theatre environment is associated with an increase in health hazards. Although the direct cause of this problem has not been established, complaints of headaches by anaesthetists working with un-scavenged anaesthetic circuits, data demonstrating ill-effects in laboratory animals induced by low concentrations of anaesthetic agents, and laboratory studies demonstrating impaired psychomotor performance in human volunteers breathing trace concentrations of anaesthetics have led to pollution of the theatre environment with waste anaesthetic gases being incriminated as a possible aetiological factor. The National Institute of Occupational Safety and Hygiene (NIOSH, 1977) has laid down criteria for the permissible concentrations of gases in the environment of medical workers. These are a concentration of nitrous oxide of 25 p.p.m. (when used as the sole agent) and a concentration of halogenated anaesthetic of 2 p.p.m. These suggested limits are based to a large extent on the results of psychomotor performance tests carried out by Bruce and his colleagues (Bruce and Bach, 1976).

G. SMITH, B.SC., M.D., F.F.A.R.C.S., University Department of Anaesthesia, Western Infirmary, Glasgow. A. W. SHIRLEY, M.ED., PH.D., Department of Psychology, University of Glasgow.
Examination of the performance of operating theatre staff to assess the influence of pollution should be carried out, ideally, on site during normal working activities. However, the number of factors which may affect performance is large (fig. 1) and such a task would be extremely difficult and complex, if not impossible. So far, studies have been confined to the artificial environment of the laboratory in an attempt to stabilize as many factors as possible with the exception of the composition of the inspired gas. However, it should be clear that even if a detrimental effect on performance is demonstrated in subjects breathing trace concentrations of anaesthetics in the laboratory, it is conceivable that such an effect may be minor and may be masked by more potent influences which either increase or decrease performance during normal working.

Before reviewing the literature on trace concentrations of anaesthetics and performance, we should consider briefly the concept of performance and its various aspects, but the practical assessment of performance has been the subject of a recent review (Herbert, 1978) to which the reader is directed.

Performance may be defined as the ability to display a complex sequence of activities which has been acquired by learning processes (Fitts and Posner, 1967). Thus, innate reflex activity is not indicative of skilled performance. Although various skilled activities may appear to be "reflex" (for example, typing, driving, talking), each skill has been acquired by the processes of understanding the task initially, and of sufficient repetition (or association) until the process becomes automatic and ceases to intrude into conscious thought. Thus, reaction-time tests involve...
these processes and are therefore tests of skill rather than demonstrations of intact physiological reflex arcs, but are not tests of the more basic abilities needed initially to develop those skills. Figure 2 describes in simplified form some of the component processes involved in the demonstration of skilled performance and is drawn largely from the text of Fitts and Posner (1967).

For practical purposes, tests of performance may be divided broadly into two types. Both may be seen as the exercise of perceptual motor or language skills, or both (fig. 2). However, one involves predominantly a fast motor response to a perceived stimulus, as in reaction time experiments. The other is related more logically to language skills. It utilizes to a greater extent memory stores and higher mental processes and involves what may be loosely described as the most basic characteristic; namely that which decides whether a response is or is not made in conditions of uncertainty and involves a degree of risk-taking, the urgency for which can be controlled experimentally. It is evident that such factors may inhibit the exercise of motor skills. This second type, broadly described as language skill, is related to the more abstract qualities of attention, understanding and level of arousal in its psychological aspects. All these factors affect the making of responses.

**Measurement of performance**

The assessment of performance may be undertaken at several points in the systems diagram illustrated in figure 2. An appropriate test to employ at any stage would be one of a function which is likely to suffer in response to the situation under examination. In the study of Bruce, Bach and Arbit (1974), areas which were studied were perceptual–motor skills, short-term memory for digits and verbal passages, and certain aspects of intelligence. To measure motor skills, an audiovisual reaction-time test was employed, while memory and intelligence functions were assessed using the Wechsler Adult Intelligence scale which is well established as a reasonably reliable and valid test of these aspects of performance. In a later study, the same authors expanded their assessment to include a simple dexterity test and, more importantly, a vigilance test to measure loss of attention by change in reaction times to variations in a visual oscilloscope signal (Bruce and Bach, 1976).

The latest published study in this area (Frankhuizen et al., 1978) included a similar reaction-time test as a measure of degree of arousal, a memory item involving word–number combinations and a measure of a higher mental function of the intelligence type by anagram problem solving. The slight differences in the memory-type tests between these two groups of workers do lead to the measure of slightly different skills in view of the various processes involved in the storage of activity. This can be demonstrated by the fact that in the committal to memory of nonsense syllables, one might be tempted to relate them by auditory patterning (VAP–MUJ), whereas the memory for digits might be attempted by an examination of their series links (for example 94685—all of which can be given in terms of 3 and 2: $3^2, 2^3 3 \times 2, 2^3, 2+3$).

One aspect of performance which is clearly of tremendous concern to the anaesthetist is decision making in response to incoming signals. There are a number of aspects of this process which are not readily portrayed in diagrammatic form but which are of considerable importance and have been extensively investigated. The reaction-time tests utilized by various studies of the effect of trace concentrations of anaesthetics have measured only the speed of decision making; the vigilance test utilized by Bruce and Bach (1976) also involves only this aspect of decision making. However, if one considers the effects of vigilance upon the degree of risk-taking as in the classical Signal Detection Theory model, then one can measure performance decrement in terms of loss of efficiency as an increase in the likelihood of a subject taking risks. These measures are obviously extremely pertinent to the work in operating theatres. There is a vast literature in the journals of applied psychology on this subject and, as an introduction, the reader is referred to the article by Broadbent and Gregory (1963). In experiments modelled along these lines, the degree of risk involved can be controlled by varying the rewards and losses pertaining to the correctness of the decision made while the "risk-taking" level is assessed by the ratio of the correct positive response probability to the false positive response probability. This ratio is termed the precision criterion. The tasks involved in such a test can be varied considerably but one common feature of them is that the signal is presented against a "noise" background. The ratio between the signal and the noise is obviously a very important variable. The subject is required to depress a key when he detects the signal as present against the noise, the signals being presented randomly over time in a sequence of regularly spaced possible occasions when it might be presented. This decision criterion has been found to
be extremely sensitive over a wide range of conditions and in particular in response to the effects of sleep deprivation (Williams, Lubin and Boodnow, 1959) and alcohol (Wilkinson and Colquhoun, 1968).

In terms of the diagram shown in figure 2, this decision-making aspect of performance may be located as acting upon the motor response function. What makes it of importance is that in contrast to the choice reaction-time tests, this function is related to those higher factors which are known to control the motor response and thereby only indirectly its speed. No study to date appears to have tested the effect of trace concentrations of anaesthetics on this function.

The selection of appropriate tests, design of experiment and analysis of data produced are of paramount importance in performance studies. However, these aspects need not be discussed further here as they have been the subject of a recent review in this journal (Herbert, 1978).

Subjective reports

Subjective impairment of anaesthetists' performance has been reported since before 1929 (reported in NIOSH, 1977). Many anaesthetists believe that they experience discomfort, in particular headache, sleepiness and fatigue in proportion to the amount of anaesthesia administered to patients. In 1970, Cameron described himself as becoming "increasingly more sensitive to the vapour of both halothane and methoxyflurane, the result being undue fatigue at the end of the day and after more prolonged exposure, severe headache and nausea". In some instances, there have been reports of problems in association with a specific anaesthetic agent and Pitt (1974) described general malaise and laryngitis associated with the use of halothane for anaesthetizing patients, but not with ether, trichloroethylene or nitrous oxide.

As small but detectable concentrations of anaesthetic agents have been detected in the expirate of anaesthetists and nurses many hours after leaving the operating theatre (Linde and Bruce, 1969; Corbett and Ball, 1971), it is not surprising that an association has been postulated between occupational exposure to volatile anaesthetic agents and subjective ill-effects. A relationship between excessive fatigue and operating theatre pollution was expressed by anaesthetists replying to a survey of fatigue amongst junior hospital doctors (Wilkinson, Tyler and Varey, 1975).

It is of relevance that the majority of laboratory studies of low concentrations of anaesthetic agents

<table>
<thead>
<tr>
<th>Anaesthetic</th>
<th>Concen (p.p.m.)</th>
<th>Concen (%)</th>
<th>% of MAC value</th>
<th>Effect</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethylene</td>
<td>100</td>
<td>0.01</td>
<td>5.5</td>
<td>0</td>
<td>Vernon and Ferguson (1969)</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>300</td>
<td>0.03</td>
<td>16.5</td>
<td>0</td>
<td>Stewart and others, 1962, 1970</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>1000</td>
<td>0.1</td>
<td>55</td>
<td>+</td>
<td>Salvini, Binaschi and Riva (1971)</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>200</td>
<td>0.02</td>
<td>11.1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>110</td>
<td>0.011</td>
<td>6.1</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>500</td>
<td>0.05</td>
<td>0.047</td>
<td>+</td>
<td>Bruce, Bach and Arbit (1974)</td>
</tr>
<tr>
<td>Nitrous oxide + halothane</td>
<td>500/15</td>
<td>0.05</td>
<td>0.047/0.2</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide + halothane</td>
<td>500/15</td>
<td>0.0015</td>
<td>0.047/0.2</td>
<td>0</td>
<td>Smith and Shirley (1977)</td>
</tr>
<tr>
<td>Enflurane + nitrous oxide</td>
<td>15/500/0.0015</td>
<td>0.09</td>
<td>0.047/0.09</td>
<td>+</td>
<td>Bruce and Bach (1975)</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>50</td>
<td>0.05</td>
<td>0.0047</td>
<td>+</td>
<td>Bruce and Bach (1976)</td>
</tr>
<tr>
<td>Nitrous oxide + halothane</td>
<td>25/0.5</td>
<td>0.0025</td>
<td>0.0047</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Halothane</td>
<td>370-740</td>
<td>0.037-0.75</td>
<td>5-10</td>
<td></td>
<td>Threshold values for + response</td>
</tr>
<tr>
<td>Enflurane</td>
<td>840-1680</td>
<td>0.84-1.68</td>
<td>5-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>50-100000</td>
<td>5-10</td>
<td>5-10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A greater range of psychological tests was undertaken by Stopps and McLaughlin (1967) in order to assess the 1965 threshold limit value of 100 p.p.m. Trichloroethylene concentrations of 100, 200, 300 and 500 p.p.m. were produced in a small exposure chamber and the odour masked by the use of lavender oil. One subject was exposed for alternative 90-min periods to either trichloroethylene or air. The results indicated that the subject's performance (in terms of manual dexterity) deteriorated as the concentration of trichloroethylene increased beyond 200 p.p.m., but there was no effect on card sorting even at the highest concentration.

Tests of visual and motor skills were undertaken by Vernon and Ferguson in 1969, utilizing a Krasno–Ivy flicker photometer, a Howard–Dolman depth perception apparatus, a Muller–Lyer two-dimensional illusion test, a written test of the code substitution type and the Purdue peg board. Eight male volunteers were studied and each subject breathed trichloroethylene in concentrations of 0, 100, 300 and 1000 p.p.m. through a mouthpiece with nose-clip. The order of administration of the gases was randomized and the results subjected to analysis of variance. Only the highest concentration of trichloroethylene (inhaled for 2 h) had statistically significant effects in three of the tests. There were no effects on flicker fusion, form perception or code substitution tests.

Although some of these earlier studies had indicated an effect of trichloroethylene on several tests involving visual perception, it cannot be concluded that there was an effect on visual pathways. Such effects could have been produced by fatigue or loss of attention with lack of vigilance. In addition, earlier studies suffered from the defect that the duration of exposure was relatively short. Two subsequent studies were designed to expose volunteers for longer durations to trichloroethylene in an attempt to emulate more closely the conditions during the working day. Stewart and his colleagues (1970) exposed five volunteers to trichloroethylene in concentrations of approximately 200 p.p.m. for 7 h per day over 5 consecutive days. Exposure was carried out in a large room and there was relatively little fluctuation in the concentration of trichloroethylene. During the period of exposure, subjective responses were recorded. A Romberg test, a heel-to-toe test and a finger-to-nose test were performed at 2-hourly periods. Crawford manual dexterity tests and Flannagan co-ordination and inspection tests were performed twice during each period of exposure. It is of interest that although the majority of individuals

Low concentrations of trichloroethylene (table I)

The earlier laboratory studies of the effects of low concentrations of anaesthetic agents on psychomotor performance were confined to studying trichloroethylene (table I). These studies were initiated as a result of concern about possible ill-health among industrial workers. Before 1961, the American Conference of Governmental Industrial Hygienists had proposed a threshold limit for trichloroethylene of 200 p.p.m., but this was revised subsequently to 100 p.p.m. In order to test these limits, in 1962 Stewart and his colleagues exposed human volunteers to trichloroethylene concentrations of approximately 160 p.p.m., 160–250 p.p.m. and 350–400 p.p.m. Although some mild eye irritation was noted in three of the seven subjects with the lowest concentration, there was no effect with the highest concentration. The only tests of performance employed were those assessing balance and motor co-ordination (Romberg's test and heel-to-toe test) and these were unaffected.

Subsequent studies failed to confirm these findings. Kylin and his colleagues (1967) exposed 12 subjects to trichloroethylene 1000 p.p.m. for 2 h in a small chamber. Optico–kinetic nystagmus was recorded by measuring the potential difference produced by eye movement between electrodes placed in the lateral angles of the eyes. There was a small reduction in the fusion limits produced by trichloroethylene but this was not as marked as the change produced by the consumption of alcohol (0.7 g kg⁻¹).
were able to perceive the odour of trichloroethylene immediately, this ability diminished during the course of the week. Within 30–60 min of exposure on the 2nd day, none was able to smell trichloroethylene. Similarly, although mild eye irritation was noted initially, this was not a complaint in the later stages of the experiment. A feeling of fatigue was relatively constant after the 4th day of repeat exposures. None of the tests of psychomotor performance was affected, although half the subjects commented that a greater amount of effort than normal appeared to be necessary.

Results conflicting with these were obtained by Salvini, Binaschi and Riva (1971). Six young male University students were exposed to trichloroethylene in a concentration of 90–130 p.p.m. Each subject was studied on two different days with an interval of 4 days. On one occasion, he was exposed to air and on another occasion to trichloroethylene. The order of administration was randomized. The exposure period on each day comprised 4 h in the morning and 4 h in the afternoon separated by 90-min intervals. During each test period, measurements were made of visual perception utilizing a tachistoscope. Thirteen slides, each containing nine squares with black circles, were presented for 0.05 s. The Wechsler memory scale was utilized to measure immediate memory and a complex reaction-time test employed comprising both visual and auditory signals which required different responses. In addition, manual dexterity was evaluated by the O'Connor dexterity test (threading three fine needles into a round hole for 3 min with one hand, 3 min with the other and 3 min with both hands). The results indicated that trichloroethylene was associated with a significant decrease in all tests of performance and the greatest decrease occurred with the more complex tests. It is notable that all subjects could detect the smell of trichloroethylene during the test periods of exposure.

Stewart and his colleagues, working under contract to NIOSH (NIOSH, 1977), attempted to duplicate the study of Salvini, Binaschi and Riva (1971), but were unable to detect any detrimental effect of trichloroethylene in a concentration of 110 p.p.m. on the same tests of performance as those utilized in the former study.

It is of note that in all the studies on the effect of trichloroethylene, concentrations in excess of 100 p.p.m. have been used and this would be detected easily by subjects. Although only two studies made comparisons between air breathing (control) and trichloroethylene breathing (test) (Vernon and Ferguson, 1969; Salvini, Binaschi and Riva, 1971), the subject's awareness of the composition of the inspired gas might conceivably influence the outcome of sensitive tests of psychomotor performance. These objections do not apply to more recent studies in which, in most instances, anaesthetic agents in concentrations lower than the olfactory threshold values have been used. It should also be noted that these studies of trichloroethylene are not as relevant to the operating theatre environment as studies which are described below, since the concentration of trichloroethylene in unscavenged operating theatres has been found rarely to exceed 50 p.p.m.

**Trace concentrations of nitrous oxide, halothane and enflurane (table I)**

Mounting concern about the possible health hazards affecting medical and nursing staff working in polluted atmospheres in the operating theatre focused attention on the effects of pollution on performance. This culminated in a study from Chicago on the effect of nitrous oxide 500 p.p.m. (with or without halothane 15 p.p.m.) in air on psychomotor performance in 40 male student volunteers (Bruce, Bach and Arbit, 1974). These concentrations of anaesthetic gases were chosen as being comparable to those found in operating theatres before the introduction of scavenging systems. Male students were examined on two occasions, at the same hour of the same day of the week on two consecutive weeks. On one occasion, the student was exposed to air and on the other to trace anaesthetic agents in air. The order of administration was balanced and the subject inspired the gas mixture from a head tent. At the end of the 4 h of exposure, the subject was taken to a psychological laboratory where the following tests were performed in sequence: an audio–visual task, four sections of the Weschler memory scale, a tachistoscope task and six items from the Weschler Adult Intelligence Scale. The audio–visual task comprised the presentation to the subject of a visual signal in the form of a fast moving pattern of e.g. activity on either the upper or lower trace of an oscilloscope and an auditory signal through headphones in the form of either fast or slow metronome beats. The subject had to record by means of a finger button the correct combination of auditory and visual signals as soon as a change occurred in the presentation of signals. In this study, the tachistoscope task comprised the presentation to the subject, for 0.05 s, a card divided into nine squares each of which contained a variable number of black circles. The subject's task was to reproduce on a black grid the location of the circles in each presentation.
Of the 40 students studied, 20 were exposed to nitrous oxide 500 p.p.m. alone in air, and the other 20 to halothane 15 p.p.m. and nitrous oxide 500 p.p.m. in air. The results indicated that, in comparison with the controls, the combination of nitrous oxide and halothane produced significant decrements in the audio-visual task, tachistoscope task and tests of immediate memory. Subjects exposed to nitrous oxide alone showed a significant decrement in performance only on the digit span test. In addition, six of the 20 subjects exposed to nitrous oxide and halothane fell asleep during the test exposure but not the control exposure, whilst two of the students exposed to nitrous oxide alone fell asleep during the test. Only one subject fell asleep whilst breathing air. The students denied any knowledge of the gas they were inspiring and the somnolence produced was adduced as extra evidence of an effect of the anaesthetic gases. This may not necessarily be so, but it should be noted that testing of psychomotor performance after a period of sleep would not be consistent with attempting to control as many variables as possible, and the period of sleep itself would be expected to cause alteration in performance.

Similar results were obtained by the same workers in tests of the effect of enflurane and nitrous oxide on performance (Bruce and Bach, 1975). Thirty subjects were exposed to enflurane 15 p.p.m. and nitrous oxide 500 p.p.m. in air and 10 were exposed to nitrous oxide 500 p.p.m. alone. As before, all the subjects were young male students in good health, receiving no medication and the exposure was via a head tent. The same pattern of testing of psychomotor performance was undertaken. The anaesthetic gas combination was found to produce a significant decrement only in the audio-visual task and the digit span memory task and nitrous oxide alone produced a significant decrease in performance only on the digit span test.

In both these studies, psychological testing was commenced some 5 min after cessation of exposure to the anaesthetic gases and it was postulated that, had testing been undertaken during exposure to the agents, an even greater decrement in performance might have been observed.

This hypothesis was pursued in subsequent studies by Bruce and Bach (1976), in which an attempt was made to obtain a dose–response relationship in terms of anaesthetic concentrations and impairment in performance. One hundred male students aged 20–30 yr from North Western University, Chicago, were allocated to five groups. Each group was exposed to one of the following test gases: nitrous oxide 500 p.p.m. and halothane 10 p.p.m.; nitrous oxide 500 p.p.m.; nitrous oxide 50 p.p.m. and halothane 1.0 p.p.m.; nitrous oxide 50 p.p.m.; nitrous oxide 25 p.p.m. and halothane 0.5 p.p.m. Comparisons were made between measurements obtained with the patients breathing the appropriate gases and, on a separate occasion, atmospheric air. All studies were performed on the morning of the same day of the week and although each subject was allowed to ingest tea or coffee for breakfast, the period of exposure was not interrupted. Gas was administered via a lightweight tightly fitting mask and no subject reported his ability to detect any odour in the inspired gas. On each occasion, after 2 h of exposure, performance was assessed utilizing a tachistoscope followed by Raven matrices and O'Connor dexterity tests, and at about 2.25 h of exposure, a 2-min audio-visual task. After 3 h of exposure, a 60-min vigilance test was performed and at 4 h exposure a 7-min audio-visual task was given, followed by a digit span test. The audio-visual task was similar to that employed previously, apart from an alteration in the visual signal to either a pattern of ventricular fibrillation or a flat line displayed on only one channel of an oscilloscope.

No alteration in manual dexterity was noted from the O'Connor dexterity test, but visual perception was impaired by the anaesthetic agents. The most sensitive test utilized was again the audio-visual reaction time test and this demonstrated a significant decrement in performance with nitrous oxide 50 p.p.m. and halothane 1 p.p.m. and also with nitrous oxide 50 p.p.m. alone. No effects were seen in any tests in subjects exposed to nitrous oxide 25 p.p.m. and halothane 0.5 p.p.m. Of considerable interest was the fact that no decrement in performance of the vigilance task was noted and in fact there was a significant increase in performance with the 60-min vigilance test in subjects exposed to nitrous oxide 50 p.p.m. and halothane 1 p.p.m., although an explanation for this was lacking.

These three studies from Chicago were all well designed, well controlled and well executed. Perhaps the only criticism which might be applied from a design standpoint is the fact that none of the studies was double-blind. It is remarkable that the scatter of individual results for the reaction times was extraordinarily small and this was explained by the fact that all the students were extremely highly selected and highly motivated ("highly motivated achievers who are accustomed to performing at a high level of excellence"). It is of interest that studies performed elsewhere, which are described below, also utilized
students from University populations and yet the scatter of individual results in reaction-time tests were more in accord with expectation. From a design point of view, however, it may be stated that "highly motivated achievers" may be more influenced by occult influences from the observers and such a group of test subjects would require a double-blind technique of investigation to a greater extent than less "highly motivated" subjects.

The results of Bruce and his colleagues have not been confirmed by subsequent studies performed by three independent laboratories in three different countries (Cook et al., 1976, 1977; Smith and Shirley, 1977; Frankhuizen et al., 1978). Using tests identical to those employed by Bruce and his colleagues, the collective results of these studies indicate that the threshold at which performance decrements occur is considerably higher than those concentrations occurring in unsaunched operating theatres.

The first studies failing to confirm the work of Bruce and his colleagues were those of Smith and Shirley (1977). Initially, 10 subjects were exposed to halothane 100—150 p.p.m. in air through a facemask. The sense of smell was obtunded by spraying the nasal mucosa of the subjects with 4% lignocaine. After 3—4 h, complex reaction times were measured in which the subject was required to respond, by pressing a button, to an increasingly more complex illumination of one of 32 bulbs. No difference was found in the response of the subjects when breathing either air or halothane in air. Subsequently, Smith and Shirley (1977) attempted to reduplicate the earlier published study of Bruce, Bach and Arbit (1974). Fifteen male psychology students unused to the operating theatre environment were tested in the laboratory on two occasions at the same time on the same day of the week. On one occasion, each was exposed to air and, on another, to nitrous oxide 500 p.p.m. and halothane 15 p.p.m. in air. The order of administration was balanced and, before exposure commenced, an audio-visual reaction-time test similar to that employed by Bruce, Bach and Arbit (1974) was given. After 3.5 h with the subject still breathing through a tightly fitting Air Force-type facemask, the following tests were performed: audio-visual reaction-time test, four aspects of the Weschler memory scale and tachistoscope measurements. No significant differences were found between the control and test situations. A possible explanation for the difference in results of this study and that of Bruce, Bach and Arbit (1974) might be the differences in the subjects studied, the groups varying enormously in cultural background. In addition, the subjects in the U.K. study were allowed to remove the mask briefly during the period of exposure in order to ingest one cup of coffee. As caffeine in a dose of 100—200 mg has been shown to counteract the increase in complex reaction times produced by large doses of alcohol (Carpenter, 1959), it was not possible to exclude caffeine as the explanation for the negative findings in this study. However, it should be pointed out that in the later study from Chicago (Bruce and Bach, 1976), the subjects were allowed to ingest caffeine immediately before the test and yet positive effects were found with very much lower concentrations of the anaesthetic agents under study. The tachistoscope task employed by Smith and Shirley was more sensitive than the same test used by Bruce, Bach and Arbit (1974) as the former employed 30 cards each containing 16 squares, in comparison with 15 cards containing nine squares. This test was significantly affected in the U.S. but not the U.K. study.

The only double-blind control study which has been performed to date in this field is that of Frankhuizen and colleagues (1978). Twenty-four male subjects were exposed in two different 2-h sessions in a chamber to either air alone or nitrous oxide 1600 p.p.m. and halothane 16 p.p.m. The tests of performance utilized were those of an audio-visual reaction time test based upon the one described by Bruce, Bach and Arbit (1974), and tests of short-term memory (lists of word-number pairs, recognition of words and numbers, recall of word-number pairs) and anagram-solving problems. Although this study was designed to reduplicate under more strictly controlled conditions the earlier study of Bruce, Bach and Arbit (1974), no effect was found on performance by the anaesthetic gases. The authors drew attention to the differences in conditions between studies, notably different methods of gas administration, the shorter duration of exposure in the Dutch study (2 h), the very slight difference in the reaction-time task inasmuch as different types of auditory stimuli were employed (clicks as opposed to pitches) and the use of a double-blind design. Nonetheless, the authors were unable to reconcile the negative findings of their study with those of Bruce and his colleagues.

Recently, independent studies from the U.S.A. have revealed that the threshold for an effect of nitrous oxide, enflurane and halothane on psychomotor performance is in the region 5—10% of the MAC value for each anaesthetic agent (Cook et al., 1976, 1977). Initially, seven paid male volunteers were exposed for up to 2.5 h to varying concentrations
of halothane and halothane with nitrous oxide in air (Cook et al., 1976). Both digit span tests and also a choice reaction time mimicking that of Bruce, Bach and Arbit (1974) revealed that an alteration in performance occurred when the inspired nitrous oxide concentration exceeded 5–10% and the inspired halothane concentration exceeded 0.01%. Subsequently, 10 male colleague students were exposed to enflurane, halothane and nitrous oxide in varying concentrations for a time sufficient to produce a constant alveolar concentration for 30 min. Tests of performance during the last 10–15 min of this constant period included the choice reaction-time test, a digit span test and the Purdue pegboard assembly test. All the anaesthetic agents impaired function as measured by all three tests in concentrations exceeding 5–10% of MAC (Cook et al., 1977) (table I).

It is difficult to reconcile the different results found by Bruce and his colleagues with those of Smith and Shirley (1977), Frankhuizen and colleagues (1978) and Cook and colleagues (1976, 1977). Although these last three studies were designed to emulate the first study as closely as possible, there must inevitably be small yet subtle differences in the administration of the tests employed. In addition, the duration of exposure of the subjects varied in all the studies and of most importance, perhaps, is the variation in the subjects under study. Despite the fact that, in all studies, the subjects were young, healthy, University students not receiving any medication, there must be wide variations in cultural and social backgrounds. Nonetheless, it would seem that if three independent laboratories from three different countries fail to confirm the findings of Bruce and his colleagues, it is reasonable to state that there is no convincing evidence that anaesthetic agents in concentrations equal to those found in unscavenged operating theatres have any affect on the psychomotor performance of healthy subjects in the laboratory. This statement is given further weight by the current unpublished observations of the authors, who are measuring the threshold concentrations of nitrous oxide on performance in fasting volunteers (not influenced by caffeine). Our preliminary results are in agreement with those of Cook and colleagues (1977), in that the threshold concentration of nitrous oxide which affects the audio–visual reaction-time test lies between 8% and 12%.

Subhypnotic concentrations of anaesthetic agents

Subanaesthetic concentrations of nitrous oxide have been employed in a large number of psychological studies as a tool to facilitate the analysis of human performance into its component processes. Earlier studies suggested that 30% nitrous oxide depressed significantly a variety of performance tests (Henrie, Parkhouse and Bickford, 1961) to an extent dependent upon the complexity of the task, but that motor activity was affected to a relatively greater extent than expected by this simple concept (Steinberg, 1954). Subsequent studies revealed that 30% nitrous oxide affected performance predominantly by interfering with the acquisition of a learned process, rather than on its demonstration, and there was only a small effect on recall of long-term memory (Steinberg and Summerfield, 1957). This was confirmed by Berry, Gelder and Summerfield (1965) who exposed volunteers to 15%, 25% and 35% nitrous oxide in oxygen and tested performance with complex card-sorting tasks. Movement times were increased only by 25% and 35% nitrous oxide whilst sorting times were increased by 15% nitrous oxide. This suggested that nitrous oxide initially affected the input stages and their interactions with memory stores.

Tests of verbal memory were shown to be inhibited consistently by 20–30% nitrous oxide (Parkhouse et al., 1960; Robson, Burns and Welt, 1960), but not by 10–20% nitrous oxide (Robson, Burns and Welt, 1960). Verbal memory functions develop at a later stage than acoustic or visual memory functions and it has been shown in conscious man that the former may be depressed with low concentrations of a variety of anaesthetic gases which have no effect on acoustic or visual memory (Adam, 1973).

More recently, studies have been performed of the effects of 0, 10, 20 and 30% nitrous oxide in oxygen on the auditory evoked e.g.g. and reaction times (Jarvis and Lader, 1971), proprioceptive functions (Legge, 1965) and on memory, decision making, sustained attention (a vigilance task), the Wechsler Adult Intelligence Scale, mood and short-term memory (Garfield, Garfield and Sampson, 1975). In general, there was a progressive depression of function with increasing concentration. Although these studies were not designed to ascertain the threshold concentration which affects performance, a study of the data in these publications reveals that, by and large, 10% nitrous oxide had no significant effect, in comparison with 100% oxygen, on any function apart from subjective recording of mood (Jarvis and Lader, 1971), there being a tendency towards an increase in drowsiness and degree of mental relaxation.

Garfield, Garfield and Sampson (1975) utilized a
test of a much higher order of complexity—the probability learning paradigm—than tests of short-term memory, associative learning and psychomotor co-ordination. This test was unaffected by 30% nitrous oxide, which had marked effect on vigilance, short-term memory and numerical information coding. However, this test may be regarded as one of previously learned responses, rather than acquisition of learning during the test situation (Garfield, Garfield and Sampson, 1975) and, if so, this finding confirmed those of Biersner (1972) that orientation, visual recall and long-term memory were unaffected by 30% nitrous oxide. It should be noted that although this is a test of a high order of complexity, it does not involve Signal Detection Theory and does not test the "risk in decision making" aspects illustrated in figure 2.

All these findings suggest that the psychomotor tests which have been employed in the studies of Bruce and Bach (1975, 1976) and other workers discussed in the previous section are sensitive tests of the pharmacological effects of anaesthetic agents. However, the durations of the studies described in this section were short and therefore the possibility of vigilance depression with much lower concentrations of anaesthetics than those utilized cannot be discounted. Nonetheless, the data from psychological studies of subanaesthetic concentrations of drugs would appear to be more consistent with the findings of Cook and colleagues (1976, 1977), Smith and Shirley (1977) and Frankhuizen and colleagues (1978) than those of Bruce, Bach and Arbit (1974) and Bruce and Bach (1975, 1976).

Other factors modifying performance

Apart from inhibition by trace concentrations of anaesthetic agents, there are many other factors which may modify performance (fig. 1), although it is not the object of this review to discuss these in detail. However, it is obvious that staff may be influenced by other environmental factors. Heat, glare, noise and whispered distractions tend to produce an increase in the number of errors in performing tasks, but not a reduction in speed of performance, whilst loss of sleep may affect the speed of performance (Broadbent, 1963).

The individual is affected markedly by diurnal variation and age. Ageing is associated with a decrease in complex co-ordinating mechanisms but little alteration in simple reaction times. Perceptive processes and short-term memory are impaired, but not simply by failure of sensory information mechanisms such as vision (Welford, 1964).

Drug therapy has a dramatic effect upon performance. Alcohol has been subjected to intense study; it has been shown that a blood alcohol concentration as little as 20 mg dl$^{-1}$ (i.e. 1 pint beer in a 70-kg adult with an empty stomach) produces a marked impairment in motor co-ordination tests (Drew, Colquhoun and Long, 1958). A therapeutic oral dose of diazepam 10 mg depresses co-ordination, flicker-fusion and short-term memory (Haffner et al., 1973). Caffeine, in doses present in cups of tea or coffee, may improve (but not to the same extent as amphetamines) many aspects of performance with the notable exception of intellectual tests (Weiss and Laties, 1962).

CONCLUSIONS

The concentrations of nitrous oxide and halothane which are found in the unscavenged operating theatre environment are of the order of 600 and 10 p.p.m. respectively (Smith, 1976). These concentrations are equivalent to approximately 0.05 and 0.1% of the MAC value for each agent respectively. The balance of experimental evidence presented in this review would indicate that much higher concentrations than these (of the order perhaps of 5–10% of MAC) are required to produce detrimental effects on those aspects of performance which have been subjected so far to investigation. It is concluded, therefore, that pollution of the operating theatre with anaesthetic agents is not likely to affect the performance of staff. There are, however, two important caveats to this statement:

(1) When using unscavenged anaesthetic circuits, particularly of the Magill type, anaesthetists may be exposed to very high concentrations of anaesthetic agents in comparison with other staff in the theatre (Smith, 1976) and conceivably may suffer impairment of performance.

(2) Chronic exposure to trace concentrations of anaesthetic agents may have effects which are not seen during acute exposure in volunteers (conversely, if there were an effect with acute exposure, tolerance might occur with chronic exposure). In addition, one cannot exclude the possibility of interactions between low, subthreshold concentrations of anaesthetics and other factors (fig. 1) to produce a definite impairment in performance.

REFERENCES


