THE EFFECTS OF HYPOXIA ON PERFORMANCE.

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SUMMARY

This investigation was undertaken in the belief that most previous psychological studies of hypoxia have used insensitive experimental designs such that anything less than gross behavioural decrement is not detected. It was further felt that relatively recent studies have not used newer, more sensitive testing procedures for detecting performance impairment, procedures which have been developed especially in the field of aging.

A series of experiments were run using university students as subjects, where subjects were tested once on a variety of tasks at one level of hypoxia, induced by reducing the air pressure in a decompression chamber. Subjects were given no prior training on the tasks used before being exposed to the single level of hypoxia. Tests were carried out on short-term memory, the translation from stimulus to response (reaction time) and the time taken to make the response (movement time), discrimination of clearly visible stimuli and the cognitive task of reducing information between stimulus and response. Contrary to the common view (based on older experimental designs) that there is no performance decrement due to hypoxia below 10,000 ft. altitude equivalent, marked impairment was

found at 5,000 ft. to 7,000 ft. However above 10,000 ft. reversed effects were noted in reaction time such that performance at 14,000 ft. or 15,000 ft. was as good as at ground level. Movement time appeared to be somewhat decreased at seven thousand feet compared with ground level but above this altitude no very clear and reproducible trend was observed. It seems in general that the tasks involving most central processing deteriorated linearly with altitude up to the maximum level studied whereas tasks involving a greater speed component showed paradoxical effects at the higher levels.

Several experiments were also run to test the effects of hypoxia on acquisition of shock avoidance behaviour in the rat. Animals were exposed to reduced oxygen concentrations in repeated sessions whilst being trained in avoidance. The "traditional" effects of hypoxia were very substantially demonstrated in initial testing: there was little learning decrement down as low as 13% oxygen but marked impairment at 9% oxygen. There seemed to be some evidence from the behavioural measures of physiological acclimatisation to repeated exposure but several attempts to reproduce the behavioural effects or establish the factors influencing them were unsuccessful. Direct physiological measures showed acclimatisation type changes in red cell volume in whole blood in experiments where replication of the behavioural evidence of acclimatisation could not be found.

Taking both human and animal results together it was concluded that mild hypoxia does impair psychological functioning in man but the sensitive experimental designs bring their own problems in interpretation as subject's anxiety at the testing situation may interact with the effects of hypoxia alone.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and, to the best of my knowledge and belief contains no material previously published or written by another person except when due reference is made in the text of the thesis.

F. LEDWITH.

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SECTION 1

STUDIES ON HUMAN SUBJECTS

CHAPTER I

REVIEW OF THE LITERATURE

Hypoxia essentially means a state of oxygen lack in an organism. There are various means by which this oxygen lack can be produced. The one referred to in this thesis is more specifically known as hypoxic hypoxia: this is brought about by the reduction in the oxygen supply to the organism. It is to be distinguished from hypoxia produced by - (a) a reduction in the oxygen carrying capacity of the blood (haemic-hypoxia), (b) a reduction in the ability of the tissues to use oxygen (histotoxic hypoxia) or (c) obstruction of the blood flow (stagnant hypoxia).

The atmosphere contains approximately 21% oxygen. The rest is nitrogen, apart from a small amount of carbon dioxide and some traces of rare gases. Hypoxic hypoxia can be produced by reducing the total pressure of the atmosphere with the proportion of the constituent gases held constant. This occurs in mountain climbing or aeroplane flights. The same effect can be produced by keeping the total pressure constant but reducing the proportion of oxygen in the air breathed. The essential point is that the partial pressure of oxygen is reduced in both cases. Various investigators showed this to be the crucial measure of hypoxia and Otis, Epstein, Rahn and Fenn (1946) showed that up to 20,000 ft. it is the prime determinant of physiological and psychological changes.

For psychologists hypoxia offers a rapidly induced and readily reversible stress which strikes primarily at the nervous system and offers a means of investigating the relationship between brain structure and brain function (Halstead 1947, p. 112). The broad outlines of the physiological effects are known but not enough is known of the local effects within the central nervous system and it seems that this would be a fruitful area of co-operation between psychologists and physiologists engaged in a joint study of cerebral processes.

There are a number of recent reviews on the psychological effects of hypoxia, for example Luft (1962), Van Liere and Stickney (1963) and Tune (1964). Hence no comprehensive review will be given here but simply a background sketched to the particular approach. Evidence of particular functions studied will be given within the appropriate chapters.

Interest in hypoxia dates back to the time when men first started to ascend from the earth's surface in balloons and later in aeroplanes. Interest was accelerated during the first world war with the great increase in flying activity. However, until 1930, observations on the effects of hypoxia from flying and mountaineering were mainly of a clinical nature. Shock (1939) summarises these observations and suggests that the essential features of hypoxia noted were changes in mood, increased irritability and forgetfulness, and a failure in concentration and in fine muscular control.

Sensory Processes.

In 1929 Macfarland at Cambridge began a series of experimental studies of the psychological effects of hypoxia. In Macfarland (1963) he summarised much of this work and laid stress on the effects of hypoxia on vision since the visual tests used have many advantages in the study of hypoxia: apart from the sensitivity of vision to hypoxia, tests used had a high degree of accuracy of measurement, were relatively stable over time within a subject and were relatively independent of the degree of effort the subject exerted to try to do well. He reports the deleterious effects of hypoxia on level of dark adaptations. Visual acuity and differential brightness thresholds were also impaired particularly in low levels of illumination. Comparison of several investigations reveals that this deterioration is an accelerating function of altitude but even at an altitude of 7,500 ft. there is measurable impairment. However Tune (1964) suggests that the picture is not as coherent as might seem. He reviews four studies of the effects of hypoxia on the critical fusion of flicker: one study found a reduction of the flash rate after 12 minutes at an altitude of 9,500 ft., whilst another found no deterioration in the first hour of exposure to 18,000 ft.

Both from clinical observations and systematic research surveyed by Kline et al. (1961), it appears that auditory acuity is less affected by hypoxia than visual acuity. From observational reports, Shock (1939) suggests that audition is little impaired to the point of unconsciousness. Kline (1961) reviews some evidence showing no impairment down to 10% oxygen. Below this level hearing loss is shown in the lower frequencies between 256 and 2,048 cycles but at 4,096 cycles there seems to be some enhancement of acuity. This, however, conflicts with Macfarland (1937 C.) who showed quite the opposite effect with an increased impairment at higher frequencies.

However, one cannot accept the picture of a more or less steady decline in sensory function with increasing altitude even if one disregards failures to find any definite signs of impairment at altitudes when subjects would be visibly distressed (at 18,000 ft.). Yusfin et al. (1953) report some complicated effects of hypoxia which vary between subjects and between sessions for a single subject. However they show evidence of an enhancement in colour sensitivity in some equations of the anomaloscope at altitudes up to 9,000 ft. though above this altitude there is more or less uniform deterioration. Von Muralt (1964) summarises a whole series of experiments at a testing station at 3,450 metres of altitude indicating an enhancement of responsitivity of the nervous system shown in both touch and taste thresholds, acceleration of the rate of dark adaptation and reduction in visual reaction time. This evidence of an enhancement in mild hypoxia is supported by other evidence of reflex elicitation and muscular responsitivity of single nerve fibres which will be quoted later on.

However, all the evidence collected on the effects of hypoxia on sensory thresholds have used the methods of classical psycho-physics, in particular the method of adjustment or the method of limits. As Tune (1964) points out the formulations of Swets, Tanner and Birdsall (1961) have shown the inadequacy of threshold explanations of sensory performance and cast doubt on methods which fail to separate out differences in sensory acuity from differences in the criterion of sensory judgements. If hypoxia affects both sensitivity and the criterion used, the reported effects of hypoxia using classical psycho-physics may well be some combination of these two effects which is highly specific to the psycho-physical method used.

Reflexes.

Malmejac and Plane (1952) give a review of the effects of hypoxia on unconditioned and conditioned reflexes. They suggest a complicated picture with effects in three stages: at 3,000 to 6,000 metres there is an enhancement of the unconditioned reflex and the conditioned reflex though at upper limits there may be a reduction in the conditioned reflex. Above this level the conditioned reflex disappears and the unconditioned reflex is reduced. Malmejac, Plane and Bogaert (1954) give data on conditioning in dogs which fills out the outline given above. They note that the enhancement in the reflexes reduces with repeated exposure but fits in with the studies of Von Muralt and the reported euphoria among mountaineers.

Motor Output and Sensory-Motor Co-ordination.

Early clinical reports give as a prominent effect of hypoxia, clumsiness, failure in co-ordination and muscular tremor at altitude (Van Liere and Stickney 1963). Experimental studies have generally confirmed this impression of the marked vulnerability of motor output and sensory motor co-ordination. Otis, Rahn, Epstein and Fenn (1946) chose a hand steadiness test as a reliable indicator of hypoxic impairment when mainly interested in the physiology of hypoxia: they were concerned to examine what variables in the gas in blood were most directly related to performance. Hoagland et al. (1946) showed a deterioration at 10,000 to 12,000 ft. in a pursuit task with joystick and rudder controls. Russell (1948) found performance on two keyboard tasks to be impaired at 18,000 ft. Waldfogel et al. (1950) found a stylus test more impaired at 10% oxygen than simple reaction time and tapping speed whilst choice reaction time showed a slight improvement. Adler et al. (1950) showed deterioration in hypoxia in a pursuit task controlled by a joystick though the deterioration was much alleviated by the use of stimulant drugs. Shephard (1956) found little effect on hand steadiness at 20,000 ft. for an exposure period of 10 minutes. The mean performance did not vary although the variability was increased at altitude. Klein, Bruner and Jovy (1962) used a task involving picking up ball-bearings and placing them in small slots. Their interest was mainly in the psycho-physiological relations but the task showed reliable deterioration in hypoxia and was closely correlated with individual differences in endocrine responses. Hence such a task seems to be a meaningful means of assessing the individual's degree of hypoxic stress.

Cognitive Processes.

It might be expected that tasks involving the most central processing would show the effects of hypoxia most markedly. However this has not been generally the case. Typically, reliable differences on performance on some tasks have only been detected at altitudes at which the distress of the subjects is visibly apparent. Macfarland (1937 (b)), (1937 (c)) reports the results of experiments conducted on ten members of an expedition into the Andes. Subjects were tested at ground level and at ascending altitude to 20,000 ft. with a variety of tests of sensory motor and cognitive nature. Some of the cognitive tasks showed deterioration with altitude to a greater degree than sensory tasks. However the C.A.V.D. intelligence test was little impaired and complex calculations carried out at 17,000 ft. were subsequently found to be all correct. On one of the tests there was little effect noted below 15,000 ft. and significance testing was by comparing ground level control with each successive level of altitude. As order of presentation was confounded with ascending altitude, the tasks used were selected as being free from practice effects or prior training was used to a plateau of performance. Bills (1937) compared the effects of hypoxia with those of fatigue using a repetitive colour naming task with prior training given to the subjects. Below 15% oxygen the number of blocks (very long delays in responding) increased rapidly, yet even as low as 8% oxygen the modal response time was very little changed. Blocking increased with the duration of the task but in hypoxia the rate of increase of blocks was increased.

Shock (1939) summarising the early work on a variety of tasks indicates that impairment has been shown on many cognitive tasks but seldom at oxygen concentrations above 14%. He points out that extensive practice will reduce the value of any task as a direct measure of cognitive capacity. In spite of his statement at that time most experiments, even today, still use such extensive pre-training. Halstead (1947) stresses the maintenance of performance at altitude even though there may be reduced awareness. One subject was given exposures of aeroplane silhouettes for 20 milliseconds. After repeated hypoxia he complained that he could no longer see the shapes yet he continued to give 100% correct identification. Izaac Stern, the violinist, played from memory a difficult passage from a Bach Sonata whilst hypoxic. The recording was judged to be technically perfect yet at the time the violinist was "euphoric, mildly confused and disoriented". In behavioral studies Halstead used daily repeated exposure to hypoxia for seven subjects at 10,000 ft. to 18,000 ft. in an attempt to discover which of his factors of the brain function was most readily affected by hypoxia. In general there was little deterioration in performance even up to an altitude of 18,000 ft. The Stanford-Binet intelligence test, a formboard and formboard recall test showed no effects up to 18,000 ft. Prolonged exposure to 10,000 ft. produced reliable slowing in the C.F.F. in one subject reported. The major effect found was in a test of dynamic visual field involving simultaneous discrimination at the fovea and the periphery. Foveal discrimination was unaffected but peripheral discrimination was reduced. The experimenter relates this to general observations on the effects of hypoxia.

At the beginning of his experiments he had believed that even long exposure to 10,000 ft. would produce no deterioration. However when the experimenters began to show signs of undue forgetfulness in experimental testing and a great degree of fatigue, supplementary oxygen was used by the experimenters from then on. In general he contended that though performance at the set tasks was unimpaired, as the subjects exerted extra effort to overcome any disability, nonetheless this was obtained at the cost of narrowing of consciousness and reduced awareness of the world around. Russell (1948) found deterioration in simple addition at 18,000 ft. but with practice this deterioration was reduced. Dugal and Fiset (1950) tested subjects at 10,000 ft. during repeated exposures up to 100 hours in all. They used standardised tests of mechanical ability, space relations and object visualisation. Results for the two groups with and without supplementary oxygen were analysed separately but in general the non-hypoxic group were found to improve more with time. In the object visualisation and the advanced version of the spacial relations test there was a greater difference between the two groups. Maag (1957) used a conceptual reasoning test based on the Hanfmann Kasanin test. Subjects were given extensive pre-training and then tested at altitudes up to 18,000 ft. Little deterioration was shown until 16,000 ft. and the deterioration was in the number of very long responses, not the modal response time.

Philips et al. (1963) tested five subjects on their memory for words and numbers, and problems involving a test of rhymes and a simple computation problem. Subjects were tested for fifteen days at ground level and three days at 12,000 ft. No effect was found on any of the tests used. A further eight subjects were tested in a balanced design at ground level and 14,000 ft. The rhymes test was poorer at altitude, there was no difference in memory and the computation task was improved at altitude. Tichauer (1963) used ergonomic principles in improving the production of cycle spindles at 9,000 ft. and 13,000 ft. In the pretest, performance was slower at 9,000 ft. and there was a higher rejection rate of finished components. He redesigned the task to reduce the need for visual-tactual co-ordination and put stops on the machine. Consequent on this a vast improvement in output was noted with a lower rejection rate. Pigarola and Billings (1966) tested seven subjects at 3,000 ft. to 17,000 ft. after seven days pre-training. The tasks they used were a tracking task, a code problem and auditory vigilance. Tracking and vigilance showed the most effect at 17,000 ft. but there was little effect at 8,000 ft., while performance at the problem solving task showed a slight improvement. Subjects were also given combinations of tasks simultaneously. The greatest rate of deterioration was found in the coding task and the tracking task when tested simultaneously. It was noted that this was the only combination where both tasks used visual input.

Philips et al. (1966) tested free recall of a ten word list. Eighteen subjects were tested in a A-B, B-A design at ground level and 3,800 metres. There was no overall deterioration at altitude but there was a change in the pattern of performance in that there was a greater loss in the later part of the list learned and less loss in the earlier part. It should be noted that this change is quite the opposite of that noted by Macfarland (1937). Evans (1966) tested pistol shooting at 14,000 ft. There were 12 days of practice at ground level, twenty days practice at 14,000 ft. and subsequent practice at ground level. He found that the rate of firing increased and the accuracy decreased at altitude. He suggests that this is the result of general disinclination to try harder at altitude in the same way as Shock (1939) and Macfarland (1937 a) relate.

Contrary to expectations, cognitive processes have not generally been shown to be particularly vulnerable to hypoxic impairment. The usual reasons advanced for this are that a degree of protection is provided by prior learning of the tasks used and subjects may be able to exert more effort during the duration of testing so as to mask impairment. Whatever the reasons advanced, it is plain that strict testing procedures fail to show deterioration which is manifest in less controlled observation.

One notable advance in modern experimental psychology has been an increased concern for proper experimental design (e.g. Winer 1962) and a growing awareness that findings obtained may be a function of the particular design used (see e.g. Brown (1966), Grice (1966)).

In general the most sensitive design is one where all subjects are tested under all conditions, hence removing a major source of variance from the experiment - differences between subjects. In examining the effects of hypoxia such a design has problems of its own. Subjects tested serially at two or more levels of oxygen concentration or altitude may change through time. With training the effects of hypoxia will be reduced. To overcome this many experimenters have pretrained subjects to some plateau of performance. Hence any changes which occur in the stress can be attributed to the effects of the stress. This too has its problems. Shock (1939) says "if practice is continued so that there is no obvious improvement, it is evident that the task has lost much of its usefulness as a level of excellence of mental performance." Poulton (1966) makes the same point and draws a number of examples from nitrogen narcosis (Poulton, Catton and Carpenter, 1964) and hypoxia (Ledwith & Denison, 1964) to show how significantly poorer performance occurs at much lower levels of stress in unpracticed subjects. If the comparison in hypoxia is restricted to a control condition and one altitude condition a group one AB and group two BA design may be used. Poulton & Freeman (1966) point out that the effects of one condition may be dependent on whether it has been experienced first or second and show how the differences between experimental conditions may be reduced or exaggerated depending on the nature of the condition×order interaction.

From the nature of the condition×order interaction in hypoxia (Ledwith & Denison, 1964), it would seem that the appropriate design in the study of hypoxia would be to use different groups for the different levels of oxygen and test all subjects under one condition only. In this way more levels of hypoxia may be used instead of the single level of hypoxia which Tune (1964) notes is the typical hypoxia experiment. However the disadvantage of this design is that the effects of hypoxia are inextricably confounded with differences between subjects, hence giving a high error variance and, with small numbers of subjects, a high probability of the type 2 error of statistical inference: that is accepting the hypothesis of no effect when in fact it is false. A fuller discussion of this point may be found in the appendix 1, but for the present purpose it need only be said that following the suggestion of a number of authors (Hays 1963, Bakan 1966) levels of statistical significance will be merely one piece of information used in addition to many others to aid in the interpretation of the results obtained.

Tune (1964) surveys the more recent literature on the psychological effects of hypoxia and criticises the failure of experimenters to use recently developed techniques for studying functions which are known to be affected by hypoxia. He notes Macfarland's (1963) comparison of the effects of hypoxia and aging on the sensory functions. He points out that if this analogy holds, the work reported by Welford (1958) affords a wealth of technique for the study of hypoxia. It is from this point that the present investigation began.

In the study of aging the problem is to detect fairly small changes in cognitive functioning and it is in this area that psychology has seen considerable advances in developing new techniques and tasks to study these changes (Welford 1958, Tibbits & Donahue 1962). If the analogy between aging and hypoxia holds true at all, then the body of literature on aging affords techniques to use and suggestions for functions to study which may cast new light on the effects of hypoxia on the psychological processes.

Hence the tasks used in this study on the effects of hypoxia on humans have mostly been developed originally in the study of aging and, as stated, use designs which appear appropriate to the phenomenon under consideration.

Where more than one altitude condition is used in addition to a control, problems arise in the statistical analysis in trying to establish at what altitude performance is significantly impaired. To answer this question in the past a series of 't' tests are run of control against each progressive altitude. With the development of the analysis of variance a more powerful technique is available which is more sensitive than individual 't' tests. A further development (Winer 1962, Hays 1963) is afforded by the use of regression analysis where performance is related to level of altitude. The question is not at what altitude is performance significantly poorer but rather what is the function relating altitude and performance and what is the simplest function available adequately to describe the data gathered. In multiple 't' tests the altitude at which significance of difference is attained depends on the power of the test and the number of subjects used, as well as the form of the effect. For example subjects tested at ground level 5,000 ft., 10,000 ft., 15,000 ft. and 20,000 may show mean reaction times of 1.5, 1.7, 1.9, 2.6 and 3.0 seconds. If the significance test used causes the experimenter to reject any difference below .5 of a second as significant then no significant differences will be obtained until 15,000 ft. However if the experimenter shows that a linear trend adequately describes the data then we can say that the performance begins to deteriorate from ground level up. The question then is to decide how much performance deteriorates for each increment in altitude.

Hence in addition to the use of a sensitive design and the use of techniques originally developed in the study of aging, this investigation will be concerned with what appears to be the proper statistical analysis concerned in the study of the problems of trend. This is a fairly radical departure from the previous literature on the psychological effects of hypoxia in design, tasks used and statistical analysis. Thus the results obtained may not be readily compared with previous results obtained except in a very general way.

In a single exposure to hypoxia it seems probable that the full effects would not show until after prolonged exposure, especially in mild hypoxia. In experimental designs of the kind indicated, with the number of subjects tested once only, it is clear that prolonged exposure is not possible unless access can be gained to (a) a "captive" subjects pool and (b) decompression chamber facilities and medical supervision for unlimited amounts of time. In these experiments the subjects were students, St. John Ambulance and Royal Australian Airforce personnel who volunteered to give up some of their time from a normal working day to act as subjects. Technicians to control the chamber did this work in addition to, and apart from, their normal duties and medical supervision had to be subject to personal agreement between the experimenter and a medical practitioner who also gave up time from a normal working day. As a result it would have been impossible to expose any subject to hypoxia for more than 60 or 90 minutes at most. The question is: is such a length of exposure sufficient to show the effects of hypoxia? The physiological effects of hypoxia through time are dealt with below but it is necessary to look at the more direct behavioral evidence.

Bills (1937) showed that the blocking which occurs in hypoxia is still increasing up to 15 minutes exposure. Russell (1948) in his studies of manual dexterity and simple addition suggests that the maximum decrement is found after 15 minutes at 18,000 ft., after which performance rapidly picks up to control level. He suggests some rapid physiological adjustment to hypoxia but in fact the effects he describes are probably the same phenomenon as shown by Ledwith & Denison (1964). When subjects are properly hypoxic prior to the commencement of the test then the decrement of hypoxia, though large at first, virtually disappears even with a short time of practice on the task used.

Subjects given prior testing in the control condition first show no effects of hypoxia whatsoever suggesting that the improvement noted is a psychological and not a physiological adjustment. Simonsen & Winchell (1951) show that at 10,000 ft. there is a drop in the C.F.F. which begins to level out after 10 minutes exposure but the frequency is still falling after 12 minutes. Maag (1957) shows that there is a consistent increase in very long responses with time over 30 to 60 minutes at altitudes of 16,000 ft. to 18,000 ft., though at 13,000 ft. no such decline is apparent. Luft (1962) on the basis of observational data suggests that at low altitudes the effects of hypoxia may not be shown until after prolonged exposure. There is not much systematic evidence to show how long can be regarded as prolonged and how much more effect hypoxia would have after one, two or three hours exposure or after ten minutes exposure.

The Physiological Effects of Hypoxia.

This thesis is primarily concerned with the psychological study of hypoxia which, says Tune (1964), has not kept pace with recent advances in respiratory physiology or with psychology in general. However the stress applied is physiological and as far as possible the data obtained will be related to what is known of the relevant physiological mechanisms. It seems therefore that a basic textbook outline of the physiological effects of hypoxia should be given.

The body requires oxygen constantly for its metabolic processes. The blood becomes saturated with oxygen as it passes through the capillaries in the lungs. The bulk of the oxygen is carried not in simple solution in the blood but chemically bound to haemoglobin molecules. The amount of oxygen bound in this way depends on the pressure exerted by the oxygen in the lungs independent of any other gas (the partial pressure of oxygen). At normal atmospheric pressure the 21% oxygen in the atmosphere gives a partial pressure of oxygen of 150 millimetres of mercury and this gives a saturation of 95% of maximum in the blood. If the partial pressure of oxygen is reduced there is little reduction in saturation of the blood until 100 millimetres of mercury (10,000 ft.), after which the reduction in saturation is progressively more rapid. This means that when the partial pressure of oxygen in the cells is quite low there is a cascade effect in the capillaries and oxygen is readily reduced from its bound state to supply the cells. Furthermore if the partial pressure of oxygen in the lungs drops there is little drop in oxygen saturation until 100 millimetres of mercury or about 10,000 ft., this means that with increasing altitude at first the amount of oxygen available drops very little although its partial pressure will drop progressively. As far as is known a drop in pressure has little effect on the supply to the cells until very low levels of partial pressure of oxygen are reached (Van

Liere and Stickney 1963). In addition to the protection of blood oxygen level in a state of falling oxygen supply there are other adaptive mechanisms. There is an increase in respiratory volume, though this is held in check until 8,000 ft. to 10,000 ft. by the consequent drop in the partial pressure of carbon-dioxide in blood. Above this level respiratory volume increases rapidly and cardiac output is increased thus making more oxygen available per minute to the cells. Adrenal output is increased and there is a release of glycogen from the liver, though this takes time. However, the increase in respiration has an associated cost: there is a drop in the partial pressure of carbon dioxide which produces vaso-constriction and eventually a form of hypoxia, especially within the brain.

The nervous system is more vulnerable to the removal of oxygen than any other part of the body. In addition if it is deprived of oxygen for more than about five minutes it will be damaged beyond the possibility of repair. However the prediction of behavioral changes from the known physiological effects is by no means simple. As Kety (1963) points out there may be psychological changes before there are any detectable physiological changes indicating change in the oxygen concentration within the cells. In hypoxia there is a complex redistribution of the blood in the brain (Kety 1963) where, in general, the grey matter and other areas of maximum oxygen consumption are reduced in their oxygen uptake down to the level of other areas of the brain. The old view was that hypoxia struck first at the highest levels of cortical function and then progressively attacked phylo-genetically more primitive functions (Hughlings Jackson's hypothesis) and Kety would support this view. However studies reported by Dell, Hugelin and Bonvallet (1961) show the complications involved. In mild hypoxia irritability of the nervous system may be increased at least for a short time. Further the A.R.A.S. is activated by the emergency signals of the chemo-receptors of the carotid aorta which is also the stimulus to greater respiration. Hence the pattern of inter-relation between the A.R.A.S. and the cortex is changed and the net result may be a state of increased arousal in addition to increased irritability of individual nerve cells.

In summary it might be said that the first expectation is that performance changes with increasing altitude would follow a similar function as that relating oxygen saturation to altitude: that is little or no effect up to 10,000 ft., then a steeply accelerating deterioration beyond that. The bulk of the psychological literature on hypoxia would support this view but it has been argued that much of this evidence is based on insensitive testing procedures. It might be expected then that the function may be more complicated and that it may not necessarily show deterioration and never improvement under hypoxia where sensitive testing techniques are used.

As was suggested above when an organism is suddenly exposed to a reduced partial pressure of oxygen the reduction in the oxygen content of the cells will not be instantaneous. It will take a little time for all the circulating blood to attain a saturation corresponding to the new oxygen level and beyond that it will take some time for the partial pressure of oxygen in the tissues to drop to a level consonant with that in the blood. In addition the protective mechanisms will come into play and it will take some time for these to reach a stable state. There would be increased cardiac output, increased ventilation and hence reduced partial pressure of carbon-dioxide in the blood. This in turn would inhibit further increases in ventilation unless the partial pressure of oxygen were reduced low enough to drive ventilation. Moreover there would be a regional redistribution of blood in addition to any vaso-constriction which can be attributable to the carbon-dioxide changes. Over many hours or days further changes may take place in the acid buffering capacity of the blood consequent on changes in partial pressure of carbon-dioxide and consequently the pH of blood. However the immediate concern is the first stage of equilibration. Over the first couple of hours of exposure to hypoxia the physiological evidence on this point is more satisfactory than the psychological referred to above. Over a series of studies using a variety of methods of measuring the partial pressure of oxygen, oxygen saturation and partial pressure of carbon dioxide, it would seem that ten minutes is sufficient to allow attainment of steady states of partial pressure of oxygen and oxygen saturation, at least up to 18,000 ft. (See Horvath, Dilland Corwin 1943, Dripps and Comroe 1947, Penneys and Thomas 1950, Kety 1952, Stacy and Hitchcock 1953, Hornbein, Roos and Griffo 1961, and Simonson 1961.)

In keeping with previous arguments this is not to suggest that the complete effects of hypoxia will be manifested after ten minutes exposure, but merely to suggest that a first approximation to equilibration is attained in that time though performance may change in many sorts of ways after this. In progressive hypoxia, psychological changes may be detected before any change in the venous oxygen level. Conversely after all signs of change in the blood oxygen have disappeared, there may well still be changes in psychological functions.

CHAPTER II

SHORT TERM MEMORY

Anecdotal evidence on the effects of hypoxia on human performance (Van Liere and Stickney 1963, and Luft 1962) suggest that the higher mental processes are most directly affected by the stress. Apart from the lack of awareness of the adequacy or inadequacy of response to the stimulus situation, the most commonly noted effect is on short term memory. This applies in observations of mountaineers (Greene 1957) and in subjects in a decompression chamber given brief exposure to profound hypoxia (Luft 1962). In the latter case when a subject is at a pressure equivalent to 25,000 ft. his oxygen supply is disconnected. He may be asked to count backwards in threes from a hundred. Typically performance deteriorates very rapidly with more and more mistakes being made and the subject taking longer and longer to produce each successive response. When the oxygen supply is reconnected the subject quickly recovers and may carry on counting but has no memory at all of calling the few numbers just prior to the reconnecting of the oxygen supply.

It would therefore be expected that tests of short term memory would show marked effects with hypoxia and one could investigate how memory deteriorates with increasing altitude. It is known that at the point of collapse memory is impaired but the question remains how much is it impaired at milder levels of hypoxia? Macfarland (1937 (a)) tested six subjects at sea level and then the following day at 14,890 ft. on a variety of tests among which were tasks involving learning a code and paired associates. In general learning was significantly poorer at altitude in spite of any masking effects of practice. Macfarland (1937 (b)) carried out further observations during the international high altitude expedition into the Andes. On this expedition ascent was made, in gradual stages, to 20,000 ft. over a period of seven weeks, and subjects were tested at a series of levels during their maximum acclimatisation. Amongst other things subjects were tested on their memory for auditory patterns, and paired associate and nonsense syllable learning. Three subjects were tested at ground level, 17,500 ft. and 20,140 ft. and showed significantly more errors at both altitudes than at ground level. All ten members of the expedition were tested on paired associates and nonsense syllable learning at 9,200 ft., 15,440 ft., 17,500 ft. and 20,140 ft. Little impairment was discernable until the 15,000 ft. level but a statistical comparison of each altitude with ground level failed to show any significant deterioration until 17,500 ft. Ignoring such insensitive statistical testing (see appendix 2.), it is apparent that the number of repetitions to perfect recall and the errors in delayed recall increase sharply at 15,000 ft. compared with 9,000 ft. At this latter level they show little difference from ground level though some degree of impairment could be masked by any residual practice effects. The change in the pattern of errors was associated with altitude: contrary to the findings at sea level, at altitude the greatest frequency of errors was in the early part of the list presented.

Without the protective effects of acclimatisation, short term memory was found to be impaired at lower altitude (Macfarland 1941). After a rapid ascent (15 minutes), paired associate learning progressively deteriorated such that there was a 15% reduction in correct recall at the lowest altitude used (10,000 ft.) and a progressive linear decline above this. With a slower ascent (75 minutes) no impairment was found until 12,000 ft. and up to 20,000 ft. deterioration progressed far less rapidly than after rapid ascent.

Halstead (1947), reviewing the literature extant at that time, concluded that "In general, however, such changes (in the direction of decreased efficiency) had not been found following brief or even prolonged exposure to altitudes of 10,000 ft. or lower." In his own experiment he gave seven subjects repeated exposure to simulated altitudes of from 10,000 ft. to 18,000 ft. for four to six hours per day over a four to six week period.

Amongst the battery of tests he used was the test of the recall of the shapes on a form board. As with all the other tests used, apart from a detection task in peripheral vision, little effect of hypoxia was apparent on the memory test. Halstead does note, however, that the test results do not show an impairment which is apparent in other ways. The experimenters found to their surprise that routine and well practised tasks were performed clumsily even at 10,000 ft. Furthermore there were frequent failures to carry out the routine checking procedures involved. Halstead suggests that in doing the actual tests set, subjects may exert extra effort for a short while and so mask any deterioration, an effect that Dunlap (1918) noted in earlier experiments.

Phillips, Griswold and Pace (1963) tested subjects on recall of varying lengths of digits and common English words. After 15 days practice at ground level subjects were transported to a testing station at 12,000 ft. and retested on each of three days. Not only was there no significant difference found but there was no sign of any poorer performance at altitude. In a subsequent experiment three subjects were tested for two days at ground level and then at 14,000 ft. for the next two days, whilst frou other subjects performed the tests in the reverse order. Memory for both digits and numbers was found to be slightly better at altitude though not significantly so.

In view of the discussion of Poulton (1967) and Poulton & Freeman (1966), it can be suggested that failure to take account of any asymmetric transfer effects in such an A - B, B - A design might well have masked any real effects of hypoxia. Phillips and Pace (1966) tested 18 subjects in a counter-balance design at ground level and 14,000 ft. Amongst a battery of tests subjects were tested on immediate or delayed (30 seconds) recall of lists of common English words. Again combining all tests done at ground level against all tests at altitude, no overall difference in performance was found. However the pattern of performance changed at altitude: at altitude recall was comparatively poorer on the last five words of the list though comparatively better in the first five. This effect, the authors claim, is support for the hypothesis put forward in discussion of their 1963 experiment that hypoxia will show impairment on tasks where strongly competing responses will produce deterioration. They do not note that the results they obtained are directly the opposite of those obtained by Macfarland (1937 (a)).

A reasonable summary of the evidence would seem to be that experimental studies of short term memory do not always give evidence of impairment under hypoxia even at altitudes where subjects would be visibly distressed and at higher altitudes than those at which there are subjective and observational data to suggest memory impairment.

Failure to find impairment in any particular case may be related to the severity of rate of onset and duration of hypoxia, the task used, the amount of prior practice on the task and the extent to which subjects exerted extra effort during testing to overcome any impairment in capacity. Irrespective of such factors there is the plain fact that the experimental data fails to confirm less precise observations.

A similar situation has been found in experimental studies on the effects of aging and brain damage on immediate memory. Inglis (1957) tested two groups of elderly psychiatric patients, one with memory disorder and a control group matched for age, sex and verbal intelligence but showing no clear signs of memory disorders. The Wechsler digit span forward and several versions of the Knox cube test failed to show any difference between the two groups though there was marked impairment in paired associate learning in the memory disordered group. Bromley (1958) similarly found little impairment with age in the Wechsler digit span forward test. There was a more clearly marked decrease in the digits marked backwards as there was in rote learning and visual memory. Bromley (1966) suggests in explanation that aging has little effect on short term retention per se but if the material has not only to be retained but also transformed then deterioration will be shown. In view of the failure to find differences with digit span forward where there is deterioration in paired associate or digits backwards tests it could be suggested that the failure of digits forward to be sensitive is a result of the degree of familiarity with the task. Where less familiar tasks are used the effects are more clearly seen. Inglis and Sanderson (1962) attempt to solve "the contradiction between the high degree of apparent validity and the low degree of actual usefulness of digit span items as tests of immediate memory". The task they consider is that of dichotic recall: subjects are read two lists of digits simultaneously through stereophonic ear-phones one list to each ear. If the rate of reading is quicker than one per second (Bryden 1964) then subjects usually recall digits from one ear first and then the other ear. Broadbent's model as outlined by Inglis and Sanderson (1962) is that the first half list is immediately transmitted from the "P-store" whereas the second half list is stored in short term memory and then repeated back. Hence any impairment in short term storage will be expected to show mainly in the second half list recalled.

This suggestion was tested on thirty elderly patients, (half with memory disorders) with lists from one to four digits read out to both ears simul-taneously. No instructions were given for the method of recall. Though the groups were matched on conventional digit span the memory disorder group were significantly poorer at one, two, three and four digits on the second half list and significantly poorer on three and four digits on the first half list. In the first list recalled on four digits there was a 40% deterioration in the memory impaired group whereas in the second half list recall the impairment was of the order of 90%.

This test was also used to measure the progressive effects of age. In Inglis and Caird (1963) and McKay and Inglis (1963), subjects of various ages were matched on digit span and given list from one to six digits to each ear with again no instructions as to the method of recall. The older subjects were poorer on the second half list, especially with longer lists though there is little difference on the first half list.

It seems likely, given the proven use of this dichotic listening test, that it would prove more sensitive to the effects of hypoxia than the conventional digit span and would afford an adequate device to examine trends of deterioration in memory with increasing hypoxia.

Experiment A.

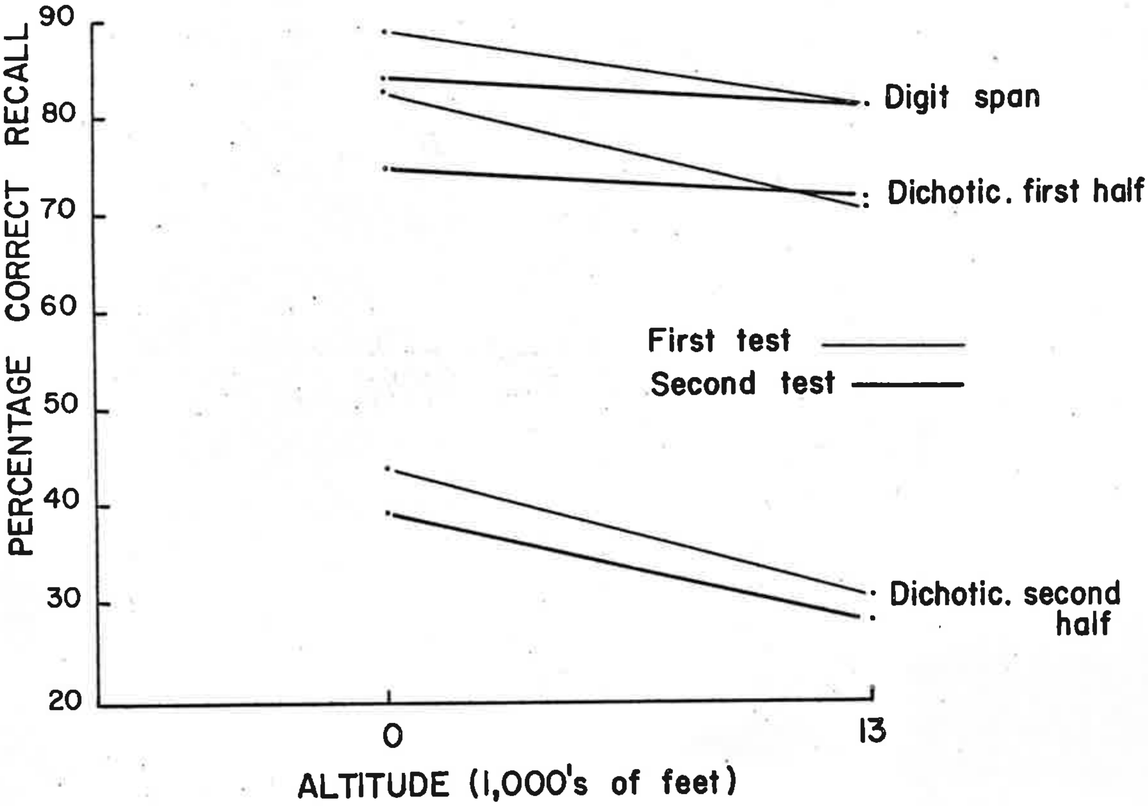
Twenty four University student male volunteers aged 20 to 26 were tested in a decompression chamber. Subjects were tested individually in the decompression chamber. They were told the general purpose of the experiment and told that they would be subjected to some altitude between ground level and 13,000 ft. They were given a preliminary "ears run" to check that they could equalise pressure to the inner ear as the chamber pressure was changed. The subject and the experimenter then sat in the chamber as the pressure was adjusted to that set for the experiment. Two conditions were used: ground level and 13,000 ft. equivalent and subjects were assigned at random with half to each group. For both conditions ten minutes was allowed to attain the pressure level required. After the ten minutes ascent (and descent in the case of ground level) ten minutes was allowed for physiological equilibration and then testing commenced. Subjects were given the first eight trials on a discrimination card sorting task (see Chapter V), which took twenty minutes. They were then given the first test of short term memory lasting ten minutes. After a further thirty minutes card sorting they were given another memory test. After this the experimental session was concluded.

The tests for short term memory were recorded on tape recorder. Each test consisted of a test of digit span and of dichotic listening. In the digit span two lists of four, six, eight and ten digits from one to nine was read out at the rate of one per second with subjects instructed to recall immediately after the reading as many digits as they could remember in the order in which they were given. In the dichotic test four lists were read consisting of two, three, four, five and six digits to each ear read simultaneously at the rate of 90 per minute. Subjects were told before each set of four lists how many digits there were in the list and were instructed simply to tell the experimenter what they heard. In both digit span and dichotic listening lists were drawn up using random number tables such that no effort was made to avoid repetitions of the same digit in a list. In the dichotic listening the only restriction imposed was that no list was used with the same digit in the same position in the both half lists.

Results.

In the dichotic listening, even without specific instructions, subjects invariably repeated the numbers from one ear then the numbers from the other ear. In scoring the results the same criteria were used as those outlined by Inglis and Caird (1963): the first half list was identified by the first number recalled; if the number given was not the first digit in either list then that recall was discarded. Scoring of recall in each half list presented some difficulties. However after preliminary scoring of a few records a set of rules was drawn up and adhered to in scoring all records. Given the identification of the first half list digits were counted forward until either (a) a pause in recall noted by the experimenter or, if no gap was apparent, (b) until the total number of digits in the half list. Any digits beyond this point were counted as belonging to the second half list recalled. As in the conventional digit span

FIG 2. I.



Experiment A. Digit span + dichotic recall. Mean percentage recall on first and second test (N=11) the recall was scored by order. If the digits presented were 1,2,3,4,5 and the subject reported 1,3,2,4,5, then four digits were recorded as correct, one being misplaced.

One subject in the control group was found to have virtually no hearing in one ear and so his results were discarded. For ease of computation of the statistical analysis one individual was selected by random number table to be dropped from the experimental group, leaving eleven subjects in each of the two groups.

Table 2.1 shows the mean percentage recall in digit span and first and second half dichotic test. Results are presented separately for the two test sessions after 30 minutes and 60 minutes in the experimental situation. In all three tests the hypoxic group show a lower percentage of correct recall. Statistical analysis was performed on the total number of digits correct in each length of list presented in the two test sessions (see Table A.3.1. of the Statistical Appendix). Only in the second half dichotic listening is the performance of the hypoxic group significantly poorer. Although the difference between the groups is greatest with three or four digits to each ear in dichotic listening, in no case is there any evidence of interaction of numbers of digits presented with hypoxia (Table 2.1).

TABLE 2.1.

EXPERIMENT A: DIGIT SPAN & DICHOTIC LISTENING.
MEAN PERCENTAGE CORRECT RECALL WITH
VARYING LENGTHS OF LIST
(N = 11)

	Digit Span				Dichotic 1st Half					Dichotic 2nd Half				
Number of Digits	4	6	8	10	2	3	4	5	6	2	3	4	5	6
Ground Level	100	100	88	70	92	92	81	76	68	82	78	52	27	15
13,000 feet	100	97	86	63	82	77	73	69	67	68	58	38	17	9

Thirty minutes or sixty minutes exposure to hypoxia show no difference in the dichotic second half list although there is a marked interaction in the first half list: the ground level group improved considerably on retest though the hypoxic group did not (see Figure 2.1).

Discussion.

The results confirm the works on aging and brain damage in showing that the second half list of a dichotic listening test will show deterioration where it is expected to occur, though the first half list and conventional digit span show less effect. This is not to claim that the latter tests were not affected by the stress. All that can be said is that the dichotic second half is more sensitive so that for a given number of subjects it is more likely to show a statistically significant difference between the groups.

The question is: why is dichotic listening more sensitive to impairment in short term memory? It could be suggested that this is a less familiar task than conventional digit span and this may be a partial explanation. However the second half list recalled shows more effect than the first half list in this unfamiliar task. It could be that only the second half list recalled is held in short term store according to the model suggested by Broadbent (1958). Yntema & Trask (1963) produced evidence to threw doubt on the adequacy of Broadbent's model as an account of why subjects recall by ear and not by the order in which they occur. Clearly there is no general agreement on the model which adequately describes the processes involved in this task.

It is possible that dichotic listening is more sensitive from being less familiar and that, in addition, the second half list is particularly sensitive as it forces subjects to store some information while doing something with another part of the information, as in the backward recall of digits. Poulton (1966) has suggested that maximum sensitivity in testing stress effects will be shown in areas where performance is at the level of 50% correct over-all. In this experiment certainly, the recall in the second half dichotic is closest to this level though the internal evidence within the test is such as to show a maximum difference in areas above 50% correct recall. This may be a partial explanation though not a complete one: analysis of accuracy of recall of ten digits alone in the digit span forward fail to show any significant difference between the two groups though the general level of recall was about 60%.

Experiment B.

Twenty nine male and three female RAAF personnel volunteered to act as subjects for this experiment. There were three male officers in the group and the rest non-commissioned. Ages ranged from 18 to 38 years and occupational level from caretaker to aircrew navigator. One of the female subjects was a telephonist used to remembering lists of numbers, whilst one of the officers had extensive experience of mess accounting and had developed a considerable facility for remembering long lists of numbers.

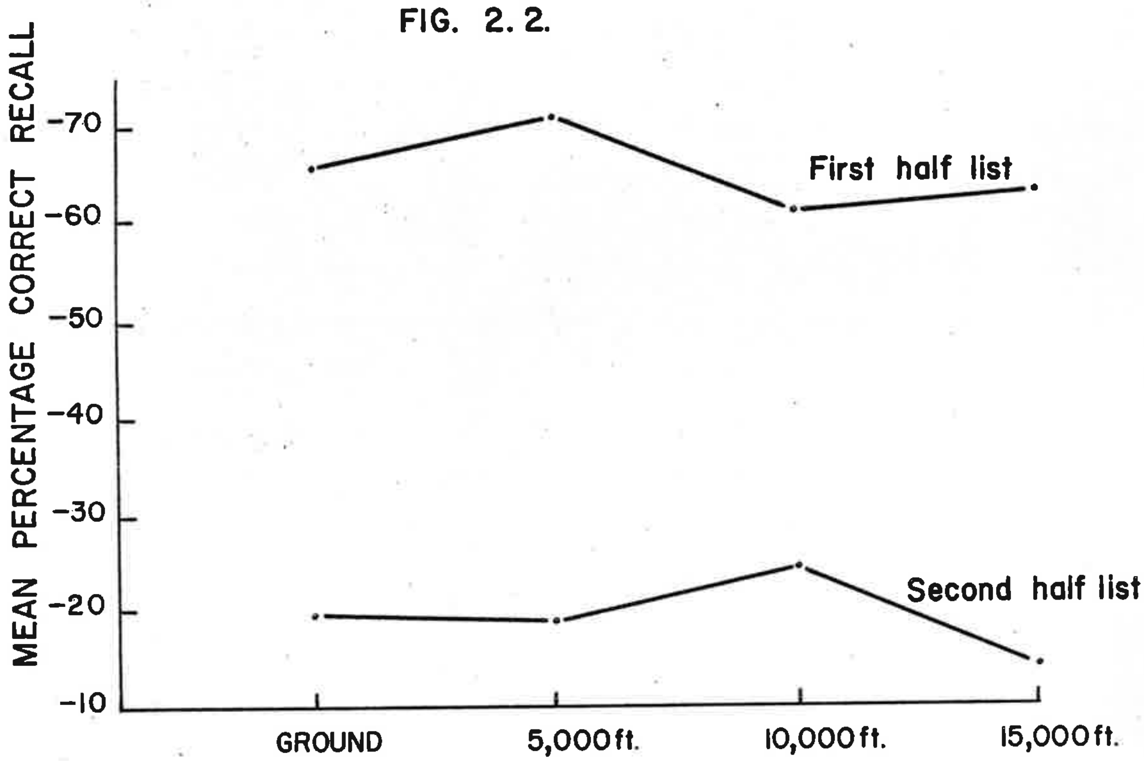
The experiment was primarily aimed at examining changes in performance at various levels of hypoxia. Analysis was to be performed using trend analysis (Winer 1962) and for this purpose equal spacing of experimental conditions is most convenient. The only trends thought likely to be found or to be readily interpretable were linear and quadratic: the latter manifesting itself as an increased rate of deterioration at higher altitudes. Hence four altitudes were used to provide an adequate test of such trends without spreading the subjects over so many conditions as to reduce the power of the statistical tests. The four levels used were ground level, 5,000 ft., 10,000 ft. and 15,000 ft. 15,000 ft. was used as the maximum altitude to obviate the possibility of any subject collapsing during the experiment. Subjects were assigned at random to each group and with equal sized groups this gave eight subjects per level.

As in all experiments, precaution was taken to try to ensure that subjects had no idea at what equivalent altitudes they were to be tested. They were tested individually in the decompression chamber. They were given a pretest at ground level on conventional digit span then, as an ears test, ascent was made to 4,000 - 5,000 ft. and down to ground level again. Subjects then sat while the pressure level was set which took seven minutes. After ten minutes further waiting to allow physiological equilibration the testing commenced. Subjects were given a dichotic listening test lasting ten minutes then another task (see Chapter IV) which also lasted 10 minutes, then the experimental session was at an end.

The conventional digit span given in the pre-test at ground level consisted of three lists of each of 8, 10, 12 and 14 digits read out at the rate of one per second in ascending order of length of list. These longer spans were expected to produce less than perfect recall and hence give a better indication of pre-experimental differences between the subjects in their ability to recall digits. This information was to be used in an analysis of co-variance to adjust the within-group variances in dichotic listening in the experimental situation and so reduce the disadvantages of using such a heterogenious group of subjects.

The dichotic listening test consisted of four lists of each of 3, 4, 5 and 6 digits read to each ear simultaneously by stereo tape recorder at the rate of one digit every 2/3 second. Lists were read in ascending order of number of digits. The lists were made up from random permutations so as to avoid, as far as possible, repetition of the same digits within a list. With five to six digits to each ear the number of duplications of a digit was kept to a minimum, no digit was repeated in a half list and no digit appeared in the same place in two half lists. Subjects were told to recall all the digits they could remember to one ear and all the digits they could remember from the other ear, no instruction was given as to which ear they should recall first. Scoring for accuracy of recall used the same criteria as in Experiment A.

FIG. 2.2.



Experiment B. Dichotic recall mean percentage correct recall at 4 levels of altitude on first and second half list. Means corrected by covariants of digit span and age (N=8)

Results.

TABLE 2.2.

EXPERIMENT B: DIGIT SPAN & DICHOTIC LISTENING.
MEAN PERCENTAGE CORRECT RECALL AT FOUR
LEVELS OF ALTITUDE
(N = 8)

	Altitude (in 1000's of ft.)			
	0	5	10	15
Digit Span	47.25	47.25	51.1	55.3
Dichotic 1st Half	64.75	69.6	60.8	65.1
Dichotic 2nd Half	16.7	16.3	24.1	18.4

Table 2.2. shows the mean percentage correct recall for each group both in the digit span pretest and the dichotic listening in the experiment proper. It can be seen that in the pretest there were large differences between groups showing the advisability of co-variance techniques. Preliminary analysis revealed that there was no evidence of interaction in hypoxia with the number of digits presented so the data was analysed in terms of the total number of digits recalled by each individual in a one way analysis of co-variance. Correction was made to the results in the experimental session for individual differences in age and pretest digit span. Figure 2.2 shows the mean for each group corrected

by the co-variate means as outlined by Winer (1962, page 585). There appears to be little effect but some deterioration in the second half list at 15,000 ft. The trend analysis of co-variance using both co-variates shows no significance (Table A.3.2. of the Statistical Appendix). None of the values for F reach the 10% significance level and the largest is in the cubic trends which are not readily acceptable as indicating any real effects.

Discussion.

This experiment used more subjects than experiment A and adjustment was made for pretest individual differences in short term memory in such a way as to allow no practice on the test used in the experiment proper. However examination of the results suggests that not only was there no significant difference in dichotic recall attributable to hypoxia but that there was no effect of any kind. Given that the results in experiment A were not spurious, which seems unlikely though not impossible, the question is why was there no effect shown in this experiment? It is true that the experimental subjects were more heterogeneous than the students used in experiment A. From observations during the experiment it appeared that a few subjects regarded the task as impossible and ceased to try to recall any digits from the second half list. This seemed clearly apparent in one female in the ground level group and may have been true of others. Any such effect would introduce discontinuities into the data and hence mask the effects of hypoxia. Although in general 50% correct may be the most sensitive level for detecting changes due to stress (Poulton 1966), this level of performance may be so low as to discourage some subjects from trying to do the task at all.

Subjects were exposed to hypoxia for ten minutes before testing but the subjects in experiment A were exposed for half an hour before their first test. Hence it is possible that the effects of hypoxia were either too small to show against a wide variation in subjects and/or the subjects at altitude were not properly hypoxic after ten minutes exposure.

These reasons could "explain away" an unexpected failure to find differences but would not enable much information to be gained from the effort of experimentation. There was one way in which the experiment could be of value. After the results were fully analysed and it became apparent that there was no effects of hypoxia discernible, the experimenter listened to the tapes used in experiments A and B to see if there was any obvious sign of a difference between them. It was apparent that the tape used in experiment B was much clearer than that used in experiment A, having been recorded by chance in a room with much less echo. It seemed possible that this audibility might be an important variable influencing the sensitivity of a dichotic recall test. Subjectively certainly it seems to require more effort to hear the numbers in dichotic listening than it does in digit span. Further if dichotic listening in noise is more sensitive to the effects of hypoxia this would be similar to the suggestion of Kimura (1963) that the effects of brain damage on auditory perception will only show in noisy conditions.

Experiment C.

This experiment was an attempt to examine the effects of hypoxia on dichotic recall where variation was made on the audibility of the digits and the length of exposure to hypoxia before testing. In addition subjects were instructed which ear to recall first but the instruction was given either just before or just after the reading of each list. This variation as in Craik (1965) is an attempt to find to what extent sensitivity of the second half list in adverse circumstances arises from subjects' concentration of limited cognitive resources on the first half list to be recalled.

Thirty first year psychology students volunteered to take part in this experiment. There were fifteen males and fifteen females and with one exception (age 26) ages ranged from 18 to 22 years. Three levels of altitude were used; ground level, 7,000 ft. and 14,000 ft. This provided equally spaced conditions for ease of trend analysis and constitutes the most powerful test of linear and quadratic trends. Subjects were assigned at random to each group with ten subjects per group. They were tested in pairs and the same procedure was used as that outlined in experiment B. Subjects were given a pretest on digit span and were then tested for the ability to equalise pressure in their inner ears. Ascent was made to altitude which took seven minutes. After a further ten minutes equilibration time one subject took the dichotic listening task repeated twice with an interpolated test of numerical transformations. This took about thirty minutes in all after which the subject transferred to a reaction time task (Chapter III). The subject who had done the reaction time task first (also lasting thirty minutes) was then tested on dichotic listening and numerical transformations. After the sixty minutes the testing was completed and the chamber was recompressed if necessary to ground level. Care was taken to try to ensure that subjects had no knowledge of what altitude they were tested at. They were simply told that they would be exposed to a maximum of 14,000 ft. but could be at ground level.

In the digit span test given before exposure to altitude, four lists of 6, 8 and 10 digits were played at 60 per minute. Subjects were told to repeat back the numbers in the order in which they heard them. The two dichotic listening tasks taken by each subject each consisted of 24 lists of 8 digits from a permutation of 1-9. Four digits per half list were used as this number seemed to show the greatest difference in hypoxia in experiments A & B and because the second half list would be expected to give the level of difficulty in the most sensitive area (Poulton 1966). Half the subjects in each group were told which ear to recall first before the reading on lists 1-12 and after the reading on lists 13-24, whilst the other subjects had the reverse order of conditions. The experimenter gave the instructions of which ear to recall first by pointing to one side or the other. In each block of twelve lists there were six lists where the first list to be recalled was from the left ear and six from the right ear. Of each six, three were noisy and three were quiet. The digits were recorded on a stereo tape recorder at the rate of 100 per minute. In the noisy trials white noise was made as the reading was played. The white noise had a sound pressure level of 65db. at the microphone which was the same level as the recording voice alone.

Subjects were told to try to recall digits in the order in which they occurred and to guess any they were not sure of. They were warned that on some of the trials the numbers might be a little difficult to hear but if they were not sure again they were to guess.

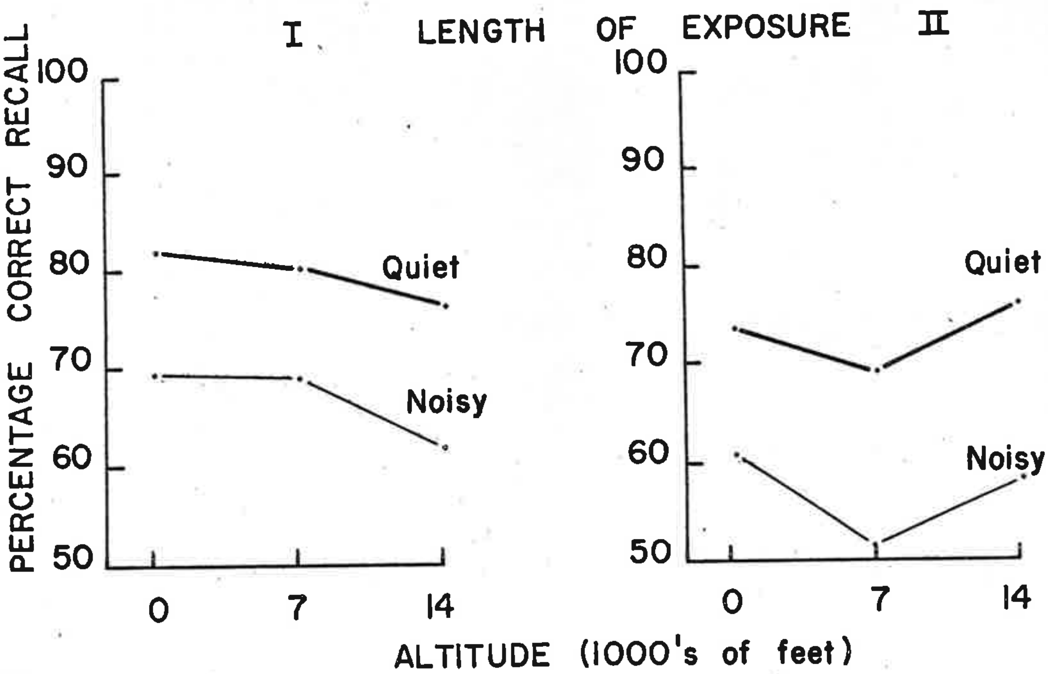
The experiment provided a comparison between subject of three levels of pressure and two durations of exposure prior to testing: after ten minutes exposure or forty minutes exposure. Within subjects a comparison is possible of the effects of noisy or quiet, left or right ear, instructions before or after the list as to which ear to recall first and the interaction of these effects with the length of exposure and pressure level. On the basis of experiment B. it was thought that the effects of hypoxia might be more marked in the noisy condition and might be more marked in subjects with forty minutes exposure to hypoxia rather than ten minutes exposure prior to the commencement of testing. If, under hypoxia, subjects compensated in dichotic listening by concentrating on one ear and trying to make sure that they recalled correctly at least one half list, then the effects of hypoxia on the second half list would be expected to be more pronounced where instructions which ear to recall first were given before the list was read.

<u>Results</u>.

Specifying which list to recall first, using only four digits per list and encouraging subjects to guess if they were not sure produced records of recall which were much easier to score than those in the previous two experiments. It was easy to determine which list was which and which numbers were thought by subjects to belong to which list since subjects explicitly distinguished each half list and almost invariably gave four digits for each half list. Recall was scored by strict criteria for each position in a list was compared with the correct answer. For example if the subject gave 1, 3, 2, 4 where the correct answer was 1, 2, 3, 4, then there were two digits in their correct place in the list. This is a stricter criterion than that used in the previous experiments but one which is unequivocal in scoring.

In the <u>first half list</u> recalled (Figure 2.3) there was some evidence that subjects tested after forty minutes were poorer than those tested after ten minutes in the experimental session ($p < .1.0$). The slight decline in recall in hypoxia was no more than that expected by chance in either linear or quadratic components (F ratios < 1.0) and there was no interaction of this with time of exposure (see Table A.3.3 of the Statistical Appendix). Nonetheless in graphical terms it seems that only those subjects tested after ten minutes exposure show any monotonic decline associated with hypoxia (Figure 2.3). Co-variance adjustment was not carried out as the within groups $r = 0.058$ and hence the adjustments would be negligible. In the variations within subjects, performance was significantly poorer in noise (Figure 2.3), was significantly poorer where instructions were given after the list (Figure 2.6) and significantly better on the second test given. None of these effects produced any sizeable first-

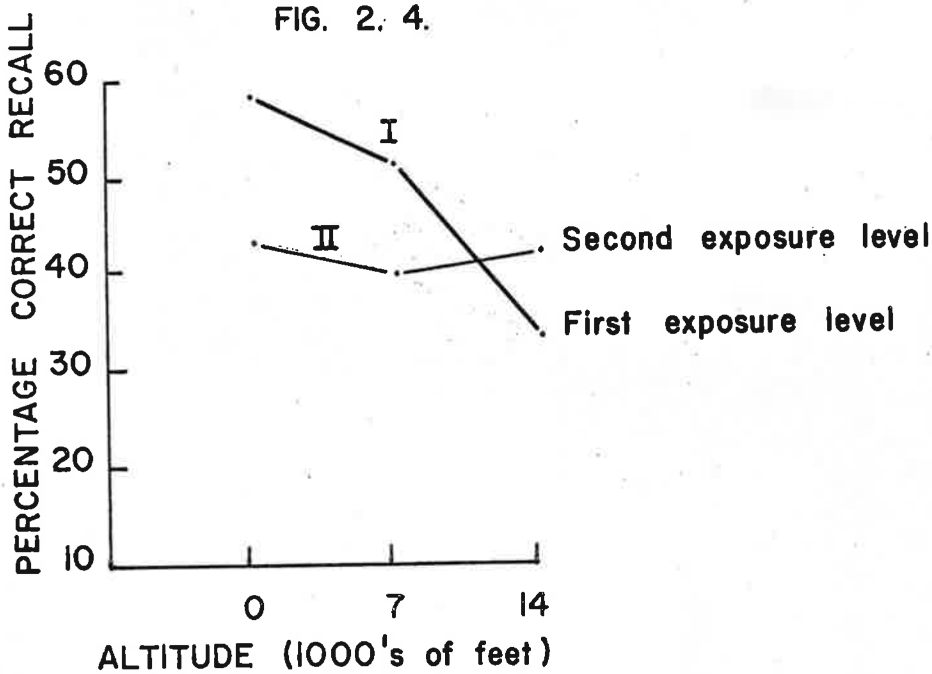
FIG. 2. 3.



Experiment C. Dichotic listening. First half list.

The effect of noise on percentage correct recall. 3 levels of Hypoxia at 2 lengths of exposure. (N=5)

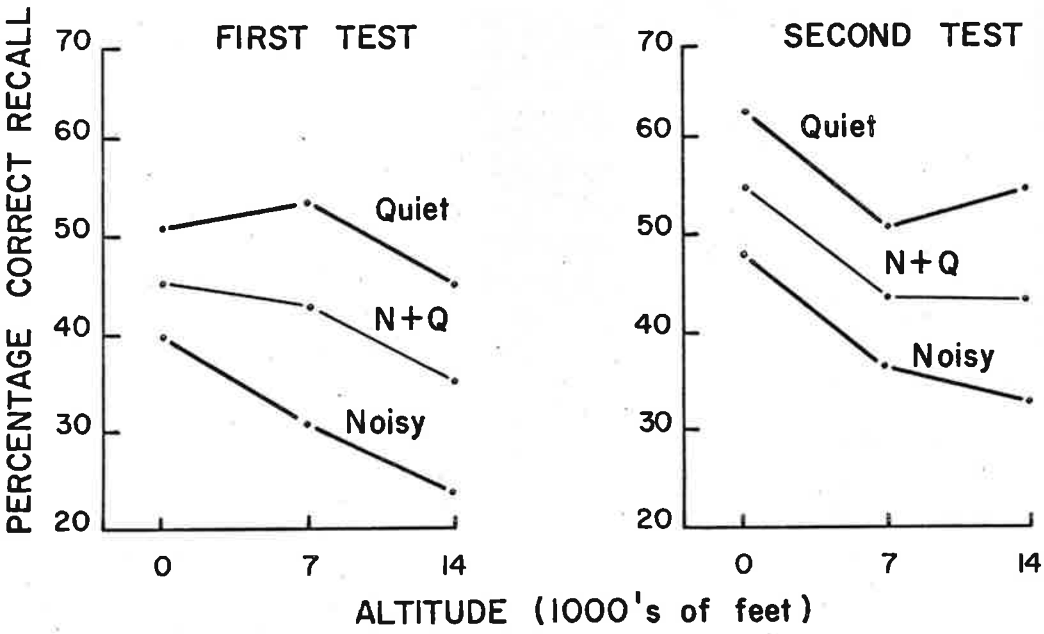
FIG. 2. 4.



Experiment C. Dichotic listening. Second half list.

Mean percentage recall with correction for covariate. Two intervals of exposure (N=5)

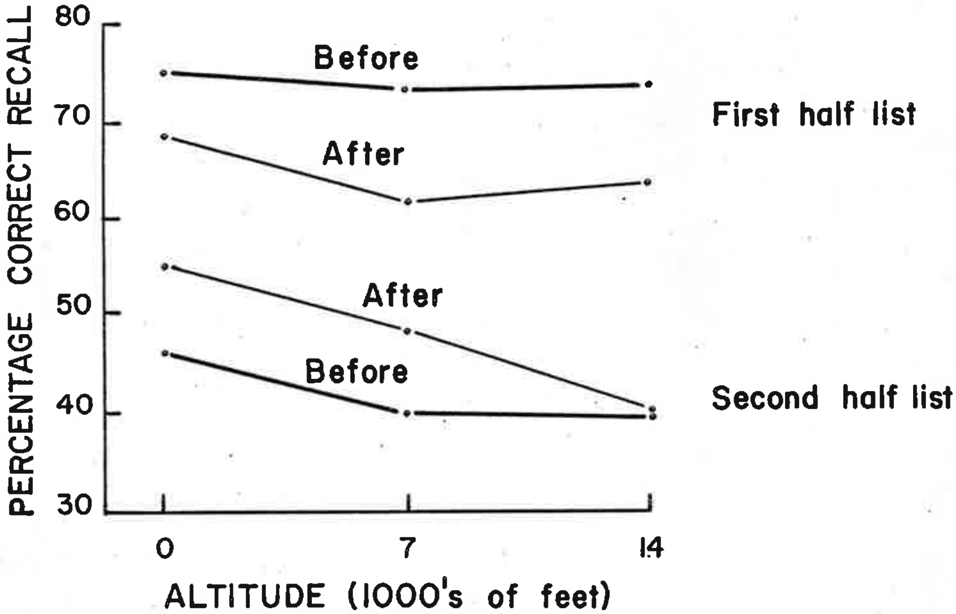
FIG. 2. 5.



Experiment C. Dichotic listening. Second half list.

The effect of quiet/noise and test-retest by levels of Hypoxia (N=10)

FIG. 2. 6.



Experiment C. Dichotic listening. The effects of instructions before or after the list on recall of first and second half lists.

order interactions with hypoxia.

Co-variance adjustment was carried out on the analysis of recall in the <u>second half list</u> since the within groups correlation with digit span co-variate r = 0.449. Table A.3.4 shows the results of the analysis in which there is a marked linear trend of hypoxia ($p < .05$) and a difference in the linear trend of hypoxia at the two times of testing ($p < .1$). Figure 2.4 shows the mean correct recall as a percentage of total. The linear trend is marked in the group tested after ten minutes exposure. In the group tested after forty minutes there is no linear trend. There is a U-shaped effect though with the adjustment for the co-variate this effect virtually disappears.

In the within subject comparisons (see Table A.3.5) the main effects are all significant at at least the 1% level: performance is significantly poorer in noise, is better on the second test and contrary to the results in the first half list is better where the instructions are given after the list which ear to recall (see Figure 2.6). Figure 2.5 shows the trend of hypoxia in quiet and noisy conditions. There is a steeper decline with hypoxia in the noisy condition but statistically the interaction is small. There is some sign that the effects of retest vary with hypoxia. Figure 2.5 shows that the improvement from first to second test is much less in the intermediate hypoxic group than in either the ground level or 14,000 ft. groups.

Discussion.

This experiment supports and amplifies the findings of experiment A. There is a deterioration in dichotic listening in hypoxia, an effect which is essentially linear using the three levels of pressure chosen. The decline appears to occur progressively from ground level upwards with no sign of compensatory adjustment at 7,000 ft.

There is not much support for the suggested reason for failure to find an effect of hypoxia in dichotic recall in experiment B. The effects of hypoxia were greater in noise as predicted from the hypothesis suggested and hence a low level of statistical confidence would be acceptable for confirmation. However the F test of the interaction has a high probability by chance.

There is no support for the view put forward after experiment B that ten minutes exposure might be insufficient to produce a significant degree of hypoxia. In both half lists the linear effect of hypoxia is clearly marked in the group tested from ten to forty minutes exposure while in the group tested from forty to seventy minutes there is a U-shaped effect which virtually disappears where covariance adjustment is made. It could be argued that subjects tested second, having already completed thirty minutes on a translation processes task, would be fatigued. This would explain why the ground level and 7,000 ft. groups tested second were poorer than those tested first but why then should the 14,000 ft. group tested second do better than the group tested first?

In Chapter IX consideration of the general effects of time of exposure are given in relation to all the data on the three different tasks given to the subjects in this experiment and to all the data from different experiments which are relevant. On the evidence here alone there appears to be some compensatory adjustment to 14,000 ft. which takes time to show itself after the onset of hypoxia, but which, after forty minutes exposure, will give rise to performance which is not noticeably inferior to the controls. In the controls and 7,000 ft. group with no such compensation the normal effects of fatigue may show, especially in such a trying task as dichotic listening. Such an explanation, although testable, may appear fanciful but it is more cogent when related to some other evidence in this thesis of poorer performance being found only at intermediate levels of hypoxia.

The effects of giving instructions of which ear to recall first, either before or after the list was read, had a similar effect to that described by Craik (1965) in aging: the difference in the recall scores between the half lists was reduced. The first list was significantly poorer and the second list significantly better with instructions given after the reading suggesting that subjects do concentrate on the first list they have to recall if they know which one this is. Figure 2.6 shows that there is no greater effect of hypoxia where recall instructions are given before the list. In the first half list there is no evidense at all of an interaction ($F < 1$). In the second half list there is some slight evidence of interaction ($F=2.60$). However in any case the interpretation is in the opposite direction to what would be predicted in view of some compensatory concentration of attention in hypoxia. There is a greater decline in performance in hypoxia where instructions are given after the list. It appears that giving instructions before the list confers an advantage in recall of the second half list (though not at the expense of the first half list) and this advantage may be reduced under hypoxia.

General Conclusions.

The test of dichotic recall of digits is a more valid indicater of changes in short term memory than conventional digit span: more valid since dichotic recall shows larger effects than digit span under hypoxia at levels where casual observation and some experimental evidence would lead one to expect that impairment would be found. It is not clear why it is a more sensitive indicator and why it is that the second half list is the more sensitive. Clearly the second half list and digit span do at least in part measure the same process since the within group correlations are high (experiments B & C). The demonstrated sensitivity is not entirely because the level of performance attained is in the region of most sensitivity of 50% correct (Poulton 1966) since those parts of digit span with a comparable level of performance fail to show such marked effects (experiment A). There is no evidence at all that the effect is due to a concentration in hypoxic subjects of an impaired capacity on one half list. There is some evidence that the effects of hypoxia are shown partially because of the difficulties in registering two inputs at once. This evidence has little statistical support and where it seems reliable only appears so in combination with other factors. This is not to suggest that the failure in hypoxia is purely in auditory perception since it is known that this is little impaired by hypoxia. It is possible that in hypoxia a slight increase in difficulty in registering the stimulus may interact with increased difficulty in storing some information whilst transforming other information at the same time. The end result of this piling up of deterioration is such as to produce a test which is more sensitive to changes which are more difficult to demonstrate experimentally than in more normal workaday situations.

Failure to find any clear effects in experiment B must not be disregarded. Although the test appears to be fairly sensitive the effects of hypoxia may be blurred by individual differences.

The subjects were a heterogeneous group in respect of intelligence, age and skills. In addition they were tested on one ten minute session on dichotic recall whilst the student subjects in experiments A & C were given two separate sessions of ten minutes. With such an unpractised task it may be that a fairly lengthy set of responses is required to get a reasonably stable estimate of a single subject's performance level.

CHAPTER III.

THE TRANSLATION FROM STIMULUS TO RESPONSE.

The work reported here does not arise from a consideration of the literature on the effects of hypoxia. It has been much guided by the experimental studies on the effects of aging and in particular Welford's (1958) analysis of the differential effects of aging on various aspects of sensory motor skill.

Welford (1958) notes that a characteristic difficulty in older people lies in translating from a given stimulus to the appropriate response. He summarises a series of studies where systematic variation has been made in the complexity of the relationship between stimulus and response. These show that the effects of age are more marked with more complicated relationships and especially in those involving a combination of sensory modalities or different types of translation in a single modality. He also reviews the effects of age on the speed and accuracy of movement. On the basis of a number of experiments he suggests that the characteristic slowing with age in skilled movement is shown primarily in the time taken to initiate, guide and monitor movement but the movements themselves are little changed with age.

If hypoxia is primarily a stress which strikes at the CNS, especially the cortex, it seems reasonable to assume that the same differential effects will show as in aging. Techniques have been developed in the experimental studies of aging which are ready-made tools to use in the analysis of the effects of hypoxia on performance. Borrowing from aging studies one derives suggestions as to what aspects of performance to examine under hypoxia and also the measuring devices to use in such an examination.

Experiment A.

Welford (1958) in his analysis of translation processes in relation to age quotes an experiment by Kay (1955) which forms the starting point for this experiment. The apparatus used was a board with twelve lights mounted on it and a keyboard with twelve keys. Subjects had to turn out each light in turn as it came on by pressing the appropriate key and as one light was turned out another came on through a series of thirty. The spatial relationship between light and correct key was varied by placing the light box directly in front of the key box, three feet away, or three feet away and turned end to end. It was found that there was little increase with age in the time taken to do the simple light cancelling with the lights directly in from and in line with the keys. In the most difficult task (with the lights three feet away and crossed over) slowing with age was in absolute terms greater. Using the same apparatus Kay (1954) had subjects identify a light by a serial number 1-12 and then to press the key with the same number, where the card containing the key numbers was placed alongside the keys or closer to the lights. In the latter condition performance deteriorated very greatly with age. Mean times were vastly increased and analysis of the type of errors made suggested that, for older people, the most complex task was almost overwhelmingly difficult.

Birren and Riegl in Tibbits and Donahue (1962) used a similar apparatus with ten lights and keys but with the light board directly in front of the keyboard at all times. Complexity of relationship between light and key was varied within very wide limits. In the simplest case the lights were turned on serially from 1-10 and the key directly beneath the light was required to be pressed to turn the light off. In more complex cases the light had numbers, words, symbols or colours beneath them and various codes and verbal rules were used to define the correct response. In general it was found that the greatest percentage and absolute increase in time in a group of elderly people was in tasks involving some word association or digit-symbol relations. The slowing with age involved far more than any slowing in speed of simple or choice reaction times which seemed minor components of the very considerable slowing found.

In the literature on hypoxia there is little evidence of the effects of changing the complexity of the relationship between stimulus and response. Most work in this area has been concerned with varying the number of possible stimuli which might have to be responded to. However Ledwith and Denison (1964) and Denison, Ledwith and Poulton (1966) used a task in which a complex spatial re-organisation was required to a stimulus array before arriving at the correct answer by pressing a left or right hand button. Marked effects of hypoxia were present even at 5,000 and 8,000 ft. but there was no clear evidence that the effects of hypoxia were greater in the more difficult aspects of the task.

However, on the basis of the experiments in aging an experiment was designed where the effects of varying the difficulty of translation (measured by response time) were to be examined at various levels of pressure. The task used was similar to that used by Kay (1954) and Birren & Riegl in Tibbits and Donahue (1962). The apparatus consisted of a signal board, a key board and a programmer-connector box. The signal board was a panel 17 ins. long and 5 ins. high mounted so as to be at right angles to the line of sight of a seated subject. On it were mounted at intervals of 1.5" ten filament lamps (12 volt) with semi-transparent plastic covers on top of each. The key board was a similar sized panel mounted horizontally with 10 strip keys (like piano keys)

2.5" by .75" mounted on it 1.5" apart. The programmer unit provided a preset sequence for lighting up the lamps and enabled any light to be linked to any key. When the programmer was started a light came on. The subject's task was to identify, according to instructions given, the correct key to press appropriate to the light which was on. When the correct key was pressed the light went out and immediately another came on. If any key but the correct one was pressed the light stayed on. After a sequence of 20 lights with their correct responses, in which each light appeared twice in random order, the programmer switched off automatically. A cumulative timer recorder to .02 of a sec. the time taken for the 20 responses.

There were three tasks used in this experiment.
Task 1. The key board was placed directly in front of the light board lined up with it. Subjects were told that when a light came on to press the key directly in line with it, (hence if light 2 came on key 2 was to be pressed, if light 9, key 9, etc.).
Task 2. The key board directly in front of the subject but the light board placed 3 ft. away but still lined up with the key board. Subjects were told to find the light symmetrically opposite across the centre of the board and press the key in line with it. (Hence if light 7 came on light 4 is symmetrically opposite to it and key 4 was to be pressed.)
Task 3. In task 3 the board was placed as for task 1.

Each light was randomly assigned a number from 0 to 9 marked just below the light. The keys were given numbers 3 to 84 in random order. What the subject had to do was to note the number under the light which came on, square it, add 3 to the result and find the key with the resultant number. (If the light with a 4 below it came on, 4^2 plus 3 = 19, hence the key with 19 below it is the correct key to press.)

Thus, task 1 is a light cancelling task, task 2 requires a double spatial transformation and task 3 a double numerical translation.

For reasons explained in Chapter II, 4 levels of pressure were used: ground level, 5,000 ft., 10,000 ft. and 15,000 ft. Subjects could not easily do more than one altitude level in a single session and it was expected that there would be a considerable interaction of order with treatments so different groups of subjects were used for the different treatment levels. Such a design is an insensitive one, involving a large error component attributable to individual difference between subjects. It was decided to try to reduce the within group variance by using a covariance adjustment. To keep to a minimum the amount of relevant pre-training, performance on Task 1 was selected as a covariate. This had been shown in a prior experiment to correlate to a limited degree with times taken in the more complex tasks.

Recording was made of the time taken to complete three runs of 20 responses on the sample task. Subjects' ages were recorded, as this test is known to be affected by age and covariance adjustment could also be used for this.

Subjects were given a test on each task in a counter-balanced order, followed by two more blocks of each of the three tasks in different counter-balanced orders.

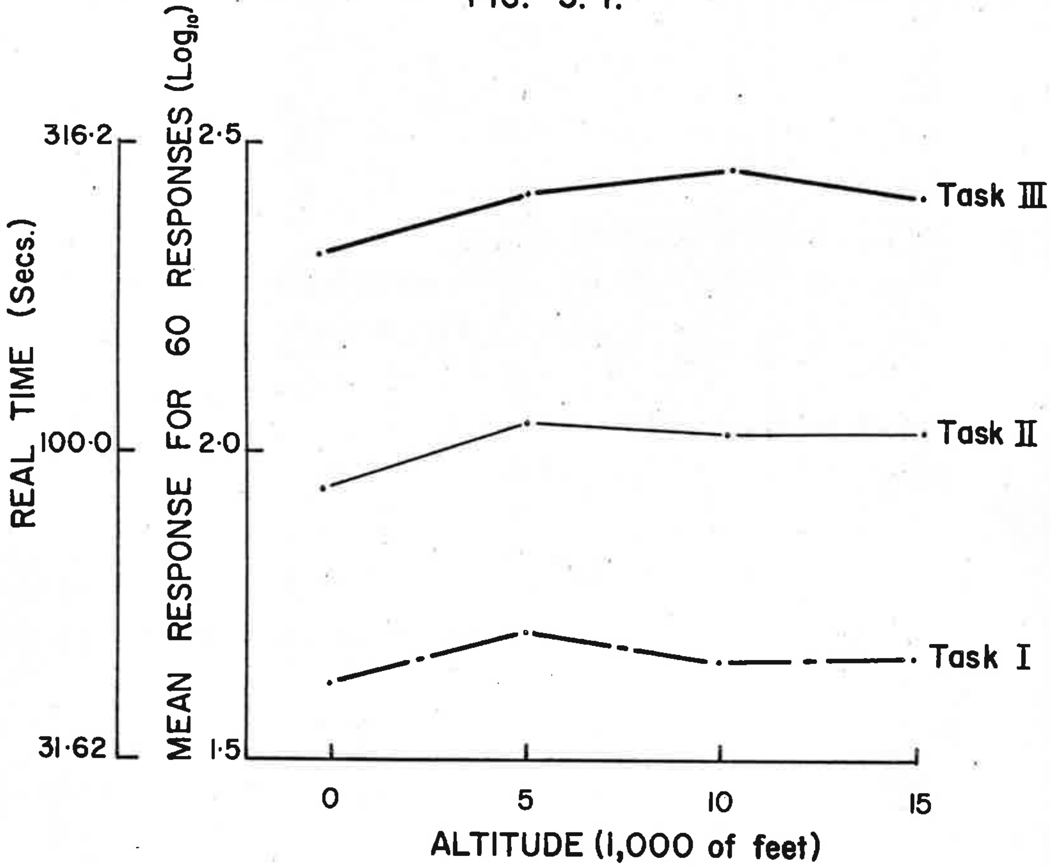
The subjects were 32 R.A.A.F. personnel, as described in Experiment B, Chapter II. Subjects were tested individually in the decompression chamber. They were pre-tested on digit span and task 1 of this test with the chamber door open. After this, a test was run to ensure that subjects could equalise the pressure in their inner ear during ascent and descent. Then ascent was made to the pre-determined pressure level which was not revealed to the subjects. Ten minutes were allowed for equilibration and then the test of dichotic listening was carried out as described in Chapter II, Experiment B. This test took ten minutes and immediately afterwards the lights test was run as described. This test also lasted approximately ten minutes after which the experimental session was concluded.

<u>Results</u>.

There were few errors made in the responses. In any case if the wrong key was pressed the light would not go out. Time could not be gained at the expense of accuracy so analysis was performed only on the times taken. A preliminary inspection of the data indicated that the times taken for the three tasks differed widely with task 1 taking the shortest time and task 3 the longest. The variability between responses in the different tasks was related in linear fashion to the mean time taken for that task. Such a case indicates a need to equalise the variances so that results from task 3 would not swamp the results of the other two tasks. In view of the form of relationship the transformation of each reading to log. to the base 10 was employed.

There were four levels of altitude, three tasks done three times each in a run of twenty responses. Analysis of variance was performed on the time taken on each task on each repeat at four levels of hypoxia according to the model outlined by Winer (1962) pages 319-320. The differences in pressure were broken down into their trend components and adjustment was made for individual differences in time taken in task 1 in the pre-test and individual differences in age. Table A.3.6 shows that though the tasks differ greatly in the time taken there is no interaction with hypoxia (F   1.0). There are significant linear and quadratic trends in the data. Mean time taken corrected for covariate mean differences (see Fig. 3.1) shows that this quadratic trend comes about with the slowest times at 5,000 and 10,000 ft.

FIG. 3. I.



Experiment A. Mean time per 60 responses on 3 light cancelling task at 4 levels of pressure (N=8) Log score.

<u>Discussion</u>.

The trend of performance with increasing hypoxia is surprising when related to the conventional views of the effects of hypoxia. Performance is markedly poorer at the lowest altitude used compared with ground level but above this point there is no progressive steepening of the trend of deterioration. In fact quite the converse occurs where the intermediate hypoxic groups show the slowest performance. In graphical terms the most difficult task seems to deteriorate most at these intermediate levels though statistical analysis suggests that this could well be a chance effect. As the analysis was performed on log. scores the failure to find any interaction shows that proportionality holds. That is the changes at three levels of difficulty are relative to the absolute level of performance: the absolute increase is greatest in the more difficult tasks.

From the internal evidence the trends appear highly reliable. It appeared unlikely that the results are due to the chance allocation of particular subjects to particular levels especially since covariance adjustment for correlated measures does not reduce the F ratios. It was possible that the effects though reliable are highly specific. This point will be taken up in the discussion of the results of all the experiments where evidence is available on trend effects. For the moment these particular results need to be placed in perspective as to the degree of change produced by hypoxia. In task 2 the maximum change of mean response time in hypoxia is 0.25 secs. from ground to 5,000 ft. On the first run of 30 responses in Kay's (1954) results as tabled in Welford (1958), the change in mean time is 0.35 secs. from an age group 15-24 as compared with 25-34. Hence the changes though apparently internally reliable are smaller than those produced by quite minor changes in age.

Experiment B.

Choice Reaction Time and Movement Time.

The effects of hypoxia on simple and choice reaction time seem reasonably well documented. Macfarland (1932) used gas mixtures of various oxygen concentration. He reported that simple RT was virtually unimpaired until subjects were so deprived of oxygen as to be near collapse (above 20,000 ft. equivalent). Choice RT however was considerably slower at the lowest altitude quoted though even this is 17,000 ft. equivalent. In these experiments subjects were given practice to some plateau of performance to eliminate practice effects before the experimental runs. Macfarland (1937 a) tested six subjects at ground level and then at 14,900 ft. the following day, after an ascent by train. The simple RT was somewhat increased in two subjects who had symptoms of mountain sickness but the measure showed no change in the other individuals. In the choice reaction time (to one of five lights) the overall mean was much higher at altitude and the variability of response was increased by 50%. Waldfogel et al. (1950) tested a group of psycho-neurotics and normal controls on choice and simple RT as well as tapping speed and a test of hand-eye co-ordination. During acute exposure to 10% oxygen the latter test showed the greatest decline, there was less decline in simple reaction time and choice reaction time was somewhat improved. However as all subjects were tested at normal air and then 10% oxygen it is possible that there was more improvement with time in choice reaction time which would therefore mask any impairment by hypoxia.

Adler et al. (1950) using a three choice RT device found a small (17 m'sc.) but reliable increase in RT at 18,000 ft. compared with ground level. Alifanov (1961) reports the effects on simple RT and delayed and choice RT after thirty minutes exposure to 15,000 ft. He distinguishes between good and poor tolerators of hypoxia and says the poor tolerators showed greater deterioration in all tasks. Delayed RT showed the most marked effects in all subjects but he gives no details of the precise nature of the task. Apparently the movement time recorded separately showed little effect of hypoxia. Gerathewohl (1951) used a complex RT device with lever and pedal controls in testing the effects of hypoxia up to 26,000 ft. on a single subject. Although the subject was well practised beforehand and there was some evidence of acclimatisation throughout the course of the experiment, which ran for several months, more errors were committed at 6,000 ft. than at ground level but between 6,000 ft. and 16,000 ft. there was little progressive deterioration found. Above this latter height performance deteriorated steadily with increasing altitude. Tune (1964) sums up what is known of the psychological effects of hypoxia and says "It is known that exposure to hypoxia slows up reaction time .... but exactly which component (movement time or decision time) has yet to be fully explored."

As noted above, Welford (1958) suggests that the major locus in slowing in response with age lies in the time taken to initiate response and that any slowing in simple RT is a minor component of such slowing. In Welford in Tibbits and Donahue (1962) there is a more detailed analysis of the effects of age at various levels of information load involved in the choice RT. Welford attempts to give a coherent picture of the effects of age on the components of the linear equation $T=a+b \log. N$, where T is reaction time and N is the number of equiprobable choices facing the subject. It is suggested that there are circumstances in which the slowing will be shown in the intercept (a) and others where it will be found in the rate of decline with increasing number of choices (b). Griew (1959) varied the information in the stimulus array with one out of two, four or eight lights and also the information load in the response by varying the size of the target to be hit to turn out the light. He reports that the movement times were little affected by age but the time taken to initiate the response was in absolute terms greater with age, especially in the higher degrees of choice. Furthermore the time taken to initiate response was greater in older subjects where the target is smaller, an effect which is not found with the young subjects. He suggests that this shows a breakdown of integration of activity with age. Older subjects programme their responses before responding while younger subjects are better able to shape the response during the movement itself.

With these suggestions in mind an experiment was designed to amplify the basic finding that choice RT increases under conditions of hypoxia. The information load of the input and the output was varied to see if greater effect was found at higher information levels and the time taken to initiate response was recorded separately from the movement time. An attempt was made to quantify the information not only in the input (using Hick's law) but also in the motor output using the formulations of Fitts & Peterson (1964). These authors suggest an index of difficulty (ID) to relate together the distance to be moved and the size of the target to be struck in such a way as to give a linear relation between increases in ID and increases in movement time. Quantification of the information contained in input and output allows, if required, a far more powerful test of the interaction of the stress with levels of difficulty than would an overall test of interaction with stress using tasks whose comparative difficulty can only be placed on an ordinal scale as the tasks were in experiment A.

The index of difficulty proposed by Fitts & Peterson (1964) is ID = $\log_2 2a/w$. a is the amplitude of movement made and w is the target width. Using a variety of values of a and w they showed that RT is primarily a function of the probability of occurrence of two signals whilst MT is primarily a function of the ID. A lack of effect on RT of the information transmitted in the movement fits with Griew's (1959) finding that in young people RTs are little affected with variation in target size at constant distance. It should be noted that in Griew's experiment with a constant distance of 8 inches and target sizes of 1.25 inches or 0.1875 inches the respective indices of difficulty were 3.68 and 6.42.

Apparatus and Procedure.

The apparatus consisted of a board 18" wide by 6" long. On it were mounted a start button in the centre and 8 keys ½" wide mounted at ½", 1½", 3" and 6" from the start button to the left and right. Above each key there was a 24 volt lamp with a red cover. At a signal the subject pressed the start button. 2.5 seconds later one of the 8 lights lit up and the subject had to press the key under the light in order to turn it out. Two measures of performance were recorded: (1) the time between the light coming on and the subject releasing the start button, and (2) the time between the light coming on and the key being pressed to turn the light out. Hence there was a measure of time to initiate a response (Reaction Time) and by subtraction of (2) from (1) the time taken to make a movement. Subjects were not told in advance which light would come on but they were told that it would be one of two lights indicated or any one of the eight. In this experiment on half the 128 trials per subject a mask was placed over the keys so that they were reduced to ¼" width.

Subjects used a steel pointer to turn off the lights so as to obtain the same degree of difficulty in motor output. This stylus had a diameter of $\frac{1}{64}$ of an inch. Indices of difficulty had been computed for both widths of target allowing for the size of the stylus at the distances of 0.75, 1.5, 3.0 and 6.0 inches from the start button. The results are shown in Table 3.1.

TABLE 3.1.

INDEX OF DIFFICULTY OF MOVEMENT FOR 4 DISTANCES OF TARGET AT 2 WIDTHS OF TARGET

		Target Distance (Ins.)			
		0.75	1.5	3.0	6.0
Actual Target	0.4375	1.78	2.78	3.78	4.78
Width (Ins.)	0.1875	3.0	4.0	5.0	6.0

It can be seen that the effect of reducing the target size is as if to place the targets slightly more than one position further out in difficulty. The range of difficulty is from far easier to slightly less difficult than that used by Griew (1959).

Subjects and Experimental Design.

30 subjects were tested in a decompression chamber following the same general procedure as described in experiment A.

The 30 volunteer subjects were University students and members of the St. John Ambulance Society who were taking a course in Aerial Ambulance work. The nineteen students' (including three females) ages ranged from 18 to 23 years. The group from the St. John Ambulance Society consisted of 8 males and 3 females aged 19 to 45 years. Subjects were allocated at random to one of three equal sized experimental groups: ground level, 7,000 ft. or 14,000 ft. The groups had approximately the same balance of students to St. John Ambulance personnel which meant that they were matched for age as well. The sex of the St. John Ambulance subjects was not known before they arrived for the experimental session and arrangements had to be made in advance for medical supervision of the 14,000 ft. runs. As a result the number of females was not the same in all groups there being three females at ground level, three at 7,000 ft. and none at 14,000 ft. This was unfortunate as prior experimentation had shown that females were consistently slower on the choice reaction time task. However covariance adjustment for differences in simple reaction time could be expected to reduce the distortion from this imbalance.

Most subjects were tested in pairs on two tasks. They were each given 12 trials on the reaction time where the simple reaction time and movement time was recorded and one practice at each of two card sorting tasks. After a test for equilibration of pressure in the inner ear involving ascent to 5,000 ft. and then rapid descent, the pressure level was set for the experimental session, a process which took 7 minutes. After ten minutes further one subject was tested on choice reaction time whilst the other subject took the card sorting task (see Chapter V). This latter test was supervised by an experimental assistant while the author tested the choice reaction times. Testing on each task took approximately thirty minutes. After the thirty minutes subjects changed position and were tested on the other task. After the completion of both tasks, that is after 60 minutes testing, the session was completed.

In the reaction time task there were two conditions of choice: one of two lights to come on or one of eight. The target key for cancelling the lights which came on was either 0.5" or 0.25" wide. Subjects were balanced within groups on order of presentation of choice and width variation. Within each level of choice for each target size subjects were given four examples of each of the eight lights. There were two choices by two widths of target and eight keys each tested four times making 128 responses in all. Subjects were not given instructions for speed. They were told to put out each light by pressing the appropriate key as soon as the light came on.

Of the ten subjects tested at each pressure level some were tested between 10 and 40 minutes of exposure (time 1) and the rest between 40 and 70 minutes of exposure (time 2). Several subjects failed to appear for the experimental sessions and for four subjects no partner could be found for the experimental session. As a result equal numbers were not tested at time 1 and time 2 in all groups. At 7,000 ft. and 14,000 ft., five were tested at each time but at ground level four were tested at time 1 and 6 at time 2.

Results.

Preliminary inspection of the data revealed that correction could not be made for individual differences in age by use of covariance adjustment. In both reaction time and movement time the effects of hypoxia interacted with age. Since the students were mostly aged 18 to 21 years and most of the St. John Ambulance personnel were older, the difference in age is confounded with difference in intelligence level and test sophistication. The subjects were stratified by age as Winer (1962) page 594 suggests in cases where the covariate interacts with the phenomenon under consideration. Results were analysed for subjects above and below the median age (21 years) and hence the statistical analysis is of a factorial design with two age levels and three levels of pressure. The results could be corrected for differences in simple reaction time and movement time recorded in the pretest session. Within cells of the factorial design analysis can be made of the effects of choice, width of key and distance of key from the start button.

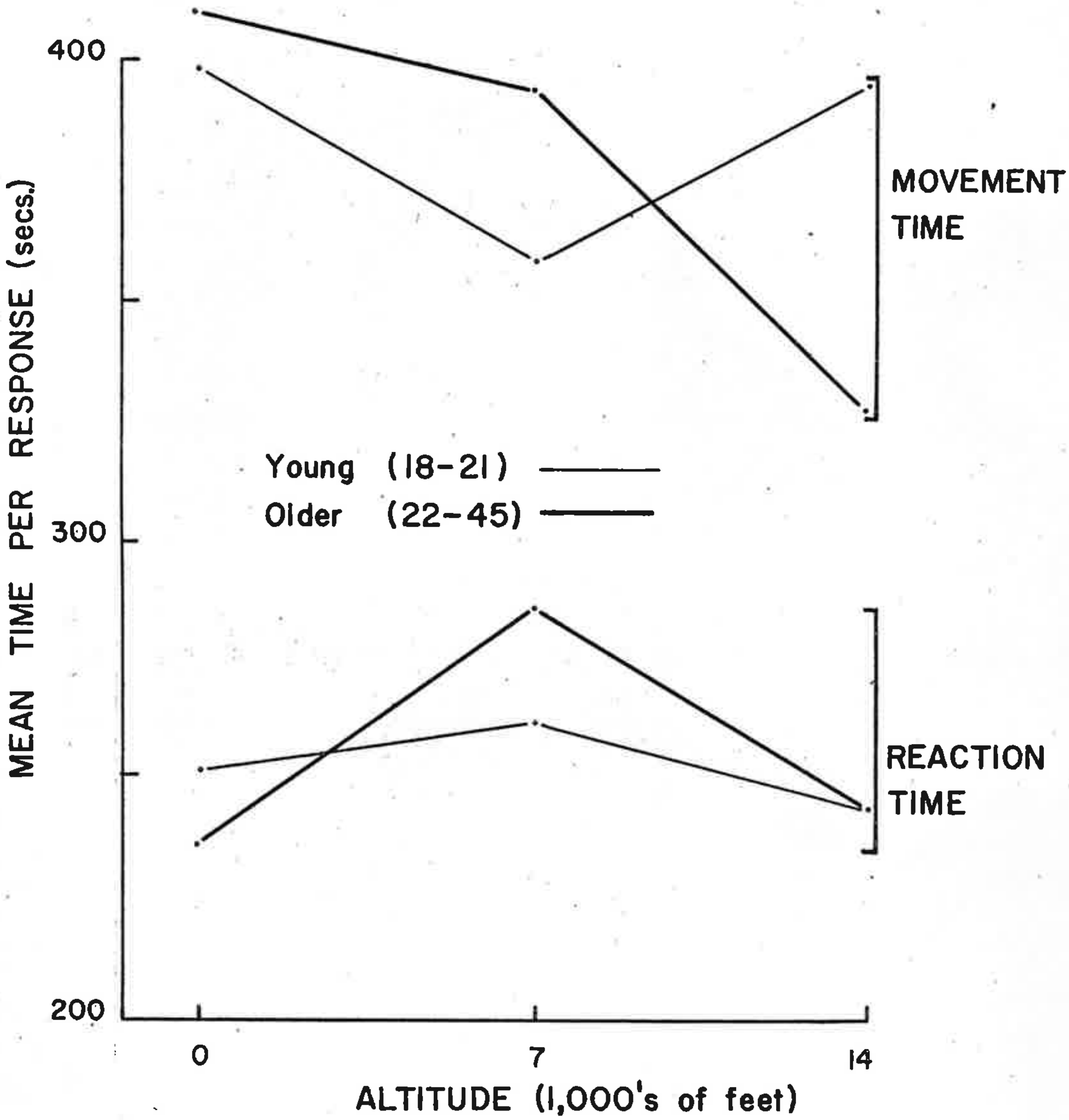
Reaction Time.

Figure 3.2 shows the mean reaction time per response for each pressure level for both old and young subjects. Means have been corrected for individual differences in simple reaction time in the pretest. It can be seen that the major effect of hypoxia is U-shaped with the intermediate hypoxic level showing the longest reaction times, an effect which appears much more marked in the older subjects. Statistical analysis of covariance (Table A.3.7 of the Statistical Appendix) confirms that the major component of trend is quadratic (U-shaped) though with the probability by chance of approximately 8%. The interaction of hypoxia with age however falls well within the expectancy by chance though what difference there is is in the quadratic component.

Table A.3.8 shows the analysis of the within and between group comparisons on the effects of choice, width of key and distance of key with results for symmetrical keys summed of the left and right of the start button.

A very simple picture is seen with no interaction of hypoxia with any of the variations of the task not even in combination with age. The age variable shows highly significant interaction with a number of choices and some interaction with width of key. Table 3.2 shows the effects of these variables broken down by age and it can be seen that the increase from 2 to 8 choices produces a greater increase in reaction time in the younger group.

FIG. 3. 2.



Experiment B. Reaction time and movement time. Mean time per response (in secs.) at 3 levels of pressure in younger and older subjects. Times corrected by pre-test covariates (N=5)

TABLE 3.2.

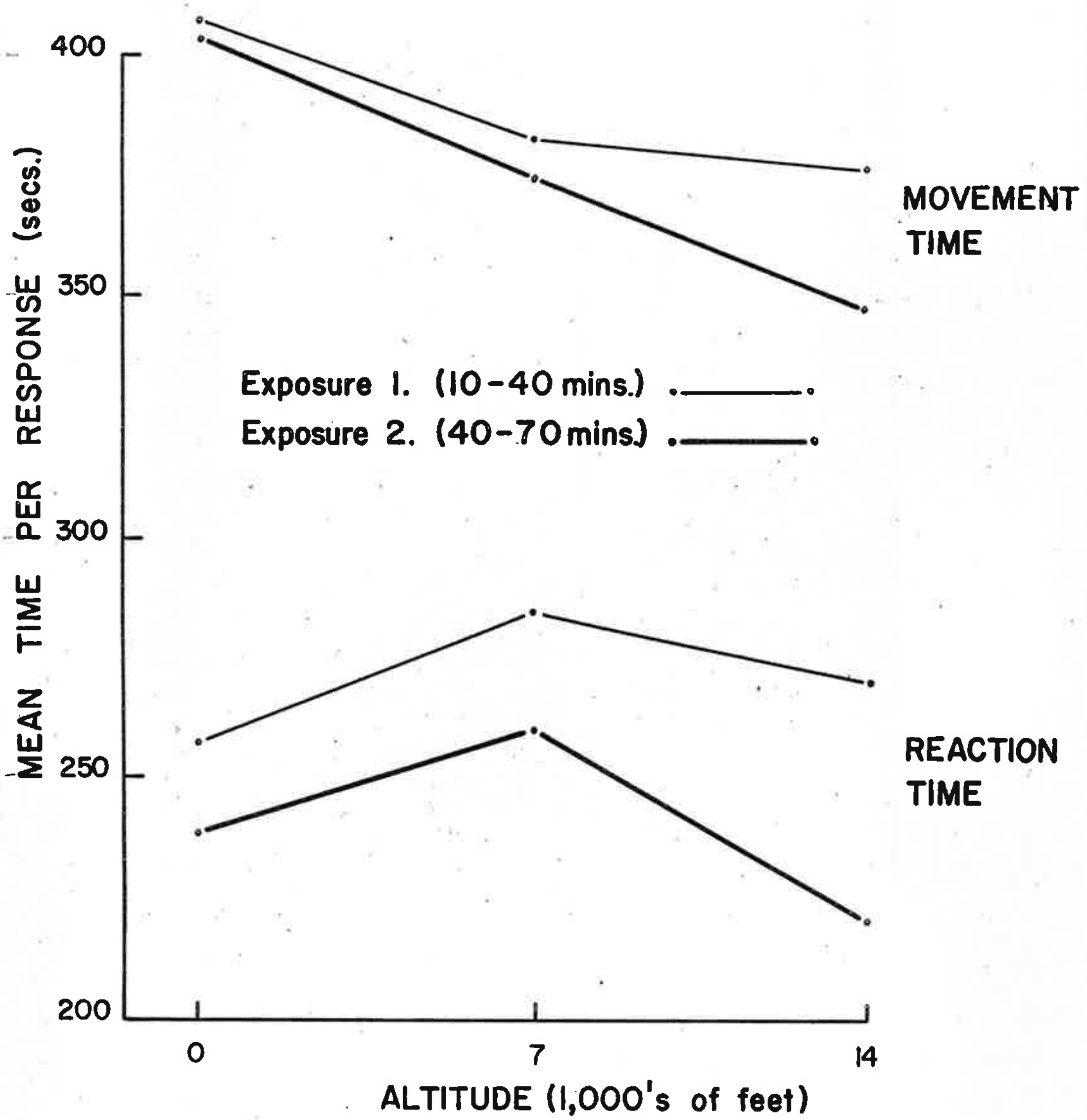
MEAN CHOICE RT IN SECS. AT 2 AND 8 CHOICES AND 2 WIDTHS OF TARGET IN YOUNGER AND OLDER SUBJECTS. ALL LEVELS OF HYPOXIA COMBINED

	Choice		Target Width	
	2	8	0.5"	0.25"
Younger Subjects (18-21 yrs.)	0.216	0.265	0.247	0.235
Older Subjects (21 yrs. +)	0.257	0.278	0.264	0.271

There is an increase in reaction time for older subjects with a narrower target though the younger subjects are, if anything, quicker to initiate response when faced with the narrower target.

Analysis of the effects of length of exposure in relation to hypoxia must be carried out with due caution. The groups are small within each cell of the 2 x 3 levels of altitude and, within each, age effects will only be partially balanced. However in view of the importance of this time variable shown in a later experiment results are analysed this way by analysis of covariance with adjustment for differences in simple reaction time. Figure 3.3

FIG. 3. 3.

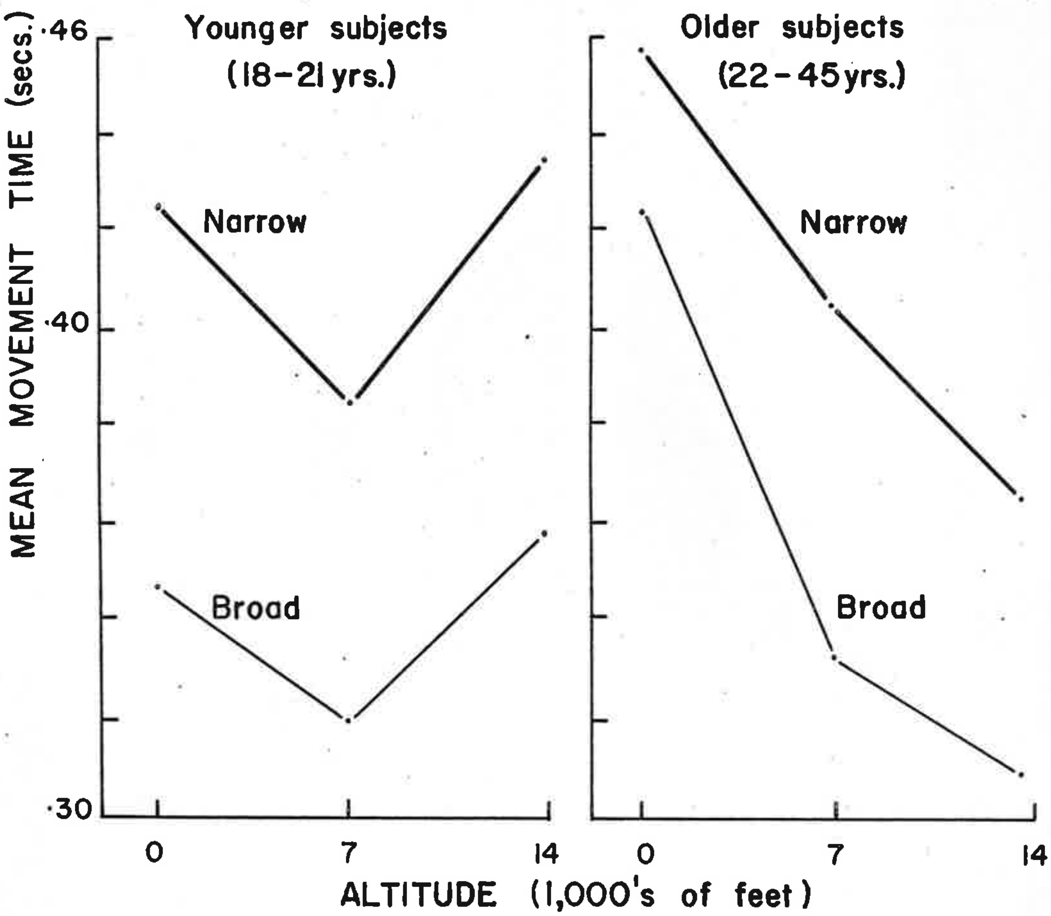


Experiment B. Reaction time and movement time. Mean time per response at 3 levels of pressure at 3 levels of pressure and two lengths of exposure. Time corrected for by pre-test covariate (N=5 ± 1) shows the corrected mean per response for each pressure level for time 1 (10-40 minutes exposure) and time 2 (40-70 minutes exposure). The quadratic component appeared in both but there is some difference in linear trend between the groups. At time 1 the group at 14,000 ft. were slower than the group at ground level but at time 2 the reverse is true. However the overall interaction test shows an F of 1.69 which with 2 and 23 degrees of freedom falls well within chance expectancy.

Movement Time.

Figure 3.4 shows the mean movement time per age group corrected for difference in movement time in the pretest. The major overall component of trend is linear (see table A.3.7) with a decrease in movement time with increasing hypoxia. Figure 3.2 shows the interaction of hypoxia with age ($p < .05$). In the younger subjects ground level and 14,000 ft. produce virtually identical movement times with the 7,000 ft. group being faster than either. For the difference in linear trend in the two age groups $p < .05$, but there is no evidence of a difference in quadratic trend. It is to be noted that the older group are slightly slower than the younger group at ground level and 7,000 ft. as is to be expected but at 14,000 ft. they are very much quicker.

FIG. 3. 4.

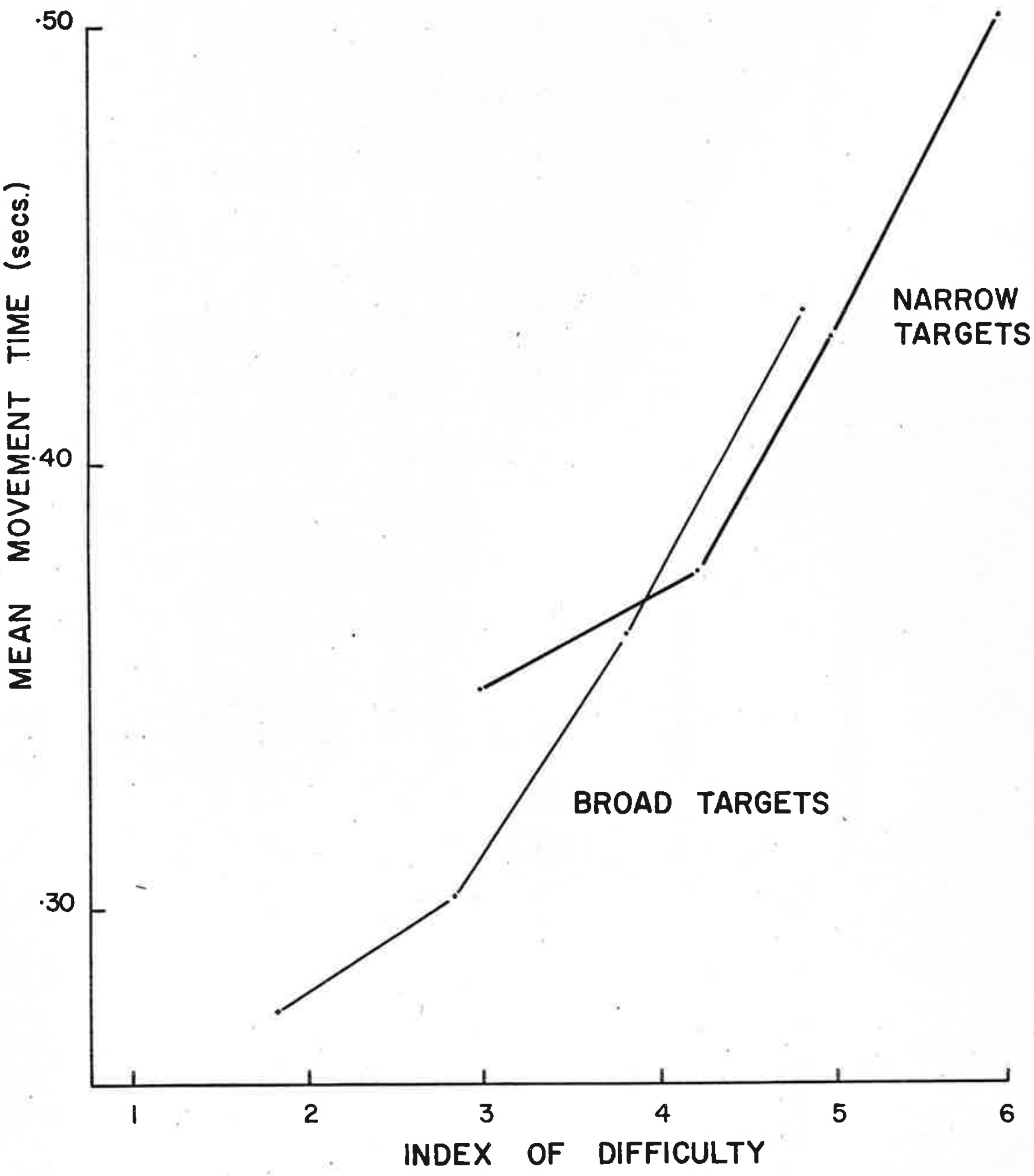


Experiment B. Movement time. The interaction of width of target with the 2 age groups at 3 levels of altitude.

For the within group comparison of the effects of hypoxia on movements at various levels of difficulty times were combined across right and left symmetrical keys at two levels of choice. Table A.3.9 shows the results of this analysis. There is a significant effect of width of target with hypoxia in conjunction with age. Figure 3.4 shows this complex effect: in the older group the linear decrease in movement time with hypoxia is greater in the task with the broader target. In the younger group there is no such interaction of broad and narrow and hypoxia. The interaction of width x distance x hypoxia (B x D x H) indicates that it is not possible to analyse distance and width as equivalent variables to be combined in the single scale for an informational analysis. Over all groups movement times are approximately related to the information measure of the index of difficulty though distance and target width are not exactly equivalent (Figure 3.5). Marked deviations from linearity are found in some groups especially in the keys closest to the start button (Figure 3.6). Hence it would not be warranted to perform an analysis of differences in slope relating indexes of difficulty to the various levels of hypoxia.

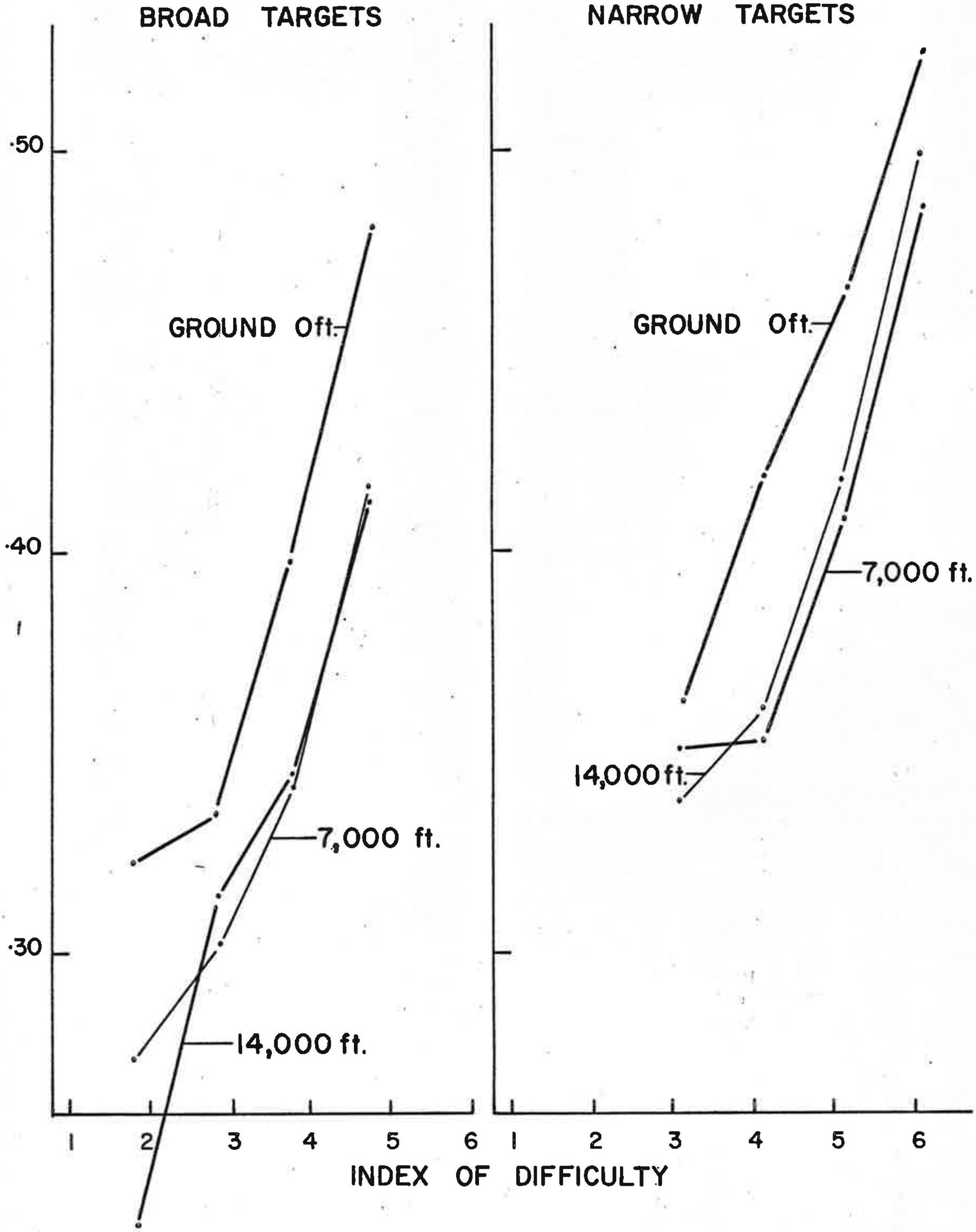
As in RT an analysis of variation in the effects of hypoxia with change in exposure time can only be carried out with due caution. Figure 3.3 shows the mean time per movement with shorter or longer exposures. The overall decrease in movement time

FIG. 3. 5.



Experiment B. The effect of target width and distance on movement time. All 30 subjects combined.

FIG. 3. 6.



Experiment B. The influence of target width and distance on movement times at 3 level of altitude (N=10) with increasing altitude is much greater in the group tested after 40 minutes exposure than after ten minutes to 14,000 ft. Analysis of covariance with correction for simple movement time in the pretest gives an overall F for interaction of 3.81 which with 2 and 23 degrees of freedom has a probability of less than 5%.

Discussion.

The overall trend of reaction time is U-shaped as was found in experiment A but in that experiment the total time to cancel 20 keys was recorded and this of course includes reaction time and movement time. Here the movement time itself shows effects which are even more unexpected: there is an overall steady decrease in movement time with increasing hypoxia, an effect which is shown much more strongly in the older group.

In experiment A the tasks involved much longer times and more "mental work" than in experiment B. In this latter experiment the reaction times are a minor component of the total response time (not much more than a third of the total time). It would be reasonable to assume that with the greater complexity of translation and hence longer reaction times of experiment A the movement time would be a minor component of the total response which would therefore reflect primarily the effects of hypoxia on reaction time. If this is so it would seem that the paradoxical effects of hypoxia on reaction time must be the same over a wide range of tasks from the simple pressing of a key as soon as a light appears to tasks where detecting which light came on would be a small component compared with finding the number, doing the arithmatic computation and finding the resultant number in front of a key.

The greater effects of hypoxia on older subjects probably does not reflect the interaction of age and hypoxia alone. The older subjects were generally not university students whereas most of the young ones were. Hence there would be many differences between the two age groups. Moreover in experiment A no such effect was noted where older and younger subjects were not differentiated by testing experience. Hence it is probably misleading to graph out the effects of hypoxia in relation to "age". The essential difference may not be age at all but unless one knows what is the crucial difference no other label is immediately available.

Welford (1962) in organising the data from aging in relation to variation in number of choices, suggests that an increase in slope with age will be found only where the stimulus is brief. If the stimulus remains until the response is completed no change in slope is likely to be found with age. This latter condition occurred in this experiment and here too no increase in slope is found. The effects of choice and age not only show no increase in slope but even a decrease in the older group. Though similar to Crossman and Szafran (1956) the similarity may be spurious as the similarity here is probably not the pure age variable.

In the initial analysis, the effects of time of exposure were looked at but passed over as non-significant in RT. In the movement time the results seemed extremely strange with greater decrease in movement time with hypoxia after the longer exposure. However the results obtained became more comprehensible in the light of later evidence which suggested greater impairment after 10 minutes hypoxia than after 40 minutes.

Experiment C.

Evidence from experiments A & B suggested that in the light cancelling task there was a reversible effect of hypoxia such that subjects at 5,000 - 10,000 ft. were slower than at ground level but that subjects at 14,000 ft. or 15,000 ft. showed much less impairment. This effect seemed true of tasks involving a direct relationship of lights to a key immediately beneath them. It was equally true in responses involving complex spatial and numerical translations between light and key. This reversible effect with hypoxia seemed to be a function of the time taken to initiate the response whereas the time taken to move and cancel the key was affected quite differently by hypoxia. Furthermore there seemed to be some effect of time of exposure: the effects of hypoxia seemed not to be identical when testing commenced after ten minutes exposure as compared with after forty minutes exposure.

The R.A.A.F. consented to provide chamber operators to run the decompression chamber at Adelaide for one final experiment using human subjects. Until about a week before the experiment began it was not clear how long the facilities would be available nor how many subjects would be available for testing. Accordingly an experiment was designed to retest, with little variation, the effects of hypoxia on reaction time and movement time since the results obtained previously fitted none of the available literature. Rather than try something radically new a retest of previous work would be of considerable value even if, as seemed likely at one time, only ten or twelve subjects could be tested.

In fact 30 subjects were tested. They were volunteer first year psychology students of the University of Adelaide. There were sixteen males and fourteen females. With one exception (aged 26) ages ranged from 18 to 21 years. The same procedure was used as in experiment B. Subjects were tested in pairs. They were given a pretest at ground level on simple reaction time and movement time and on digit span for the dichotic listening task. After a test for the equilibration of pressure in the inner ear, ascent was made to the predetermined pressure level for the run. Subjects were allotted at random to one of the 3 equal sized groups tested at ground level, 7,000 ft. or 14,000 ft. After ten minutes waiting subjects were tested on the reaction time task or dichotic listening task each of which took 30 minutes. The two subjects then changed over and each subject was tested on the other task. After seventy minutes the session was concluded. The reaction time task was run by a research assistant. Subjects were given printed instructions on the tasks and times for each reaction time and movement time were recorded by the assistant who also changed the light stimuli and marker cards for the light box and the key box.

The Task.

The same apparatus was used as in experiment A. The light box with 10 lights was placed immediately behind the key box which also contained 10 keys. A morse key was placed immediately in front of the light box and beside it a warning light. When the warning light came on subjects had to place their hand on the morse key and hold it down. A second later one of the lights came on and subjects had to release the starting button and press the correct key for the light which came on. After a short pause (during which times were recorded and the apparatus set for the next light) another warning signal was given and another light came on.

There were three types of relationship of light and key used.

1. The key to be pressed was directly under the light which came on.

2. Each light had a number 0-9 under it with lights numbered randomly. Each key also had a number 0-9 in a different order and subjects had to press the key with the same number as the light which came on.

3. Each light had a nonsense shape of a black outline on white ground. The shapes were selected from a group of 4-pointed shapes in Sidowski (1966) page 374. Care was taken to ensure that none of the shapes used could readily be associated with any verbal label.

Hence task 1 was similar to task 1 in experiment A though here reaction time and movement time were recorded separately. Tasks 2 & 3 were similar to those used in experiment A but here there was no computation involved. The basic difference between the conditions 2 and 3 was that in one case (the number) the symbol required to be found by search on the keys was readily stored in verbal terms whereas in the other case no such verbal coding could be used. The question to be examined was whether short term retention would be markedly poorer during the search process in cases where the material to be stored was not readily assigned to familiar categories. Birren & Riegl in Tibbits and Donahue (1962) found that in the latter case the effects of aging were particularly marked.

The three tasks were each given twice in the order task 1, 2, 3, 2, 3, 1. Within each test of each condition reaction time and movement time were recorded to 20 discrete responses, two to each of the ten lights with each light tested once in one random order and then again in another random order. With two repeats of three tasks and with two repeats of ten responses within each task record was made of 120 responses per subject.

Subjects were told to press the appropriate key as soon as a light came on. If they asked if the aim was speed they were told that the times taken were recorded but that they should respond as they felt inclined. Some subjects asked, in the two more difficult tasks, whether they should keep their hand on the start button until they found the correct key or whether they could move their hand as they started to search. Again a non-commital reply was given and subjects were told to act whichever way seemed natural to them. As in previous experiments only one key would turn out any one light and hence subjects were forced to be correct in their choice and any incorrect choice would not decrease the time taken.

Results.

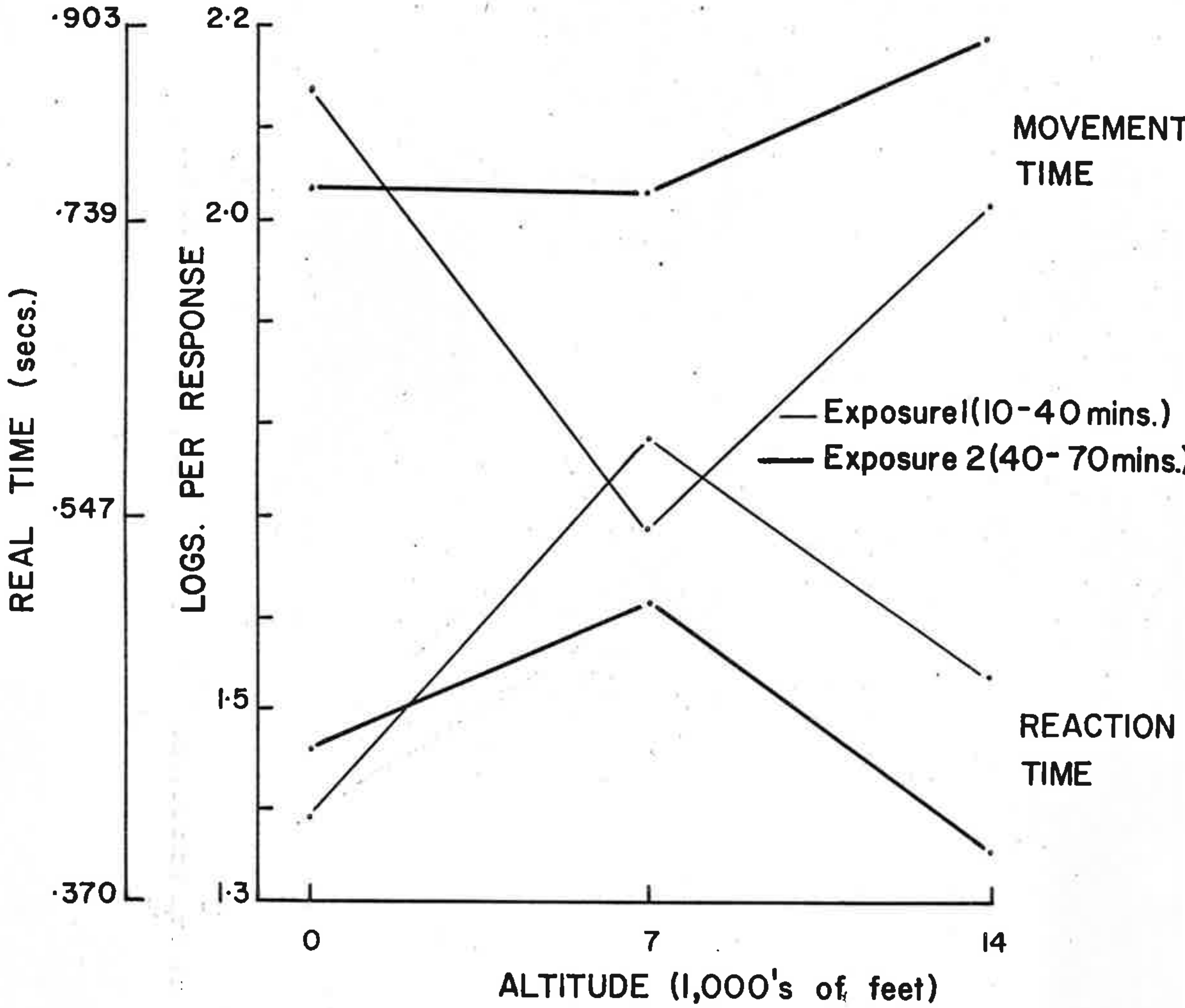
The times taken for both reaction time and movement time varied greatly within groups. As in experiment A the variability between subjects was much greater in the tasks taking the longer time. To equalise the variances each individual value of response time was converted to natural logs.

Reaction Time.

Analysis was carried out for a total of 120 responses (transformed to logs.) at three levels of pressure with two durations of exposure. Results were corrected for the difference in the total of 15 reaction time responses taken in the pretest. The corrected means (Figure 3.7) show once again an inverted U-shaped curve as in experiments A & B. Statistical analysis of covariance shows that the U-shaped (quadratic) component has a probability of less than 5% (Table A.3.10). In the interaction, the only component of trend (though of high probability by chance) is in the differences in linear trend: at the first interval the 14,000 ft. group are slower than ground but at time 2 the reverse is true.

The analysis of within and between groups of the effects of tasks, repetitions of tasks and keys shows a very simple picture with little interaction with hypoxia (Table A.3.11). Such a complex analysis must be used with caution. Where effects and their interactions are 9, 18 and even 36 degrees of freedom for the sum of squares for

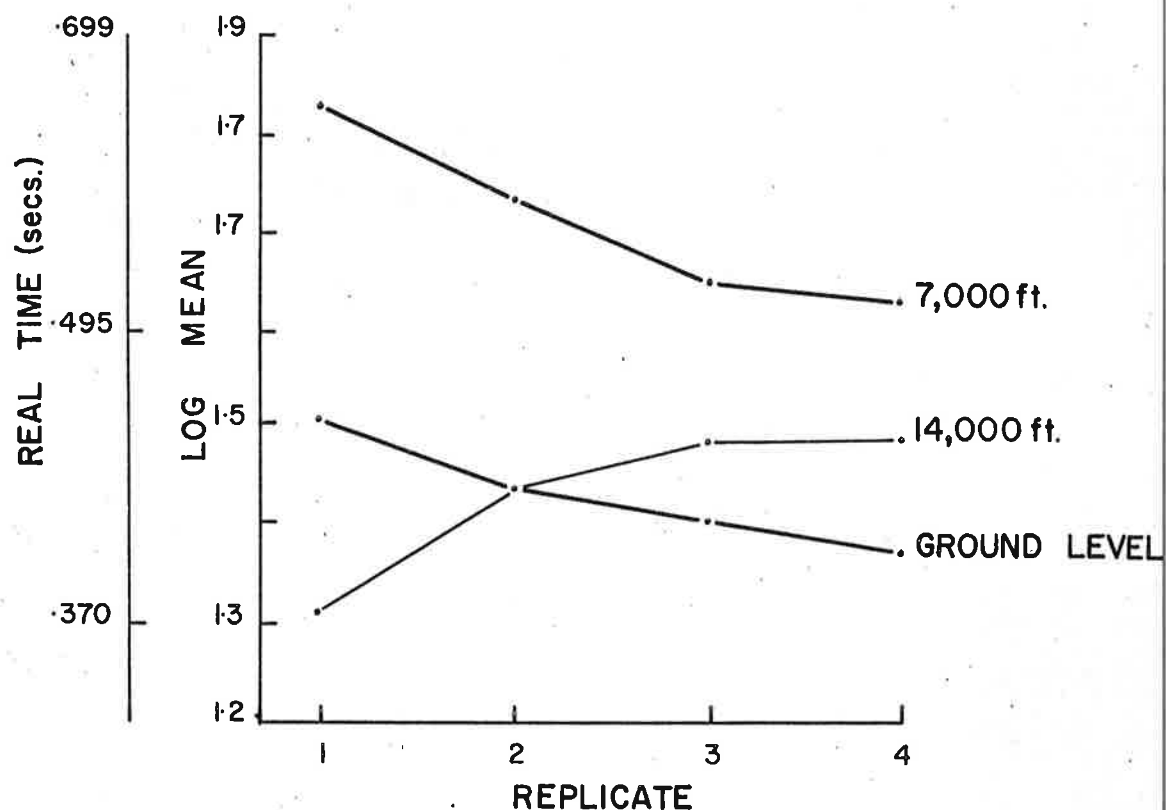
FIG. 3. 7.



Experiment C. Reaction time and movement time. Mean response for 3 levels of pressure at 2 duration of exposures. Scores in natural logs and corrected for pre-test covariates. (N = 5) treatment, the resultant mean square for the F test is the variance of all possible pairs of totals. A simple linear or quadratic effect which is clearly apparent on a graph and is meaningful and reliable may be part of an overall F ratio not much above unity. Thus overall F tests with low ratios cannot be dismissed as being of no account on this basis alone. It is necessary to graph out the results to ascertain that no consistent and simple effects are present if there is any reason to suspect that such effects might occur.

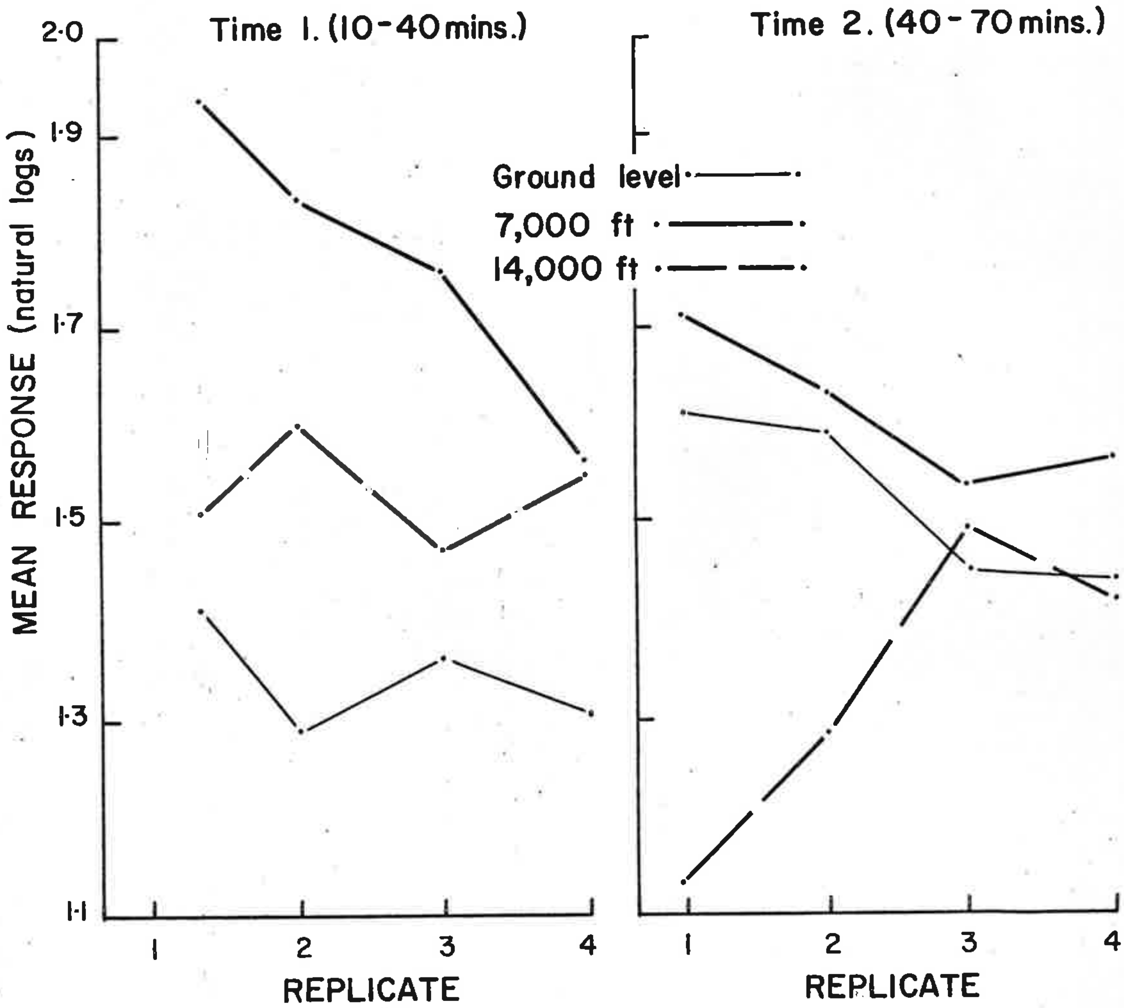
One effect which does stand out from the analysis is the interaction of hypoxia with repeated testing. This has a probability of less than 1%. Figure 3.8 shows this effect: the 14,000 ft. group gets slower with repeated testing whereas the other two groups show the normal pattern of consistent increase in speed with practice. If anything those tested after 40 minutes exposure show this effect more strongly than after 10 minutes though the overall F is 1.35 and nonsignificant (Fig. 3.9). The only other interaction of any magnitude in relation to hypoxia is keys by hypoxia though its probability is about 25%. The graph of the effect shows no coherent trend. If anything the difference lies in the fact that the 7,000 ft. group varied less from key to key in their reaction time.

FIG. 3. 8.



Experiment C. Mean reaction time for 4 replicates of the same task at 3 levels of pressure. Scores transformed to natural logs. (N = 10)

FIG. 3. 9.



Experiment C. Mean reaction time for 4 replicates of the same task at 3 levels of pressure at 2 time of exposure. Scores transformed to natural logs (N=5)

Movement Time.

The overall movement times (transformed to logs.) show an overall U-shaped component which is in the reverse direction to the reaction time (Figure 3.7). In the analysis of covariance with the adjustment for movement time in the simple reaction time pretest (Table A.3.10), the quadratic component has a probability of approximately 2% and the difference in quadratic trends has a probability of less than 1%. The corrected means (3.7) show what this effect is: the reduction in movement time at intermediate altitude is much greater in those subjects tested after ten minutes exposure. At time 1 the 14,000 ft. group are quicker than those at ground level. At time 2 the reverse is true though the difference in linear trend has an F ratio of little more than 1.0.

In the analysis of the effects of the three tasks four repetitions and ten keys there is little sizeable interactions of these variables with hypoxia (Table A.3.12). However the effects of keys seem somehow linked to hypoxia. The keys x hypoxia interaction has a probability of about 25%, and keys x hypoxia by exposure time has a probability of about 10%. Naturally in task 1 the movement times could be expected to be relatively pure measures of the time taken to move. In tasks 2 & 3 times recorded might involve some search time. Hence the interaction of keys x hypoxia x time with tasks is of interest here too and it should be noted that its probability is less than 10%. When the results are laid out the amount of information to be handled is very large. In general no simple picture emerges: the differences between groups are not uniform over the keys. For example on task 3 key 10 (which many found a very difficult shape to recognise) produces a much bigger difference between groups than any other key in that condition. It might be suggested that the differences between groups were greater on keys to the right of the start button (6-10) than on keys to the left (1-5) but in all there is little coherent difference by different keys.

Discussion.

The effects of hypoxia on reaction time are very similar to those seen in experiments A and B and the effect is similar for all three tasks. The quadratic trend attains a fair degree of statistical significance but this would be regarded as of lesser weight than the repeated finding of the same functional relationship in three experiments using tasks requiring serial and discrete responses of widely differing complexity. As in experiment 1 the raw scores were transformed to logs. and no interaction was found with hypoxia for the tasks varying in time taken from 0.5 to 4.0 or 5.0 secs. This indicates that whatever changes took place as a result of hypoxia, the changes were proportional to the time taken in the control group.

The interaction of hypoxia with time of exposure in reaction time is remarkably similar to that seen in experiment B though in neither case is the difference anything near statistical significance. In both experiments the quadratic trend is similar in those tested for 30 mins. after 10 mins. exposure and those tested after 40 mins. exposure. However in both the experiments at time 1 the 14,000 ft. group is slower and at time 2 they are quicker than the ground level control.

The finding that the 14,000 ft. group became slower through the 30 minutes of testing is more extraordinary than the repeated finding of the reversible trend of hypoxia. The reliability of this effect for this group of subjects seems beyond question. Nonetheless it is strange that it did not occur in the two previous experiments. In experiment A testing was carried out in a similar way with each of three tasks tested once then the three tasks given again in another order and then again. No such effect was discernible: all the groups improved with repeated testing to a similar degree. Though it was true that the 15,000 ft. group improved less than any other group the difference was very small. The testing only lasted ten minutes whereas in experiment C it lasted 30 minutes, but even over replicates 1 - 2 in experiment C (the first 15 minutes) the effect is still seen. In experiment B testing lasted 30 minutes but the design was such that any replicates of a single task combination of choice and width of key took place within a single cell. That is the same conditions were never given at widely different points of time. However over a group there might be some time effects discernible as the various tasks were balanced over groups. No such effect was discernible and hence the effect in experiment C stands on its own. The results find no backing in the literature. The crucial finding by Ledwith & Denison (1964) was that in hypoxia subjects improve more rapidly than controls so that marked difference in the reaction time at the outset between ground and 8,000 ft. had virtually disappeared at the end of 10 minutes testing. It is true that the altitude at which this effect was seen here was 14,000 ft. but there is no more comparable evidence in the literature to add.

The effects of hypoxia on movement time (a U-shaped effect) are very similar to those shown in the younger subjects of experiment B. However the similarity may be spurious as the results should not be expected to be similar. Task 1 was very similar to the tasks used in experiment B but in tasks 2 & 3 subjects were free to continue searching for the correct key after removing their hand from the start key. The fact that hypoxia had the same effect on all three tasks and hence showed the same effects overall as the young subjects in experiment B seems odd enough to be fortuitous. This of course leaves aside the question of why, in experiment B, younger subjects showed a quadratic trend whilst older subjects showed a steady decrease in movement time with increasing hypoxia.

Times are shorter at 14,000 ft. than at ground level in time 1 but at time 2 the reverse is the case. In experiment B in both cases times were shorter at 14,000 ft., but the difference at time 2 was even more marked to the advantage of the 14,000 ft. group. So in experiment B the 14,000 ft. group were comparatively much better at time 2, whereas in experiment C they were comparatively much worse.

In summarising the results of movement time in experiment C it seems reasonable to conclude that movement times are merely a reflection of some coherent and consistent changes in reaction time such that with increase in reaction time the movement time is decreased. No reason can be offered to suggest why this seems to be the case in experiment C whereas in experiment B movement times changed relatively independently of changes in the reaction time in the different groups. Certainly it is true that in both experiments similar effects were shown in the young subjects but why they should produce different results in the older subjects is not readily explicable.

General Conclusions.

The general conclusion from all these experiments is that the time taken to initiate a response varies in an inverted U-shape from ground level to 15,000 ft. Clearly the reversible trend above 7,000 ft. to 10,000 ft. involves some compensatory mechanism. The effects of exposure time on reaction time and movement time in experiment B and on reaction time in experiment C would lead one to argue that this compensation was more effective after 40 minutes exposure to 14,000 ft. than after 10 minutes. Further the reversal in trend in reaction time had associated with it a reduction in movement time which was more marked when the reversal effect on reaction time was more marked. Discussion of the possible nature of this compensatory effect will be carried on later where an attempt will also be made to suggest why the effects observed here are quite at odds with the published literature.

There is, however, one point of general interest relating to studies in changes in reaction time with hypoxia. Poulton (1966) has argued that with sensitive experimental designs which are appropriate to the stress under consideration, significant impairment will be found at much lower levels of stress than previously had been shown. He uses as one of his examples Ledwith & Denison (1964) on the effects of hypoxia where impairment is found at 8,000 ft. compared with ground level. On initial testing the reaction time at 8,000 ft. was 3.3 secs. whereas at ground level it was about 1.7 secs. However from the results obtained from the experiments reported in this chapter one might add that if the sensitive design revealed impairment at lower levels of stress it does not follow that one can generalise to higher levels of stress on the basis of previous evidence using insensitive designs. If impairment is found at 8,000 ft. it can not necessarily be assumed that above this point the impairment gets progressively worse. In the experiments reported here there was marked impairment at 5,000 - 10,000 ft. but above this level performance did not continue to deteriorate.

CHAPTER IV

INFORMATION REDUCTION

In Chapter III examination was made of the effects of hypoxia on the performance of tasks with varying degrees of complexity of relationship between stimulus and response. Starting with the simple base-line of a light placed directly in front of a key the spatial relationship was complicated by having the light box 3 feet away and turned end to end. In the tasks where both light and key were identified by symbol, numbers or nonsense shapes were used and in one of the number tasks computation was involved in going from light number to key number.

These variations represented an attempt to vary the compatibility of stimulus and response, i.e. to vary the number and complexity of the steps between input and output. Welford (1958) has discussed this compatibility in relation to aging and discusses whether the number of steps was the crucial variable or whether the problem for older people was combining different sorts of translations in a single response. Prior to the commencement of experiment A of Chapter III, attempt had been made to make use of tasks which varied both in complexity, number and heterogeneity of the steps in a translation. It had been found that it was difficult to vary number and heterogeneity separately as translations involving two steps of the same kind soon became for the subjects a single step. Further there was a limit to the complexity of steps since if the complexity increased too much and the number of steps increased as well, the task became closer to problem solving where measuring time to respond might be a poor measure of adequacy of performance especially if subjects were unable to effect the correct translation.

The problem was, as often, to quantify the translation so as to effect systematic variation. Posner (1962) has dealt with this problem of quantification within the framework of application of information theory to activities of higher order than choice reaction time. He deals with that area of human activity where the subject is required to reduce the information in the input, not by filtering out information, but by coding all the available information. He argues that such information reduction is characteristic of many activities coming under the general heading of thinking. He suggests a quantitative relationship such that the greater amount of information reduction from input to output the greater the time taken to accomplish the task.

Reducing this hypothesis to experimental size he quotes a task used: eight digits each from 1 - 64 are read out. Subjects are required to reduce the 48 bits (6 bits for each of 8 digits) by varying amounts. In the simplest task the subject merely records the numbers. This gives 48 bits output hence zero information reduction. In the most complex task the subject adds up all the numbers. The answer is a single number containing 7.68 bits of information hence an information reduction of 40.32 bits. Posner (1962) quotes results which show with increasing speed of presentation (digits read at 1 every 4 secs. down to 1 every sec.) deterioration in performance is greater in the tasks involving the greatest information reduction. Also the relationship between percentage accuracy and information reduction is reasonably linear.

Posner's classification of "information reducing tasks" seems to include a wide range of activities which are regarded as cognitive. Further the tasks he outlines give a wide and quantifiable variation in mental work and require very little time to administer. It was decided therefore to test whether the tasks and procedures outlined are sufficiently sensitive to detect the changes produced by the mild levels of hypoxia used in these experiments. The test of the usefulness of the information reduction tasks was meant to be a short one added into experiment 4, the main aim of which was to attempt to confirm and amplify findings on tasks used in earlier experiments. Three information tasks were used with the intention of encompassing the whole range of information reduction from zero to maximum.

As in Posner (1962) 8 digits were read out each from 1 - 64. Task 1 required subjects to record each digit as it was read out, a task with zero information reduction. In task 2 subjects were required, as Posner (1962) says, "to add up each successive pair of digits" giving an information reduction of 21.5 bits. However "each successive pair" was taken to mean digits 1 & 2, 2 & 3, 3 & 4 etc. When the experiment was concluded the results for addition were found to be very much poorer than expected on the basis of Posner's results using American University Students. Examination of the scoring scale then revealed that Posner collected 4 responses per 8 digits, i.e. subjects gave the sum of digits 1 & 2, 3 & 4, 5 & 6 and 7 & 8. Hence the task used here is not directly comparable. Posner computes the information per sum of 2 digits of 6 bits to be 6.25 bits. Hence with 7 responses the output is 46.37 bits. The input of successive pairs of 6 bits each which gives 84 bits input in all. In Posner's terms the information reduction was 27.63 bits. This is not much more than Posner's 21.5 bits but the task used here involved simultaneous manipulation and storage of the same material which is a different order of task. Task 3 used here required the subjects to classify each number as an A or a B. A was a high number (33 or above) which was odd or a low number (32 or below) which was even. B was the opposite hence the information in the input (6 bits) was utilised in the production of 1 of 2 equally probable responses, a reduction of 5 bits per response and 40 bits per list of 8 responses. This task involved slightly less information reduction than a serial sum of all the digits which was not used as Posner had found difficulty in scoring this latter task.

The 8 digits 1 - 64 were played back at a rate of one every 2 secs. through a tape recorder which subjects listened to through head-phones. Subjects were asked to record their answers on an answer sheet provided. They were given printed instructions for each task before its first occurrence and were allowed to keep the instructions in front of them whilst doing the tasks. They were asked to try to write down the answers as the list was read and not to try to remember the numbers and write the answers after the reading was finished. Any such "cheating" was supervised by the experimenter and subjects were reminded if the instructions were not obeyed.

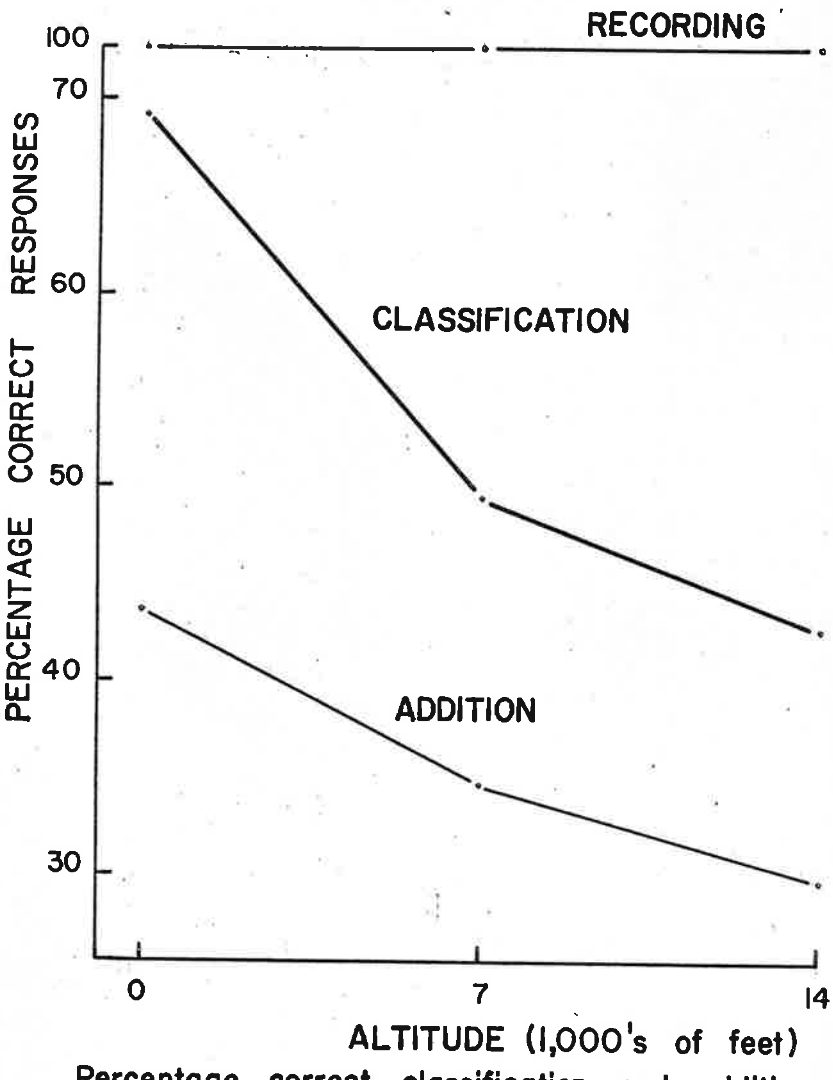
All subjects took the tasks in the same order (Tasks 1, 2, 3 then 2, 3, 1). In each presentation of each task 2 lists of 8 digits were read out, the lists being separated by a 15 secs. pause. The lists of digits were made up from random number tables. For the recording and addition tasks a measure was taken of the number of correct responses in each presentation of the task. For the classification task the same procedure was adopted as that by Posner (1962) of taking as a measure of accuracy the number of correct responses minus the number of incorrect. It is possible that the score obtained may reflect differences in readiness to write down answers when not sure but it is less contaminated by criterion differences than a simple measure of total correct.

The subjects were the same as those who took part in experiment C of Chapter II and experiment C of Chapter III. There were thirty student volunteers including 14 females. Ages ranged from 18 - 21 years with one exception aged 26. They were tested in pairs and assigned at random to one of three levels of pressure: ground level, 7,000 ft. and 14,000 ft. After ears testing, ascent to the pressure level set for the experiment and 10 minutes equilibration time, half the subjects were tested on two repetitions of the dichotic listening with information reduction tasks in between repetitions. They were then tested on the lights and keys task whilst the other subjects were tested in the reverse order of lights and keys first followed by dichotic listening and information reduction. This latter task took some 10 minutes to administer and was taken after the first 8 minutes of testing on dichotic listening which commenced after 10 minutes or 40 minutes of testing. Hence subjects were tested on information reduction for ten minutes starting at approximately 18 or 48 minutes after reaching the pressure set for the session.

Results.

The percentage correct responses on three tasks at three levels of hypoxia is shown in Figure 4.1. It can be seen that the simple recording task is unaffected whereas the classification and addition tasks decline in hypoxia. As almost all subjects attained 100% accuracy on the recording task but not on the other two it is obvious that analysis of variance cannot be carried out on all three tasks as the within task variances differ so widely. However analysis of the addition and classification tasks (Table A.3.13 of the Statistical Appendix) with two replicates of each task reveals that the overall trend in the effect of hypoxia is primarily linear and significant at the 1% level. There is little interaction of any effect with hypoxia. The major difference in trend of hypoxia in the two tasks is linear but it is not significant with an F of 2.3. If anything the easier task shows the greater decline in hypoxia. The subjects tested after 50 minutes generally perform better than those

FIG. 4. I.

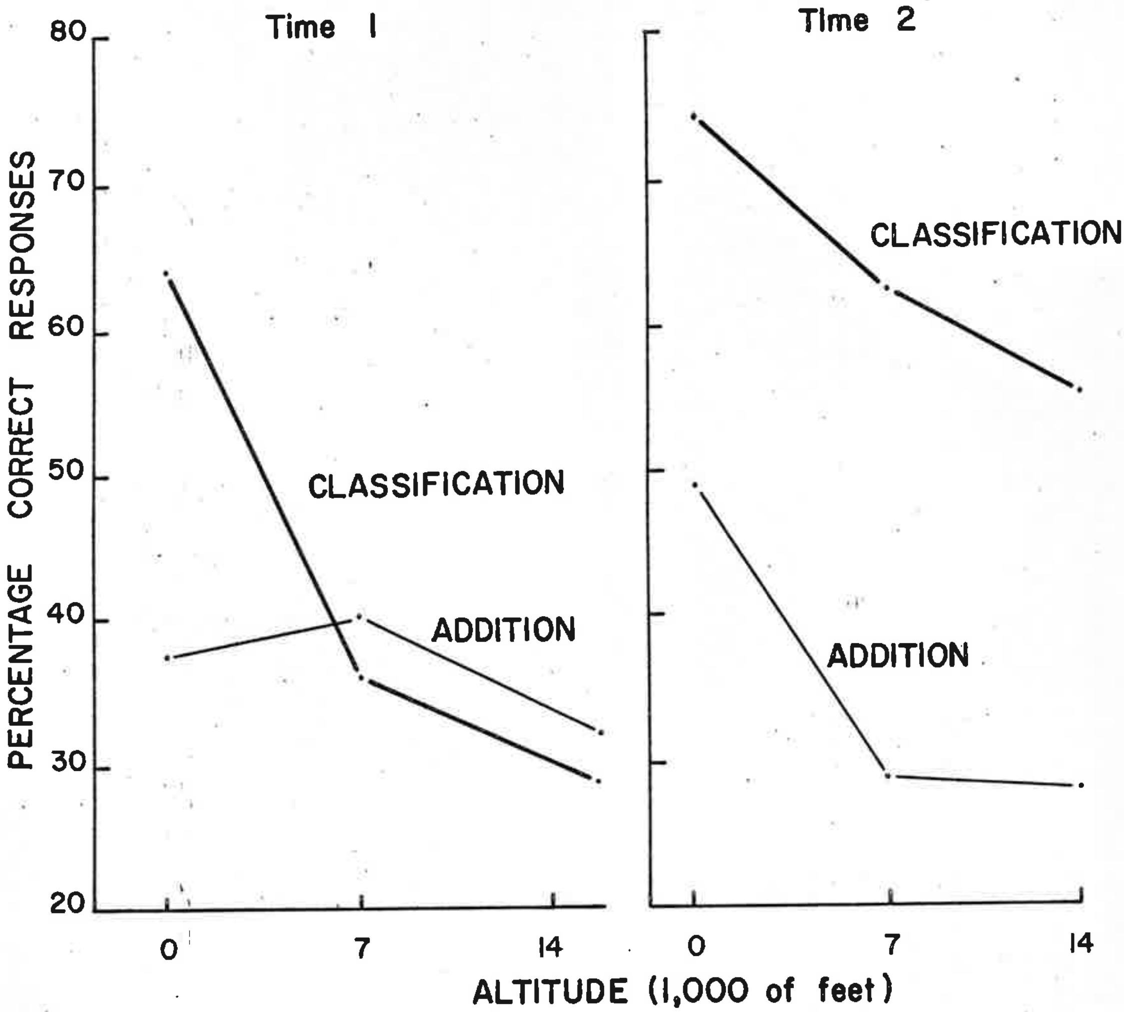


Percentage correct classification and addition tasks at 3 levels of pressure (N = 10) tested after 20 minutes exposure ($P < 10\%$) though the effect is more marked in the classification task ($P < 5\%$). There is no evidence of a difference in the overall effects of hypoxia at the two time intervals. Inspection of Figure 4.2 shows that the classification task declines more after an interval of testing, the reverse being true on the addition task. However differences in a linear trend have an F of 2.13 ($P > 10\%$).

Discussion.

It is obvious that the basic testing technique outlined by Posner (1962) provides a sensitive technique for studying the effects of hypoxia. The overall effect of hypoxia appears highly reliable certainly under the conditions of testing used in these experiments: 10 minutes actual testing time for each of 30 subjects showed clear cut deterioration under hypoxia. The technique offers ample scope for the systematic and quantitative variation in the mental work load involved. In this experiment the simplest possible task shows no deterioration in hypoxia whereas the two more difficult tasks did. The recording and classification tasks represent the two extremes of difficulty in the Posner (1962) tasks. Clearly more experimentation is needed with intermediate tasks to determine in what degree deterioration is related to the degree of difficulty and clearly such experimentation would be fruitful. It is unfor-

FIG. 4. 2.



Percentage correct classification and addition tasks 3 levels of pressure and 2 exposure times.

tunate that the addition task was by mistake not comparable to Posner's. Clearly a measure in information reduction is not a complete measure of the task difficulty in comparison to the classification task: the information in the input is higher and the task involved simultaneous storage and manipulation. Addition and classification tasks did not show any clear difference in the degree in impairment in hypoxia. If anything the more difficult task showed less impairment but it is probable that this is a function of the scale of measurement used. Where performance is measured in such a way that higher numbers represent poorer performance (for example mistakes) then typically one might find greater differences in hypoxia with higher levels of difficulty, as for example in reaction time. This may be a function of the scale used and is in no way necessarily a reflection of the basic processes. The same is probably true in the present experiment where the easier task and higher numbers show more variation in hypoxia.

The effects of time of exposure are equivocal though the same subject groups showed less hypoxic impairment after the longer exposure in dichotic listening and translation from stimulus to response. There is no overall evidence of reduced deterioration in hypoxia at time 2 though such an effect does show in the classification task but not in the addition. However on the basis of other evidence and the graphs here it would be fair to suggest that with more data a similar beneficial effect of longer exposure might well be demonstrated.

CHAPTER V

DISCRIMINATION AND CARD SORTING

Chapter III dealt with the effects of hypoxia on more or less complex translations from stimulus to response or choice reaction time. In these tasks the stimulus, a red light, was easily discriminable. Even in experiment C with translations involving numbers and shapes the symbols were clearly visible and the problem was to match the stimulus symbol or shape with an identical one near the response key. In this chapter examination is made of another aspect of sensori-motor performance, namely where variation is made in the discriminability of the stimulus. Crossman (1955) deals with the general problem of measuring the variation in the likeness or discriminability of stimuli which are well above threshold. In developing the model of the process of discrimination and its measurement a card sorting task is described where subjects have to sort packs of cards into two piles according to the number of dots on each card. Discrimination is varied by varying the absolute number of dots on the card and the ratio between the two denominations in any pack. To relate together absolute numbers of dots and their ratio Crossman proposes a measure which is the difference in the log. values of the two stimuli. Though the model of the process involved has been severely criticised by Hughes (1964) still the confusion function as Crossman calls it, does fit Crossman's data fairly well and has been independently validated in a number of situations (see McCoy (1963), Shallice & Vickers (1964)).

Crossman and Szafran (1956) used the card sorting task in testing the difference with age in four levels of discriminability. Normally with more difficult tasks older subjects show a greater or equal absolute deterioration (Welford 1962) but in this case the reverse was true: although the older subjects were slower overall in the more difficult task the difference between them and the young subjects was reduced. Botwinnick, Brinley & Robbin (1958) using a task involving the detection of which of two lines was shorter found a more normal picture of similar increases in the older subjects in more difficult discrimination tasks. The Crossman task was selected here because the effect described seems so unusual in the field of aging. If the same thing occurred under hypoxia then it would constitute a challenging finding. If it did not show under hypoxia then some explanation would have to be sought to explain the disparity in findings between hypoxia and aging in view of their similarity in many respects (Macfarland 1963). A further attraction of the method outlined was that it was easy to administer and required no apparatus beyond a stop watch and a few packs of specially prepared cards.

The Method.

The cards used by Crossman (1955) had three millimetre dots placed "at random" on the cards but varying in number from 1 to 18. Subjects were given a well shuffled pack containing 20 of two denominations. They were told to hold the pack face down in their left hand and turn them over one at a time and sort them into the two denominations as quickly as they could without making more than one or two mistakes per sorting task. In Crossman and Szafran (1956) little detail is given of the cards used or the procedure. A task involving sorting ordinary playing cards into 2, 4 or 8 categories was also used and here it is related that subjects were given 3 practice trials, three experimental trials under each condition and were told to work at top speed but not to make any errors. It is not clear whether the same number of trials were given or the same instructions used as to the avoidance of errors in the discrimination card sorting.

The procedure adopted in this experiment was based primarily on the fuller details for experimental procedure as outlined by Crossman (1955). Packs of ordinary playing cards without face markings were used and three millimetre diameter black dots were drawn on these placed at random over the card. Each card for each denomination had different arrangement of dots. Four packs of forty cards were made up using the denominations from Crossman and Szafran (1956): 1 versus 4, 6 v 12, 8 v 12 and 8 v 10 dots. In each pack there were equal numbers of each denomination. Subjects were told to sort the well shuffled pack into the two denominations as quickly as they could but to try not to make more than one or two mistakes per sorting. Times were recorded on a hand held stop watch to the nearest 0.2 sec. At the end of each sorting the experimenter checked for errors in full view of the subjects and this had the effect of keeping errors within the prescribed limits. Subjects were given each set of four tasks three times with order of presentation varied for each subject within each set. They were then given three tests on each task in turn with the order balanced across subjects. Within this final testing they were also given three tests of movement time alone. They were told to hold the cards face down, turn them over one at a time and place them alternately on each of two piles irrespective of the markings on the cards. Hence this measured the time taken to manipulate the cards without any discrimination.

Procedure and Subjects.

24 male student subjects used were also tested on dichotic listening (experiment A, Chapter II). The subjects were assigned at random to two equal sized groups at ground level or 13,000 ft. They were tested singly in the decompression chamber.

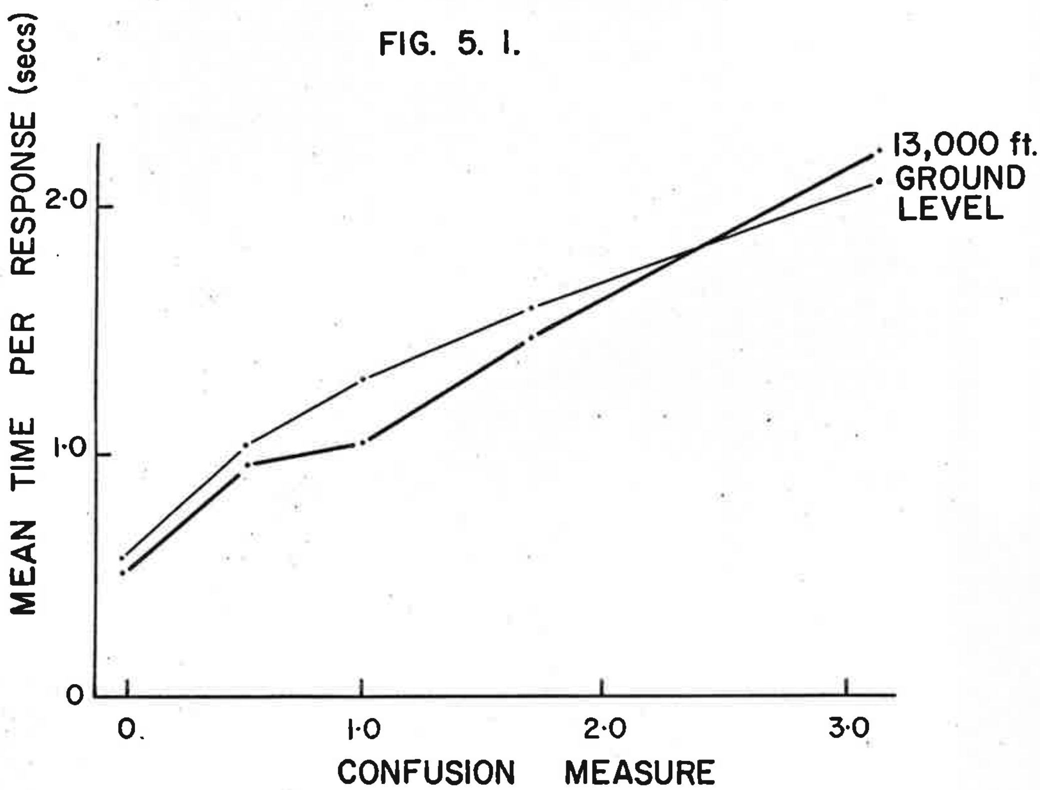
After a check for equilibration of pressure in the inner ear involving rapid ascent to 5,000 ft. and then descent, the pressure level for the experiment was set which took seven minutes. After a further ten minutes wait, testing commenced. Subjects were given two trials at each of the four sorting tasks which took approximately 20 minutes. They were then given the first dichotic listening task which took ten minutes. This was followed by one final practice at each of the four card sorting tests and then subjects were given three tests at each condition in turn. By this time subjects had been at altitude for 60 minutes and after a further ten minutes dichotic listening the session was concluded.

Results.

Few subjects made more than the stipulated 2 errors in the sorting of a pack of 40 cards and when errors were made subjects often corrected them in spite of instructions to the contrary and hence increased the total sorting time. As there is no systematic variation in errors related to group differences the effects of hypoxia have been analysed only in the terms of the time taken to sort each pack of cards.

There were four levels of task difficulty. The twelve subjects in each group had three attempts at each level of task difficulty and then three further trials at each level interspersed with three trials of movement time alone. Figure 5.1 shows the mean time taken per card in the final three runs for both discrimination and movement time tasks. Over-all the ground level group was slightly slower but at the most difficult task they were slightly quicker than the 13,000 ft. group. Analysis of variance on the data (Table A.3.14 of the Statistical Appendix) shows that the F test of difference is less than unity. Crossman's (1955) confusion function fits the variation in difficulty very closely but the difference in linear slope between the two groups is non-significant. Inspection of the within group variance reveals that the analysis of variance might not be very accurate in estimating probabilities. Of the total sum of squares for subjects within groups (13,308.24), the ground level group contributes 10,812.03 whilst the 13,000 ft. group contributes only 2,496.21. A variance within one group of four times the other would normally be an indication against the analysis of variance but here the difference between the groups is quite small anyway. Using a Mann-Whitney test U = 67 which has a probability far greater than 10%. The reason for variation in sums of squares can be seen from the difference in the range of scores within the two groups. At ground level sorting times per card over all four tasks range from 1.06 sec. to 2.05 secs. with seven subjects taking

FIG. 5. 1.



Experiment A. Movement time and discrimination card sorting Mean time per card for two levels of altitude (N=12) less than 1.45 secs. At 13,000 ft. the range was from 1.10 secs. to 1.68 secs. with only four subjects taking less than 1.45 secs. The variation between levels of difficulty across groups is much more homogenious with the variation being approximately twice as large in the ground level group. Hence the estimate of the reliability of the interaction effect is probably much more accurate. Statistical analysis of the differences in discrimination card sorting minus movement times shows much the same picture but no overall difference in interaction ($F = 1.24$). Analysis was performed of the first three trials at each level of difficulty as well as the mean for the last three trials and showed no variation with practice in the picture outlined above (see Table A.3.14).

Discussion.

The overall difference between the groups in sorting time is not great. Although the 13,000 ft. group was slightly quicker overall the ground level group contains rather more of the quicker sorters. It also contains two subjects who are by far and away the slowest sorters hence the higher variance at ground level. Apart from differences in speed of discrimination a major component affecting sorting times is the pace a subject sets in doing the task: some subjects fumble and snatch at the cards in their haste to finish while others sit and sort with no great air of haste about them. In the latter the sorting times were longer but this is not to say the discrimination time is any longer. Correction for differences in movement time is not satisfactory as the range of times taken is much smaller (0.45 secs. to 0.81 secs. per card) than in the card sorting task. Analysis of co-variance would correct the differences in range but clearly separate analysis of co-variance would be required for each level of task difficulty as their ranges differ so much.

The interaction of difficulty with hypoxia is contrary to that found by Crossman & Szafran (1956) where the older groups showed the flatter slope. However it is true to say that in both cases the group which was slower overall showed less increase in sorting times with increasing difficulty of discrimination. In this experiment subjects took about one second for the 1/4 sorting and 2.35 secs. for the 8/10 sorting. In Crossman & Szafran (1956) subjects aged 20-40 took .8 secs. for 1/4 and 1.0 secs. for 8/10. Hence the subjects used here were a little slower in the simple tasks but very much slower in the 8/10. This is in spite of the fact that instructions not to make more than two errors per sorting whilst in Crossman & Szafran (1956) it might be inferred that no errors were allowed. Clearly unless there is a vast difference in the amount of practice the subjects had in the two experiments, which is unlikely, there is a different order of magnitude in varying the levels of difficulty.

In view of the wide differences found between results for young subjects in the two experiments a study was conducted on differences by age in the discrimination card sorting using the materials of procedure as used for the hypoxia study. Results are reported in appendix 2. 10 young students and 10 older graduates were tested. Both the overall times and slopes were greater in the older subjects but neither difference attained statistical significance. When age differences were analysed in relation to sex, the older males were less affected by increasing difficulty than young males. In the females the reverse effect was noted. Thus the males showed effects like Crossman & Szafran (1956) but females showed the reverse effect to a much greater degree so that for males and females combined the overall effect was the opposite of Crossman & Szafran's results.

Although Crossman's confusion function fits the mean time very well, inspection of the individual results shows that some individuals do not fit the pattern at all. In at least two cases in the ground level group the 6/12 & 8/12 sorting times were longer than expected given the time taken to sort the 8/10 pack. In one case it was obvious that the reason for this was that the subject counted the dots and hence cards with more dots took longer to sort irrespective of the ratios involved. It is impossible to say how much this strategy was used but it certainly would give some reason for the wide individual differences found in the pattern of sorting times at various levels of difficulty. This wide range of individual differences was also found in the aging comparison mentioned and accounts for the lack of significance in the data where graphically there are marked differences.

Experiment B.

The conclusions drawn from experiment A were that if hypoxia had any effect on the discrimination task then it seemed to increase the difference in times between easy and difficult discriminations but also might produce quicker sorting times on the easy tasks. Unfortunately any differences between small groups at various levels of hypoxia were difficult to establish due to wide individual differences. Given that the number of subjects was limited the only solution seemed to be to try to reduce the individual differences by co-variate adjustment.

Although a short amount of prior practice may mask the deleterious effects of hypoxia (Ledwith & Denison 1964) it was decided to pretest subjects on card sorting prior to exposure to hypoxia as there seemed no other way available to establish the effects of hypoxia.

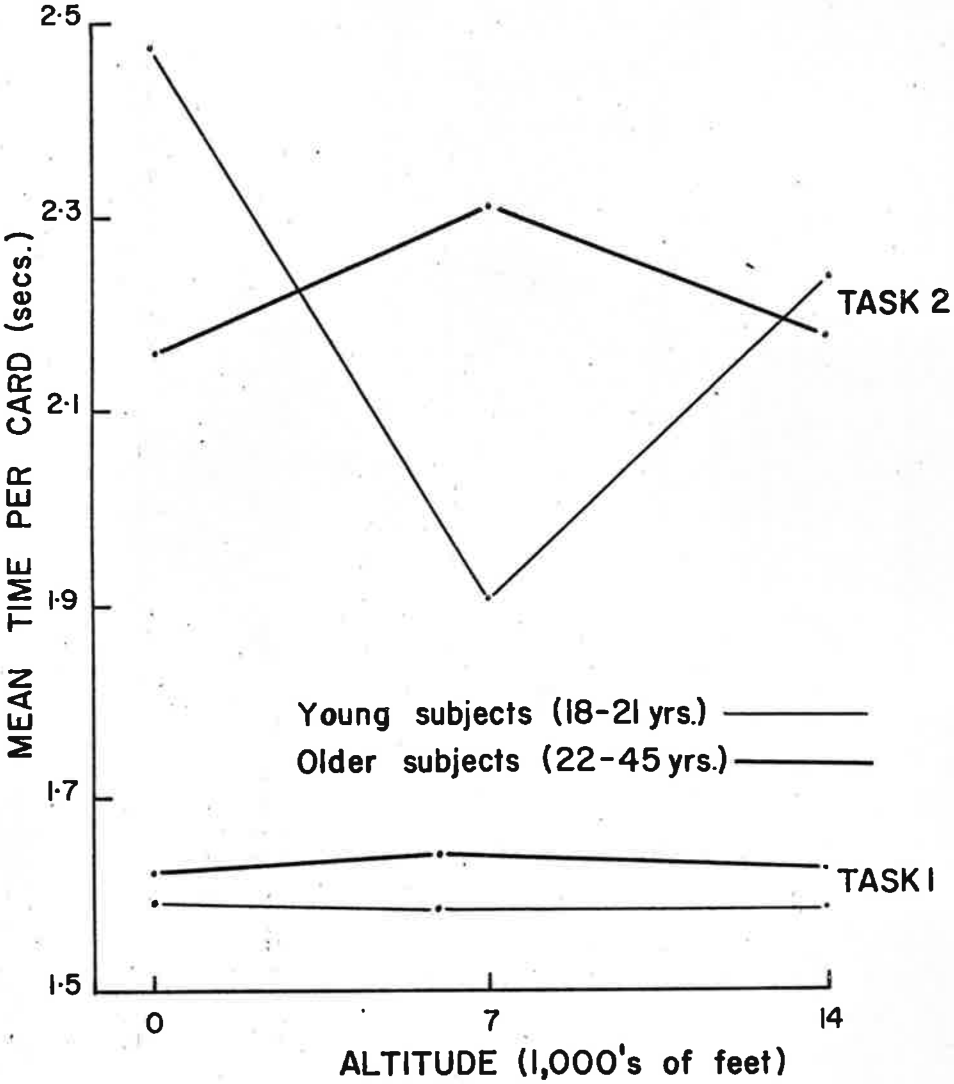
The subjects were 30 students and St. John Ambulance volunteers who also took part in the choice reaction time task of experiment B in Chapter III. Subjects were mostly tested in pairs and given one test of sorting one pack of 40 cards containing 1 and 4 dots and one pack containing 8 and 10 dots. In both packs there were equal numbers of each denomination. Order of presentation of packs was alternated between subjects in a single group. After a pretest on simple reaction time subjects were given an "ears run" then ascent was made to the pressure level set for the run which was either ground level, 7,000 ft. or 14,000 ft. equivalent. The ascent took 7 minutes and after a further 10 minutes testing commenced. Subjects were given 4 tests on each card sorting task (1/4, 8/10) with conditions alternated. This testing lasted some 25 minutes and was given either before or after the reaction time testing and hence was carried out between 10 and 40 minutes in the chamber or between 40 or 70 minutes of the testing session.

The same cards were used as in experiment 1 and the subjects were given similar instructions. They were told to sort the cards one at a time and to try not to make more than one or two mistakes per sorting. The testing was supervised by an experimental assistant who checked for errors, recorded sorting times on a stop watch and reshuffled the packs between sortings.

Results.

As in experiment A errors were almost invariably maintained to within the limits set of no more than two per sorting. Therefore analysis was carried out only on the times taken to sort the packs. There were three groups of 10 subjects each of whom took each of two tasks once in the pretest and then four times in the experimental session. Results in the experimental session were analysed by analysis of variance with co-variance adjustment for pretest times. In this way correction can be made for individual differences in overall time and the individual differences in the increase in time from 1/4 to 8/10. Each group was divided into older and younger subjects as it had been found on choice reaction time that age interacted with the effects of hypoxia. The within group variances were much more homogenious than in experiment A. The variance in the 7,000 ft. group was approximately twice that of the ground level or 14,000 ft. groups which were very similar. Overall very little difference is found between groups at different levels of hypoxia (see Table A.3.15). There is some sign of an interaction between hypoxia and age though the F ratio has a probability of somewhat more than 10%. Figure 5.2 shows this effect: in the younger group the 7,000 ft. group is the quickest whilst in the older subjects it is the slowest. This effect is not identical in

FIG. 5. 2.



Experiment B. Card sorting. Mean times per card at to levels of difficulty for 3 levels of Hypoxia at 2 age levels both tasks, the F ratio for task by hypoxia by age is 1.71 though the probability is not much less than 25%. Figure 5.2 shows this effect: the same interaction trend of hypoxia by age is shown in both tasks but the effect is much more pronounced in the more difficult condition. The effects of time of exposure were examined in relation to hypoxia by analysis of co-variance. It was found that the subjects tested between 40 and 70 minutes of exposure were quicker at sorting than those tested between 10 and 40 minutes as shown in Table 5.4. The F ratio was 14.5 which with 1 and 23 degrees of freedom ($P < .001$). This was the overall effect but the effect was greater in the more difficult task. The interaction F was 6.99 with 1 and 23 degrees of freedom P is less than .05. However the time effect seemed equally great in all groups as the interactions of hypoxia with time were negligible.

In this experiment a measure was taken in pretest and in the experiment proper on the same task and hence direct comparison of results can be made. It was found that at each level of altitude most subjects improved slightly from pretest to the first test in the chamber but overall there were 6 subjects whose first experimental run on the 8/10 task took 10 to 30 seconds longer than on the pretest. Of these six, two were at ground level, one at 7,000 ft. and 3 at 14,000 ft. All the subjects who showed this unusual effect were among those tested first at card sorting, that is between 10 and 40 minutes of exposure. Thus these few subjects contributed most if not all to the overall time effect found.

Discussion.

The results of experiment B did not agree very closely with the fairly small differences observed in experiment A. In the older subjects where hypoxia showed any effect (at 7,000 ft.) there was a slightly steeper slope from 1/4 to 8/10 than at ground level or 14,000 ft. However in the young group the overall trend was in the opposite direction such that at 7,000 ft. the slope was flattest. This effect was much more marked than that shown in the older subjects so the overall effect was: no difference between ground and 14,000 ft. but 7,000 ft. showing what differences there were between the pressure level and these, on the whole, contrary to experiment A. The pretest in experiment B might have served to mask any differences due to hypoxia but the task would appear not to be a procedure which produces reliable results.

The overall times taken were again slower than those reported by Crossman and Szafran (1956) and showed a greater increase in the more difficult condition. No differences in variability between subjects within a group was found between ground and 14,000 ft. though in experiment A the variance at 14,000 ft. was very much greater than at ground level. On the basis of the evidence from both experiments little can be concluded on the effects of hypoxia on this above threshold discrimination using card sorting. It might be suggested that the task is not very suitable for detecting what must be fairly small effects of hypoxia at the altitude used. As the subjects are self-paced the style or pace they adopt in response to uniform instructions may differ greatly and mask any experimental induced changes in discrimination alone. Clearly it is not just a question of the times taken to manipulate the cards since any differences reasonably attributable to experimental condition were shown more in the difficult tasks than in the easy tasks.

The most valuable information yielded by experiment B is that provided by comparison of pre-test and experimental performance in the same task. The increase in time taken noted in a few subjects indicates how performance may be changed by the very fact of being locked in a decompression chamber. The effects are quite striking since the author has tested some 80 subjects on card sorting where the conditions are the same from test 1 to test 2 and has never found any sign of increased time taken on test 2. Presumably the effects produced here are mediated by anxiety but there is no way of knowing whether the effects are specific to the particular task used or may have occurred undetected in other tasks described in this thesis. In experiment A of the translation processes the same light cancelling task was used in the pretest and in the experiment proper and here no such increase in time was found within the experimental situation. However this latter task is very much easier and very much more automatic and may be one where anxiety would not show any great changes. Hence all that can be concluded is that the anxiety produced by the testing situation seemed to affect this task and may have had an undetected effect on other complex tasks set to subjects in various experiments reported in this thesis. Thus the final interpretation of the results will have to be carried out with this possibility in mind.

SECTION 2.

STUDIES ON ANIMAL SUBJECTS.

CHAPTER VI

INTRODUCTION & EXPERIMENT 1

After completing several experiments on human subjects it seemed clear that on certain tasks performance impairment was found at lower levels of hypoxia than in any previous studies. However in the light-cancelling tasks there was some sign of a paradoxical effect at higher levels of hypoxia of a kind not previously reported. It was resolved to extend the research work to include some studies on rats to find if the same effects occurred. Rats were used as experimental subjects for convenience and economy as well as the fact that the appropriate behavioural testing techniques are well developed.

Surprisingly enough there is comparatively little work reported in the literature on the effects of hypoxia on the rat and the general psychological reviews of hypoxia deal with this aspect very little, if at all. Hurder (1951) distinguished between effects shown during exposure and after exposure to hypoxia. In this latter field there are a number of experiments on several species including rats. Jensen, Becker & Windle (1948) tested guinea pigs for retention of maze running ability where the maze contained blind alleys in which animals were shocked. Animals were tested after up to 250 hours exposure for 6 hours per day 6 days per week to an equivalent altitude of 30,000 ft. Examination was made for errors, perseveration and speed of running. In general retention was impaired in experimental animals and extensive histo-pathological damage of the CNS was found. Sola, Becker & Windle (1949) found no such effects on a similar task after exposure to 23,000 ft. for up to 400 hours and no histo-pathological damage was found. Becker & Windle (1944) and Becker & Donnell (1952) found guinea pigs asphixiated in utero were poorer in maze learning in adulthood especially on the more difficult task. Among the animals so treated no difference was found between animals that recovered naturally from the treatment and those that had to be resuscitated from asphyxia. Nielson, Zimmerman & Colliver (1963) using dogs as subjects tested performance in a T maze and the ability to walk along two widely spaced poles. Anoxia was induced by cerebral occlusion before or after initial learning of the task. The conclusion drawn was that hypoxia affected the learning of a skill which is resistant to deterioration if learned before hypoxia. Learning ability appeared to be more sensitive to disruption by hypoxia than psycho-motor performance which, it is noted, is a commonly used observational criteria of hypoxic impairment in animals.

Richardson (1954) asphyxiated rats in utero for the maximum time consonant with survival (20 minutes). Probability of survival was not related to exposure time within this period. Testing in adulthood on the Hebb-Williams open field test showed the previously asphyxiated rats to be inferior to controls and to improve less with successive testing.

Hurder (1951) exposed rats for 30 - 360 minutes to 30,000 ft. and tested the animals 7 weeks later on the learning of a multiple T maze. The longer exposure times created greater decrement in learning though in the severe conditions positive skewing of the distribution of the number of trials to criterion was found indicating that some few animals were comparatively unaffected. Bryant & Thompson (1957) gave rats 10 to 20 minutes exposure to 20,000 ft. or 10 minutes at 30,000 ft. and then tested them on the learning of a horizontal vertical discrimination. No after effects of hypoxia were detectable in any group. It should be noted that the exposure was brief and Hurder (1951) found marked impairment only after 3 hours at 30,000 ft. Meier et al. (1963) report a series of studies in cats and rats of the after effects of hypoxia in utero or at adulthood. Rats were exposed immediately after birth to 30 or 60 minutes decompression to 3% oxygen (40,000 ft.). Subsequent testing on the swimming of a T maze, acquisition of bar pressing in a Skinner Box and reversal learning in a T maze showed no effects of 30 minutes exposure and poorer learning at all tasks after 60 minutes exposure. The authors discussed their findings in relation to others where less effects of hypoxia have been found. They point to the influence on subsequent performance of the severity of hypoxia, the age of the animals and the species used. They further suggest that some animals may be little affected and so increase the within group variability in the experimental groups. In support of the age effects they quote the studies of Fazekas, Alexander & Himwich (1941) which showed that animals which are immature at birth survive hypoxia better than animals more mature at birth like guinea pigs. In fact rats at birth can survive hypoxia much better than adults but by 17 days of age their survival tolerance is no different from the adult.

In addition to studies on the irreversible damage to the CNS caused by hypoxia and the subsequent behavioural effects, work has been done on the retro-active effects of hypoxia. Thompson & Pryer (1956) and Thompson (1957) subjected animals to hypoxia immediately after attaining criterion in a horizontal/vertical discrimination. Retention was impaired by such treatment if given very shortly after learning and the effects were similar to electro-convulsive shock in similar circumstances. The reasons for these effects are not clear.

In ECS the explanation originally given was in terms of the disruption of the reverberating processes involved in the laying down of long term memory traces. Coons & Miller (1960) and Madsen & Mcgaugh (1961) have attempted to differentiate such anti-consolidation effects from the effects of an aversive stimulus which is contingent on the response. Hudspeth & Gerbrandt (1965) attempt to make sense of the data on ECS and suggest that their systematisation of the basis of disruptive effects could well be extended to hypoxia and anaesthesia which produce similar effects as ECS though the time courses are different.

Compared to the number of studies on the pro-active and retro-active effects of hypoxia there are few on the behavioral effects of hypoxia during actual exposure. Seitz and Keller (1940) used four 100 day old male white rats as subjects. These were given two days training on bar pressing in a Skinner Box with a food pellet given for each bar press when animals were 22 hours deprived of food. Animals were then given two days training on an interval schedule of 1 food pellet every four minutes and on the third day were tested at 17,500 ft. equivalent in an oxygen chamber with an atmosphere diluted with extra nitrogen. The rate of bar pressing was depressed in hypoxia. When animals were tested subsequently with a reinforcement for each bar press many of the food pellets were left uneaten suggesting that the reduction in bar pressing was a reflection of reduction in hunger drive. Shock & Scow (1942) also used a gas chamber for their studies. They tested 20 male 100 day old rats (5 albino and 15 hooded) on a variety of discrimination tasks involving a maze with 12 choice points. To motivate movement through the box the maze floor was filled with cold water and the maze brightly lit while the goal box was warm and dark. After 21 days training on a black-white discrimination in normal atmosphere animals were tested at 12% to 15% oxygen for 11 days. No increase in errors was found in reduced oxygen though with repeated testing running time was increased. 17 of the same animals were trained in a horizontal-vertical discrimination for 7 days in normal air and then the oxygen concentration was dropped to 15% on days 8-12. On days 13 & 14 it was dropped to 12% and on days 15, 16 & 17 to 9.5%. No increase in errors were found though running times increased steadily with severer hypoxia. Following this 15 of the same animals were trained at 7.5% to 9.5% oxygen on discrimination of upright versus inverted triangles. After 9 days testing no learning had occurred and running times were increasing steadily. Between 10 and 18 days of training animals were tested at ground level. Times and errors decreased. Animals were tested from 19 to 27 days in low oxygen and given a further 5 days in normal air. Times were greater in hypoxia and the running times were even more affected. Furthermore variability increased in conditions of low oxygen.

Weinstein (1965) reported the effects on carbon-dioxide escape on white mice exposed to hypoxia. Reductions in oxygen as low as 10% were associated with faster escape time though severer levels of hypoxia (as low as 6%) produced progressive slowing.

The literature reviewed would suggest that in hypoxia general activity and speed of movement were depressed and the acquisition of learned responses was more affected than the retention of them. Further, more complex learning tasks are more affected than simple ones. It would seem too that adult rats can tolerate a fairly severe degree of hypoxia without damage though the motivating effects of mild aversive stimuli or positive drives might be reduced.

The suggestion that acquisition is more affected than retention fits in with the results obtained by Ledwith & Denison (1964) using human subjects. This therefore seemed a useful line of enquiry and it was decided to use shuttle avoidance procedure outlined by Mowrer & Lamoureaux (1943). Here a rat is trained to avoid an electric shock by associating some stimulus with the imminence of the shock. The animal learns first to escape from the shock and then to associate this response with some warning signal. The motivation is a relatively mild electric shock and normally learning to criterion of 8 out of 10 successful avoidances is readily learned in 30 to 50 trials at most. It was decided to test the acquisition of the avoidance response in oxygen concentrations as low as 9% since from the literature and preliminary observation this was a level at which rats showed no great signs of respiratory or general distress and probably would not suffer any cumulative damage (Bryant & Thompson, 1957).

The Design.

24 rats were divided into 4 groups of 6 rats, matched on the basis of spontaneous activity in the experimental situation as explained below. Each group experienced one of 4 oxygen concentrations: 21% (normal air), 17%, 13% or 9%. One group was tested at the same concentration on 5 days, twice a week with 3 or 4 days interval between tests. Then all groups were tested once at 9% oxygen in an attempt to discover the degree of protection against hypoxic impairment afforded by prior training.

Apparatus.

The shuttle box had a grid floor and was 36" long by 6" wide by 18" high. It was divided into two 18" long compartments by a partition with a gap 2" high from the floor of the box. The whole box was painted white and on each end wall there was mounted a 24 volt 10 watt bulb, supplied by a 30 volt A.C. source. The grid floor was linked by way of a 4 relay shock scrambler to the secondary of a transformer giving 0.2MA current across a 10,000 ohm resistor.

The box was enclosed in a plastic bag, large enough for the box and 6 retaining cages 5" by 5" by 5". In these the rats were kept while waiting their turn in the experimental box. The oxygen concentration in the bag was varied by feeding in a gas mixture derived from two separate cylinders of nitrogen and oxygen. The flow from each cylinder was controlled by a flow meter making it possible to supply the gases in any desired proportion. The oxygen concentration was monitored by a Beckman oxygen analyser and checked on some runs with samples analysed on a mass spectrometer. Within the plastic bag 2 dishes of soda lime were placed in an attempt to keep the CO_2 concentration as low as possible. In fact it was found to be as high as 0.4% by the end of a 3 hour experimental run.

Procedure.

Pre-Training.

The rats were pretrained in the shuttle box in normal air prior to the experiment. Each rat was placed in the box and left there for 10 minutes, during which time note was made of the number of crossings made from one side of the box to the other under the partition. The number of crossings made in this time was used to match the animals for the different experimental groups. After this 10 minutes the 0.2MA shock was turned on and left for 10 seconds, unless the animal escaped to the other side of the box which was not "live". The animals were given one shock every 90 seconds until they had accomplished 8 successive escapes.

Test Procedure.

6 rats were tested in a single session at one oxygen level. All 6 were placed in the retaining cages and the bag closed. A gas mixture was fed in for 30 minutes at 6 litres per minute then the flow dropped to 3 L.P.M. It took 30 minutes to drop the oxygen concentration to 9%, 17 minutes to 13% and 12 minutes to 17%. 45 minutes after turning the gas on the first rat was placed in the test box, handling being by rubber gloves attached to the side wall of the sealed bag. The rat was left in the box 5 minutes with no light or shock. The number of crossings under the partition was recorded. After this the light was switched on in the end of the box in which the animal was. The light was left on for 10 seconds and then the shock was turned on. The rat could avoid the shock by moving through to the other end of the box while the light alone was on. If he did this the light was turned off, thus providing optimum conditions for learning, (Mowrer and Lamoreaux, 1943). If the animal failed to avoid the shock the light and shock were left on for 10 seconds unless he escaped in which case both were switched off.

After the end of each trial a pause of 90 seconds (plus or minus 10 seconds) was allowed before the light was switched on again. Each rat did 10 trials per day and the number of avoidances and escapes was recorded and a stop-watch was used to measure the time taken for these responses. The animals in any group were tested in a different order each day according to an orthogonal, 6 x 6 latin square so that at the end of 6 days testing each rat had been tested once at each position within a session.

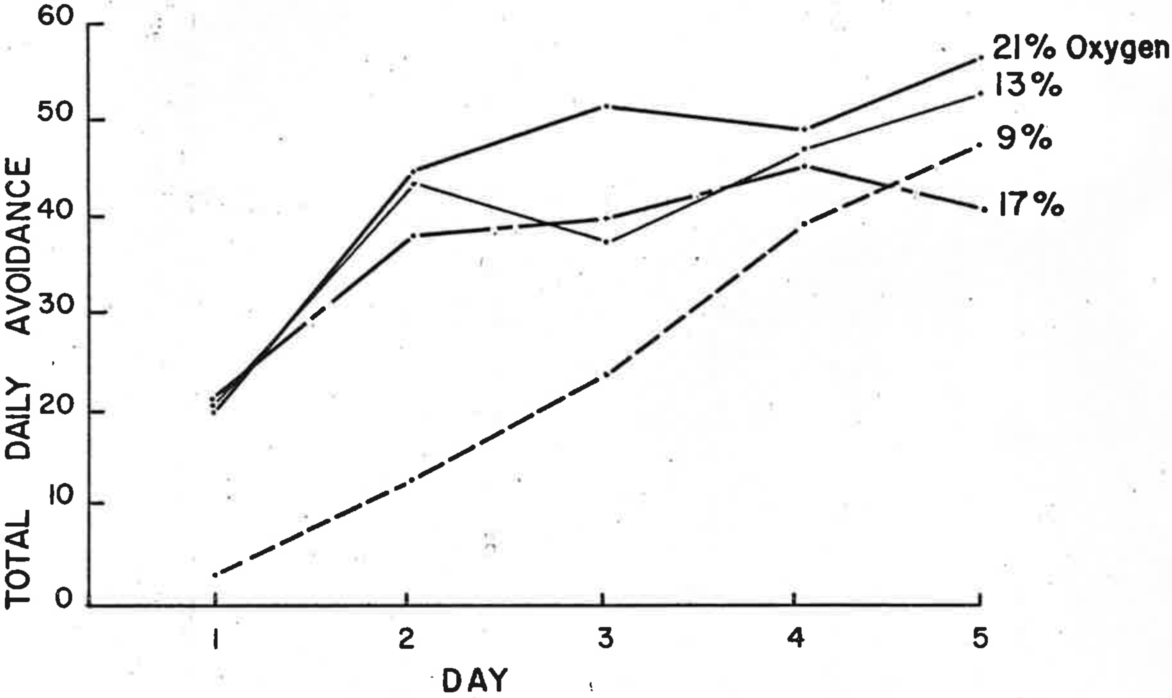
The Experimental Subjects.

The experimental subjects were 12 albino and 12 hooded male rats from the university rat colony. They weighed between 220 and 350 grams. They were given food and water ad lib. and housed two to a cage for several weeks prior to the commencement of the experiment during which time they were handled occasionally.

Results.

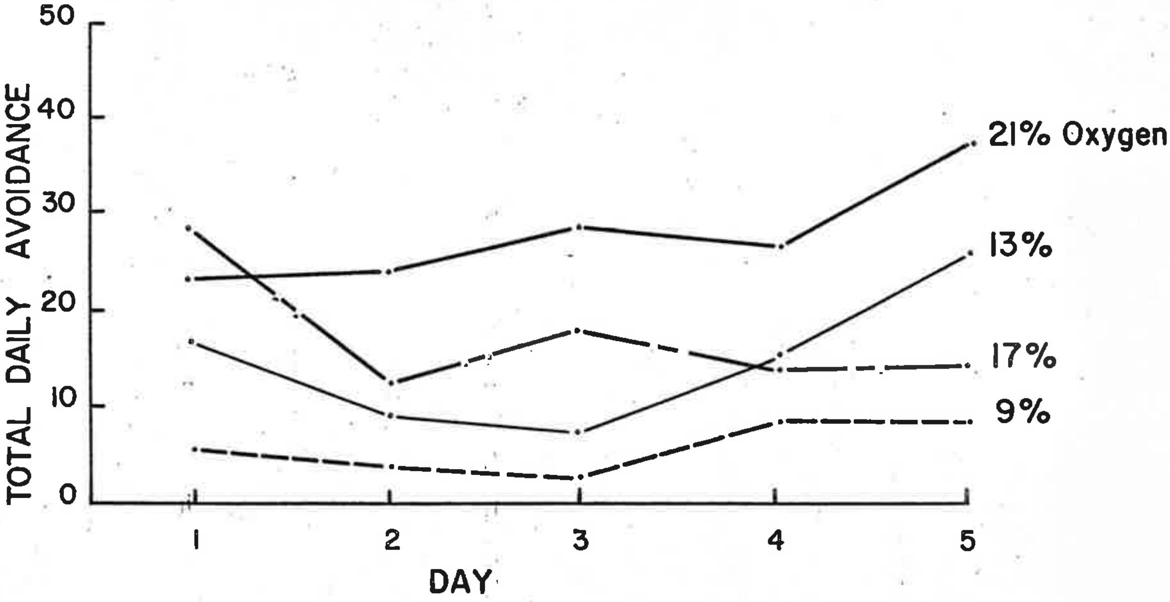
Figure 6.1 shows the total number of avoidances made by each group of rats on each of 5 days. Though the ground level (21% oxygen) performed best overall there is little difference between them and the 17% & 13% groups. The relatively poor showing of the 17% group can be attributed to one rat which was the only rat in all the groups to fail to make any avoidance in the 5 days of testing. The 9% group were

FIG. 6. 1.



Total avoidance responses per group of 6 rats at 4 level of Oxygen Concentration.

FIG. 6. 2.

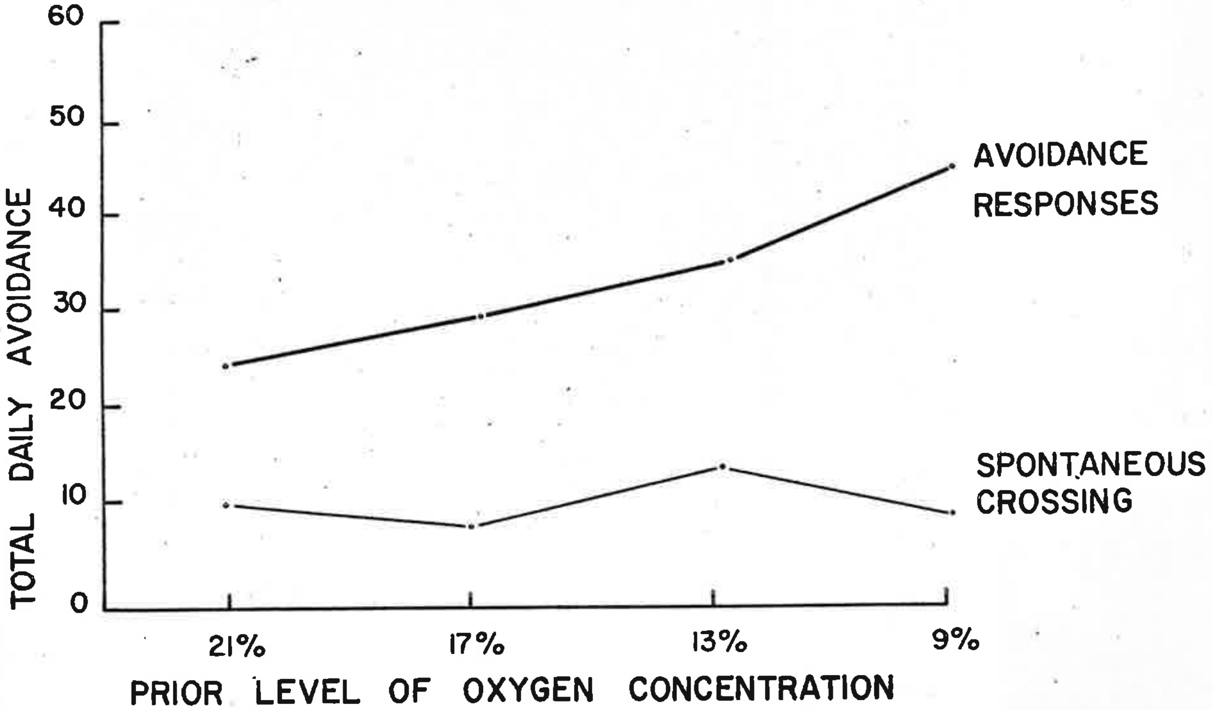


Total spontaneous crossing per group of 6 rats at 4 levels of Oxygen Concentration.

markedly poorer on the first day but improved rapidly thereafter. Figure 6.2 shows the amount of spontaneous crossings from one end of the box to the other in the first 5 minutes of each test session before any shock was given. This activity though the same as avoiding and escaping does not have the same powerful motivation and is nearer to a measure of general motor activity. It can be seen that the groups are more evenly spaced with hypoxia producing lower rates of responding.

After 5 days testing at different oxygen levels all groups were tested once at 9% oxygen. Figure 6.3 shows the groups that were tested on avoidance at higher oxygen concentration were now poorer. It is difficult adequately to analyse this data statistically as it appears that the detriment in performance in animals previously tested at higher oxygen levels is "all or none". Table 6.1 shows the avoidance performance of each animal on day 5 (at 21, 17, 13 or 9% oxygen) and the performance of the same animals on day 6 when all were tested at nine % oxygen.

FIG. 6. 3.



Avoidance responses and spontaneous crossing at 9% Oxygen as a function of previously experienced Oxygen concentration.

TABLE 6.1.

INDIVIDUAL AVOIDANCE PERFORMANCES
IN 4 GROUPS OF RATS

21% Group

	Rat	1	2	3	4	5	6
Day 5	21%	10	10	8	10	9	10
Day 6	9%	3	3	10	1	0	6

17% Group

	Rat	1	2	3	4	5	6
Day 5	17%	0	9	6	8	8	10
Day 6	9%	0	9	0	2	10	9

13% Group

	Rat	1	2	3	4	5	6
Day 5	13%	9	9	10	6	9	10
Day 6	9%	9	8	8	0	2	10

9% Group

	Rat	1	2	3	4	5	6
Day 5	9%	8	8	9	6	9	7
Day 6	9%	10	9	10	6	1	9

In general if an animal shows any reduction in performance from day 5 to day 6 the reduction in avoidance is considerable. Nonetheless trend analysis of variance was carried out and the F ratio for linear trend was 2.70 which with 1 & 23 degrees of freedom has a probability by chance somewhat in excess of 10%.

By day 5 there was little change in avoidance according to position within a session but on day one there was a marked trend for animals tested later in a session to be poorer (see Table 6.2). The cause of this was not readily apparent but clearly it was not a sign of progressive deterioration of hypoxia as it is most marked in the 21% oxygen group. Results from this group indicate the discontinuous nature of the measure of the total number of avoidances per day.

TABLE 6.2.

INDIVIDUAL AVOIDANCE PERFORMANCE IN 4 GROUPS OF RATS. FIRST DAY OF TESTING.

21% Group						
Order	1	2	3	4	5	6
Total Avoidances	3	7	5	0	4	1

17% Group						
Order	1	2	3	4	5	6
Total Avoidances	6	0	7	3	0	5

13% Group						
Order	1	2	3	4	5	6
Total Avoidances	5	1	3	3	3	3

9% Group						
Order	1	2	3	4	5	6
Total Avoidances	0	2	0	0	0	1

The total number of avoidances within the experimental session was correlated with the measure of the original spontaneous crossings before the first shock in escape training. The Pearson r for the within group correlation was -0.180. Within group correlation of avoidance with the animals weight prior to testing gave a correlation of -0.217.

The times taken for avoidance and escape response were examined separately but in neither case was there any systematic effect of hypoxia. Hence the group at 9% oxygen were initially unable to learn to take appropriate action when the warning light came on but their median response to the shock was no slower. In general the albino rats appeared to be poorer in avoiding in hypoxia but the difference was not very large.

Discussion.

On initial testing hypoxia appears to have produced marked impairment in shuttle avoidance learning. On day one the trend of deterioration is an accelerating function of altitude. This is very much in line with the traditional view of the effects of hypoxia as outlined for example by Luft (1961) and in no way compares with the results on human studies within this thesis. Clearly the amount of shuttling in the first 5 minutes in the box prior to the avoidance trial is related to the behaviour in avoidance but is less highly motivated. In this behaviour the initial effect of hypoxia is much more linear like the more cognitive tasks in the human studies reported in previous chapters.

In some respects it is surprising that hypoxia produced such a marked effect on avoidance learning. Seitz & Keller (1940) found no effect on learning and the only effect of hypoxia was to reduce the efficacy of the positive reinforcement though here there was no evidence that the aversiveness of the shock was reduced. Shock & Scow (1942) found hypoxic impairment only in a highly complex shape orientation task but none in brightness or horizontal vertical discrimination learning. In a study of the effects of reduced cholinesterase activity in the brain on rat performance it was found that shock abolished differences between experimental and control groups which were clearly apparent on food motivation alone (Richardson 1967).

Shuttle avoidance is clearly easier to learn than orientation discrimination as it would be learnt in at most half as many trials yet it showed impairment in hypoxia (Shock & Scow, 1942). However in that study the only task which showed impairment was not only the most complex but also the first in which animals were not given any exposure in normal air prior to testing in hypoxia. Such prior testing in control conditions reduces the deteriorating effects of various stresses in humans (Poulton 1966) and may well have the same effects in animals.

The improvement in performance of the 9% oxygen group relative to the other groups was not unexpected:- there is a ceiling effect since no rat can achieve more than 10 avoidances per day. Further this is in line with the evidence in humans where the effect of hypoxia disappears with practice at the task set (Denison, Ledwith and Poulton, 1966). What is surprising is that the performance at 9% of all groups is more directly a function of previous experience of hypoxia than of the level of performance prior to this exposure. This effect could not have been purely from psychological adaptation since if it were then the 21% oxygen group would have performed better not worse than the 9% group. Hence the effect seems to be a result of physiological adaptation. The problem with suggesting physiological adaptation is that the exposure was only for 3 hours once every 3 or 4 days.

Most of the studies on the effects of repeated doses of hypoxia have used daily exposure and even then there is little clear evidence that the physiological changes, if any, are adaptive. Van Liere & Stickney (1963) suggest that the level of hypoxia and the duration of each exposure are important variables in determining the degree and direction of changes occurring. They review evidence which shows that intermittent exposure is generally deleterious on a number of criteria. They suggest that in rats exposed to 25,000 ft. the normal criteria of complete acclimatisation are not met. At 18,000 ft. the results are less clear out but they suggest that one or two hours daily exposure may produce acclimatisation but that four hours daily has been shown to produce deterioration.

The particular schedule used here of three hours once every 3 or 4 days was dictated by the requirements of the experimental design. Much of the evidence in the literature on intermittent exposure to hypoxia is not applicable as it relates to daily exposure. However Altland & Highman (1951) exposed male adult rats to 25,000 ft. for four hours once every 1, 2, 3, 5, 7 and 10 days. As their acclimatisation measure they used percentage red cell to total volume of blood (haematocrit) and found profound changes in the 1, 2 & 3 day groups. At 3 days exposure the haematocrit rose from a control lever at 100 days of age of 47.5% to 58% at 125 days of age and levelled off at 65% at 250 days of age. The changes for one and two days were even higher but little change was found in the 5 and 7 day groups and none was found in the 10 day group. The altitude used was higher than that in this experiment but the results fit together with the results produced here. However it was clear at this point that more evidence was needed since, notwithstanding the Altman and Highman study, respiratory physiologists would not expect acclimatisation changes to occur unless organisms were exposed to reduced oxygen for a considerable proportion of each day. Luft (1961) e.g. says that elevation of red cells count and concentration of haemoglobin require a minimum of 24 to 48 hours continuous exposure to altitudes over 10,000 ft. to become of measurable significance in man.

CHAPTER VII

EXPERIMENT 2.

Experiment 1 suggested that shuttle avoidance learning was retarded by hypoxia and the retardation was an accelerating function of oxygen concentration. A very rapid improvement in performance was found under severe hypoxia and this improvement seemed in part physiological. It appeared that matching the groups on the basis of spontaneous shuttling before any shock was experienced was of little value: the within group correlation was small (and negative) and matching on this basis seemed to offer no advantage over simple randomisation.

On the basis of these findings another experiment was designed to attempt more direct behavioural and physiological test of the supposed acclimatisation effects.

Van Liere and Stickney (1963) suggest as criteria of complete acclimatisation, maintenance of growth rate in the young, no reduction in body weight in adults and normal fertility. They also review the changes occurring with prolonged exposure to hypoxia in respiratory function, blood picture, circulation, endocrine glands and other organs of the body. Changes in all of these give information on acclimatisation as well as the more direct evidence of increased survival times at lethal levels of hypoxia. The most commonly used indices of acclimatisation are the volume of red cells as a percentage of whole blood (Hematocrit or Packed Cell Volume - P.C.V.) and the concentration of hemoglobin in blood (Hb). Hemoglobin within the red cells combines with oxygen diffusing into the blood from the lungs and acts as the main mechanism of oxygen transport throughout the body. Under prolonged hypoxia there is increased concentration of red cells and the increased hemoglobin increases the amount of oxygen taken up by the blood for any given rate of blood flow.

Van Liere and Stickney (1963 p. 180) point out that the benefit to the organism of increased red cell concentration is theoretically quite small though in fact there is a good deal of evidence to show that it is a potent factor in increasing hypoxia tolerance. Altland and Highman (1951) point out that the hematocrit they used is only one of the changes occurring in hypoxia: it should not be used as an overall index of acclimatisation. P.C.V. and Hb. measures are carried out routinely in clinical medicine and testing facilities for these were made available to the experimenter. Thus these measures were used as indices of acclimatisation since they are the single most commonly used measures and were administratively convenient.

Van Liere and Stickney (1963) suggest that increased output of adrenal steroids might be very much involved in short-term adjustments to hypoxia. The determination of steroid levels is much more complex than P.C.V. and Hb. When the experiment commenced it was hoped that these determinations would be carried out and plasma was extracted for this purpose. For technical reasons the measurements could not be carried out and so no further mention of them will be made in the report.

Physiological acclimatisation was suggested to explain why the group always tested at 9% O_2 (oxygen) did better than a group trained in normal air prior to testing at 9%. The method used is not a good method of demonstrating acclimatisation by behavioural measures. When rats were tested on the "acclimatisation test", i.e. on day 6, different groups of rats not only had differing experience of hypoxia, they were also at different levels of proficiency at shuttle avoidance, though the differences were not great. If there had been no acclimatisation, on day 6 when all groups were tested at 9% O_2, the 21% O_2 group would have been as good as the 9% and probably somewhat better. In fact it is difficult to specify what would be the case if the "null hypothesis" was true, i.e. if there were no acclimatisation. As a result any statistical test of the null hypothesis is difficult if not impossible. To try to overcome these problems of differential exposure to hypoxia being mixed up with differing levels of attainment in avoidance, 2 extra groups were used in this experiment in addition to the 4 groups treated as in experiment 1.

One of these extra groups was exposed to 9% O_2 for 5 days with the same interval of 3-4 days between each testing day but were given no avoidance training. A control group were exposed to 21% O_2 under a similar regime with no training. It had been intended that the 9% O_2 group should be given avoidance training at 9% O_2 after this 5 days. However, the rats repeatedly tested at 9% showed no sign of learning the avoidance, i.e. the stress was so severe as to mask any improvement. Accordingly the extra hypoxia group was given avoidance training at 13% O_2 on day 6. The control group were tested in normal air on day 6. In this way orthogonal comparisons could be made between (a) avoidance performance at 13% and 21% O_2 and (b) avoidance performance with and without prior exposure to the respective gas environments in the testing chamber.

As in Experiment 1 the other 4 groups were tested on shuttle avoidance at their respective O_2 concentrations once every 3-4 days for 5 testing sessions then all tested once at the same level of hypoxia. In this experiment they were all tested at 13% (not 9% O_2 as in Experiment 1) since this latter level seemed likely to suppress all avoidance and leave all groups equally poor.

In Experiment 1 it was surprising how little impaired were the 17% and 13% groups. The task to be learned is quite a simple one which can be learned to a criterion of 8/10 avoidances in 30-50 trials. It was thought that the intermediate levels of hypoxia might show more effect with a more difficult task. Accordingly in the 4 groups of 6 rats repeatedly given avoidance training, 3 were tested on the easy task as in Experiment 1 and 3 were tested on a more difficult variant of the same task.

<u>Easy Avoidance</u>. The warning light was lit for 10 seconds and then the grid floor electrified. The shock was left on for 10 seconds unless the rat escaped to the unshocked compartment in which case the light and shock were turned off. If the animal ran to the safe compartment during the 10 seconds warning period then the light was immediately turned off, giving immediate reinforcement.

<u>Difficult Avoidance</u>. The warning light came on for 3 seconds. 7 seconds after the light went off the shock was turned on and left on for 10 seconds as in the easy avoidance. Very few avoidances were made in the 3 seconds warning period so if a rat did run to the safe compartment there was no immediate reinforcement of the removal of the light.

In the 2 groups exposed to the experimental set-up with no avoidance training for 5 days, training on the 6th day was on the easy avoidance for all rats since little change in behaviour is detectable in a single day of testing in the difficult task.

The Experimental Design.

36 rats were randomly assigned to one of 6 equal sized groups. 4 O_2 concentrations were used: 21%, 17%, 13% and 9%. Each of the 4 groups was given avoidance training at the same O_2 concentration on 5 occasions with a 3-4 day interval between sessions. After this all groups were tested once at 13% O_2. Of the other 2 groups one was exposed to 9% O_2 for 6 sessions with the same interval between sessions but was given no avoidance training until the 6th session. The other group was similarly exposed to 21% O_2 and given no avoidance training for 5 days and trained once on the 6th day.

In the 4 groups given repeated avoidance training 3 rats were trained on an easy avoidance task and 3 trained on a more difficult version of the same general task. In the 2 groups given one day of avoidance training after 5 days pre-exposure all animals were trained on the easy avoidance. In all groups given repeated testing animals were tested in the same order on each testing session.

Apparatus & Procedure.

The apparatus was the same as in Experiment 1.

The rats were pre-trained in normal air to achieve 8 successive escapes from the 0.2mA shock with no warning given of its onset. In the avoidance training in the various O_2 concentrations all 6 rats were tested in a single session lasting 3 hours. Each rat was placed in the testing box and allowed 5 minutes rest. 10 avoidance trials were then run with an inter-trial interval of 90 seconds. The rat was then returned to its retaining cage and another rat placed in the testing box. Animals to be trained on easy and difficult avoidance (see above) were alternated in a single session and animals were trained in the same order on all testing sessions. The groups given no avoidance training were simply left in their retaining cages in the sealed bag for 3 hours then removed and returned to their home cages.

For the physiological measurements a blood sample was drawn from each rat 10 days before the beginning of the first test session. 0.5ml. of blood per 100 gms. body weight was drawn by cardiac puncture using a 25 gauge needle. The anaesthesic agent was ether. The tip of the sampling needle was dipped in heparin and samples were drawn and immediately placed in sample bottles containing E.D.T.A. as anti-coagulant. Haematological measurements were carried out by the staff of The

Institute of Medical and Veterinary Science. Packed cell volume was determined by spinning samples in a micro-haematocrit centrifuge at 12,000 r.p.m. for 5 minutes. Haemoglobin concentration was measured by the oxy-haemoglobin method, using a Unicam 1300.

At the end of the experiment (28 days later) a larger quantity of blood was extracted by the same method and haematological determinations performed as in the pretest.

Blood samples in pre and post test were drawn between 9 and 10.30 a.m. and haematological determinations and plasma extractions completed by 11.30 a.m. on the same day.

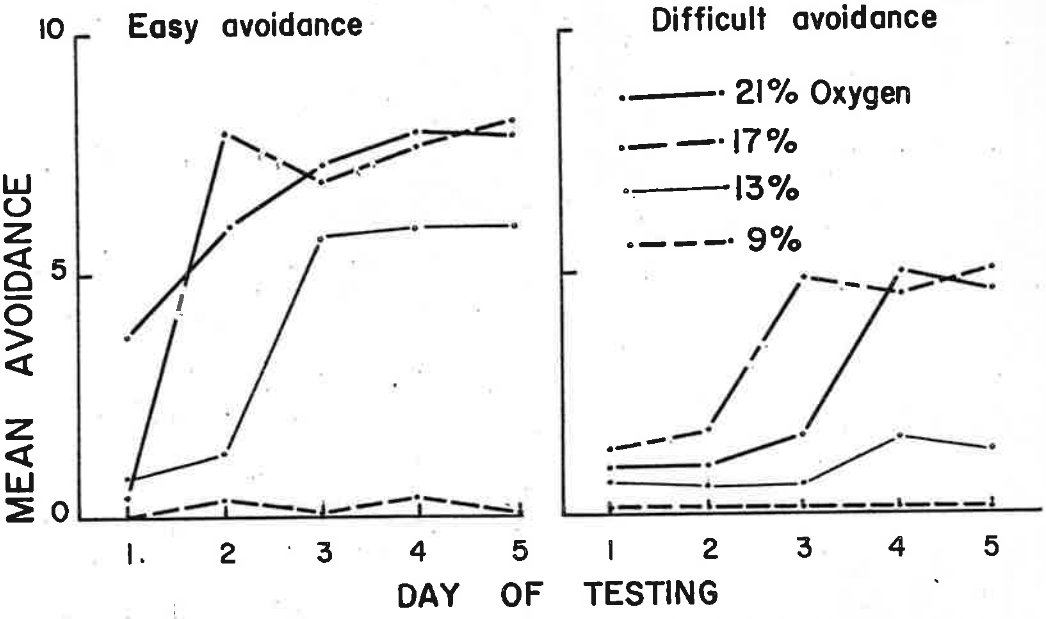
Experimental Subjects.

Experimental subjects were 36 male albino rats from the University rat colony. Body weights ranged from 270 to 370 gms. The rats were housed 2 to a cage and held in the laboratory for four weeks prior to the commencement of the experiment and during this time they were handled occasionally.

Results.

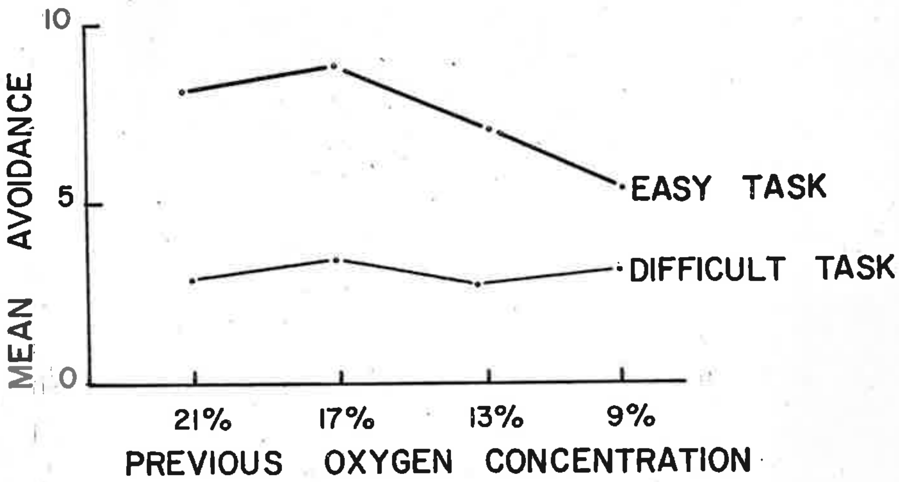
Figure 7.1 shows the mean number of avoidances per day per group of 3 rats which were trained in the easy avoidance procedure. It can be seen that the group in normal air is similar to that in experiment 1

FIG. 7. 1.



Avoidance responses at 4 Oxygen concentrations in easy and difficult avoidance (N=6)

FIG. 7. 2.



Mean number of avoidances on easy and difficult avoidance at 13% on the 6th. day of testing. (N=6) but that the hypoxia groups seem more affected in experiment 2. In particular the 9% group failed to improve their initial poor performance. Figure 7.1 also gives the data on the rats tested on the difficult avoidance. Comparison of easy and difficult tasks indicates that there is no clear evidence that with the more difficult task the intermediate levels of hypoxia show more deterioration: the 17% group was generally superior to the controls but the performance of the 13% group was nearer to that of the 9% group than it was in the easy task.

When all the rats were tested at 13% O_2, after 5 days testing at their respective O_2 concentrations, the previously hypoxic groups were not, as in Experiment 1, superior to the controls. In the easy task the reverse is true whilst in the difficult task there is no difference (Figure 7.2).

A more direct behavioural test of acclimatisation is possible independent of training at the task. Table 7.1 shows the mean avoidance performance of rats on their first day of training on easy avoidance at 21% or 13% O_2 under two conditions:-

(1) training on the first day of exposure to the experimental situation,

(2) training after 5 days in the experimental situation.

TABLE 7.1

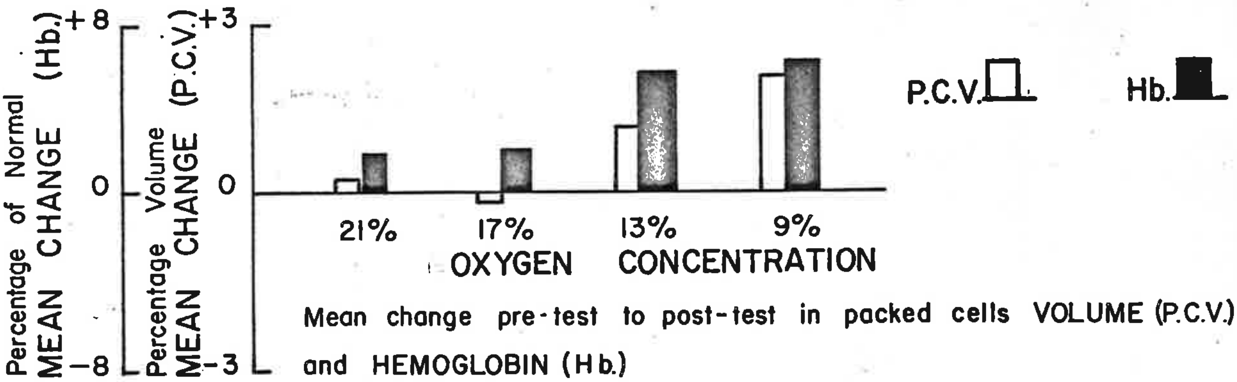
MEAN NUMBER OF AVOIDANCES ON THE EASY TASK AT 21% AND 13% O_2 WITH AND WITHOUT 5 DAYS PRE-EXPOSURE TO THE EXPERIMENTAL SITUATION.

	Testing on 1st day (N = 3)	Testing after 5 days pre-exposure (N = 6)
21% O_2 (Normal Air)	4.0	0.6
13% O_2	1.0	2.0

At 13% the group given pre-exposure is slightly superior. At 21% the group given pre-exposure is much worse, which is a most bizarre result. Table A.3.16 of the Statistical Appendix shows the analysis of variance on this data. The interaction of oxygen level and days of exposure has a probability of less than 5%.

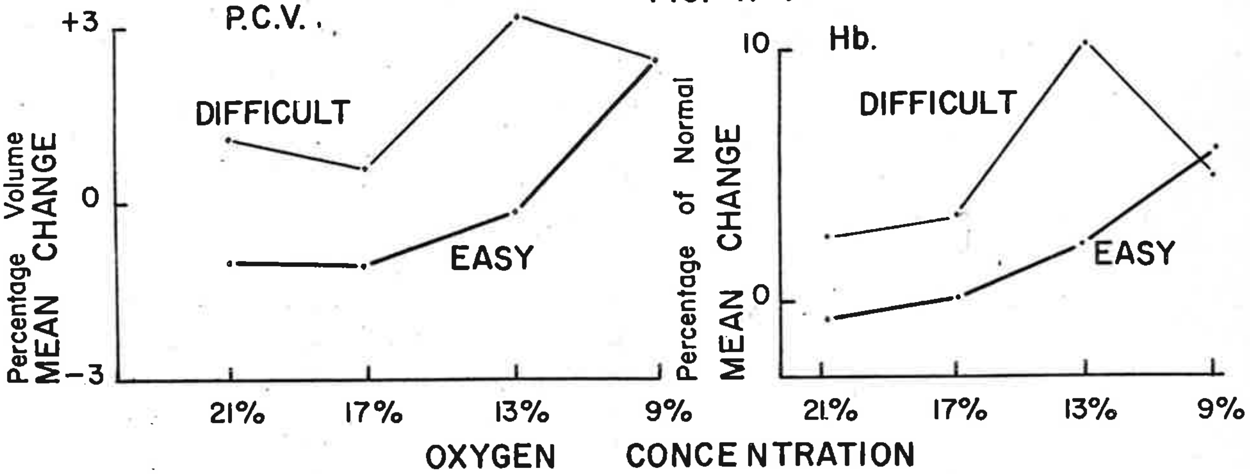
Figure 7.3 shows the mean change in Packed Cell Volume and Haemoglobin concentration from pre-test to post-test in the 4 groups given repeated avoidance training. The control group show little change but there is a progressive increase above pre-test level in the severer degrees of hypoxia. The extent of the true effect may be smaller than

FIG. 7. 3.



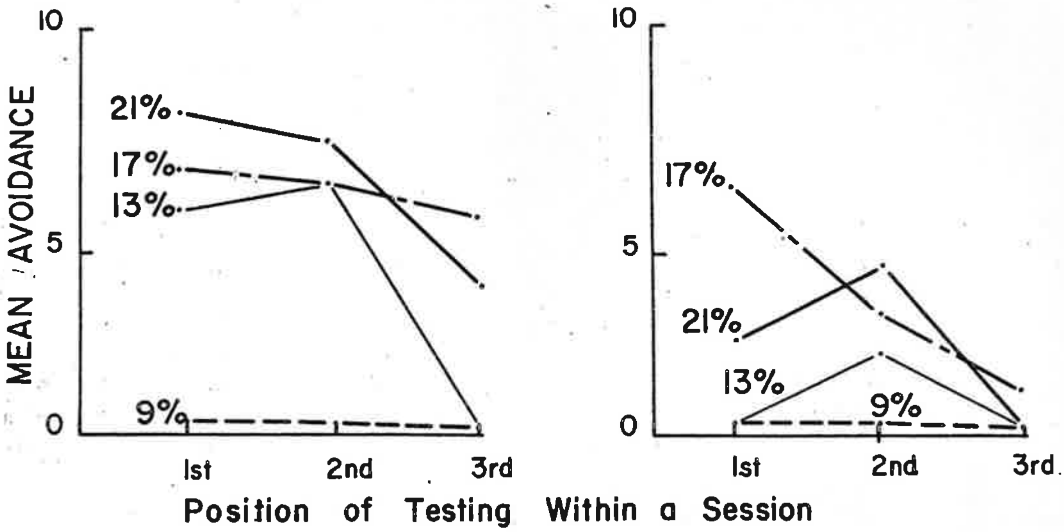
Mean change pre-test to post-test in packed cells VOLUME (P.C.V.) and HEMOGLOBIN (Hb.)

FIG. 7. 4



Mean change in P.C.V. and Hb. at 4 levels of Oxygen with easy and difficult avoidance tasks

FIG. 7. 5.



Mean number of avoidances over 5 days testing related to time of testing within a session that indicated in these samples since 2 rats (one at 13% and one at 9% O_2) had very low P.C.V. and Hb. in the first sample taken though in the post-experimental sample they were very similar to the rest of their groups. Since this was true of both P.C.V. and Hb. it is unlikely that the low pre-test level was a technical error of measurement. Statistical analysis reveals that the linear trend of increasing P.C.V. and Hb. with increasing hypoxia has a probability of less than 10% (see Table A.3.17).

Table 7.2 shows the mean change in P.C.V. and Hb. for animals who were given one session of avoidance training on day 6 after 5 days exposure to 21% and 9% O_2. For comparison data are included from Figure 7.4 of those animals who were given repeated avoidance training in the same gas environments.

TABLE 7.2

MEAN CHANGE IN PACKED CELL VOLUME (P.C.V.) AS PERCENTAGE OF TOTAL BLOOD VOLUME AND HEMOGLOBIN (Hb) AS PERCENTAGE OF NORMAL GROUPS AT 21% and 9% O_2 WITH ONE OR SIX DAYS OF AVOIDANCE TRAINING

Avoidance Training	P.C.V. 6 Days	P.C.V. 1 Day	Hb. 6 Days	Hb. 1 Day
21% O_2	+ 0.16	- 1.3	+ 1.1	- 2.6
9% O_2	+ 2.6	+ 0.5	+ 7.0	+ 2.0

Not only do hypoxic animals show a higher red cell count but so too do animals who underwent repeated avoidance training either in hypoxia or in normal air. Table A.3.18 shows that in P.C.V. for difference in O_2 concentration probability is less than 1% whereas differences in amount of training and the interaction of this with O_2 concentration fall just short of 5%. In Hb. the O_2 concentration and amount of training have a probability of less than 5% level but the interaction is negligible.

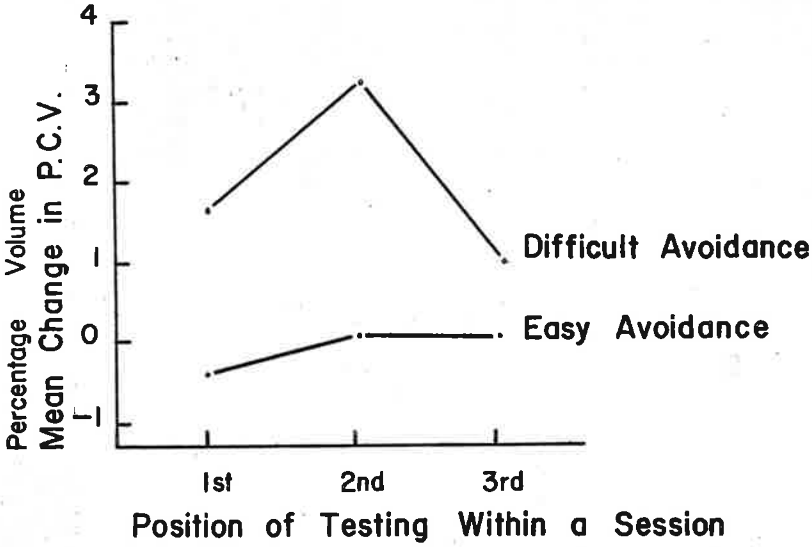
In the 6 animals given repeated avoidance training 3 were tested on the easy avoidance and 3 on the more difficult task. Inspection of Figure 7.1 shows that the animals trained on the easy task in general took fewer shocks. Figure 7.4 shows that in general animals trained on the more difficult task (i.e. with more shocks) show a higher P.C.V. except in the 9% group. However, in this group the number of shocks taken in difficult and easy tasks was substantially the same as there was little avoidance in either. This suggests that the increase in P.C.V. and Hb. as a result of repeated testing may be a result of the shock involved.

There is still one other piece of evidence on the relationship of shock to haematological changes. Figure 7.5 shows that within a single 3 hour testing session there is pronounced tendency for avoidance performance to be poorer at the end of the session as in experiment 1. The effect is more marked than in experiment 1 since each rat was tested at the same time within each session and time effects could 'pile up' in a way that would not occur in experiment 1, where this effect was only seen on day 1. If the number of shocks received increases the red cells in the blood then it would be expected that animals tested late in a session should have a higher P.C.V. and Hb. on the post test as compared to pre-test. Figures 7.6 and 7.7 show that this is not clearly shown. It is true that a coherent trend is more apparent in the easy task in which there is a more marked trend in the behavioural data.

Discussion.

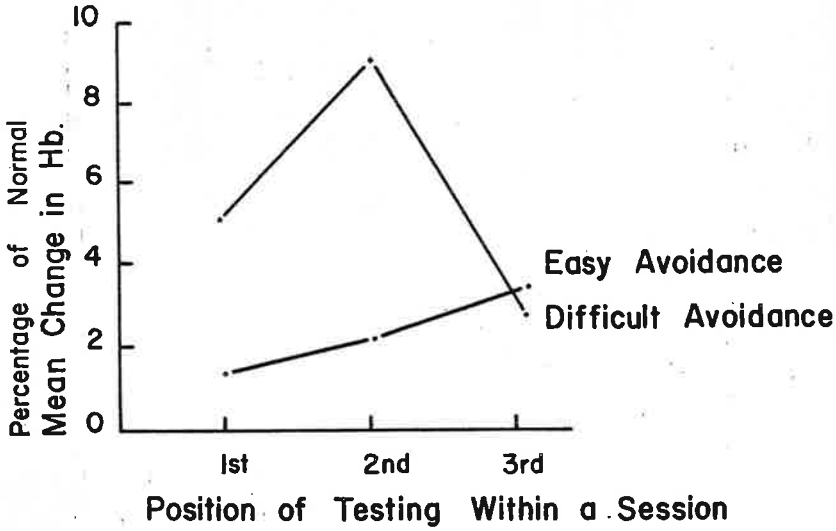
The main aim of this experiment was to examine the suggestion that intermittent exposure hypoxia produced some degree of acclimatisation. This suggestion arose from a finding in experiment 1 that animals tested for five days in hypoxia were more successful in avoidance than other animals tested at the same level of hypoxia who had previously suffered lesser degrees of hypoxia. In this experiment no such result was found: the animals who had the benefit of learning the avoidance procedure at higher oxygen levels, continued to show their superiority when tested in the severer levels

FIG. 7. 6.



Mean change in P.V.C. over 4 levels of oxygen related to position of testing within a session.

FIG. 7. 7.



Mean change in Hb. over 4 levels of oxygen related to position of testing within a session.

of hypoxia. As was pointed out in the introduction, this procedure involves difficulties in a direct test of the null hypothesis of "no acclimatisation effects" but still the fact remains that the results were not like those in experiment 1.

In the more direct test of acclimatisation in the behavioural measures, the group with six days free exposure to 9% O_2 was slightly better in their first day of avoidance training at 13% than the group tested on their first day of exposure to 13% O_2. The difference, though slight, is evidence in favour of acclimatisation but the comparison is vitiated by the inexplicably poor performance of the 21% O_2 group given six days pre-exposure compared to the group tested on their first day in the test chambers. It would be rash to interpret these results as giving evidence of acclimatisation unless satisfactory explanation can be found for the poor performance of the pre-exposed normal air group. No very cogent explanation can be found and so the conclusion drawn from the behavioural testing is that there is not much convincing evidence of acclimatisation.

However in the haematological data there is strong evidence that exposure to intermittent hypoxia produced changes which would be indications of acclimatisation. The need to examine the physiological changes was suggested by the behavioural evidence of experiment 1 and the changes observed here are in the direction expected on the basis of those results. It should be remembered however that no behavioural evidence of acclimatisation was found in the same animals as showed the predicted physiological changes. This lack of agreement between psychological and physiological measures is not unusual (Kety 1962) but it makes the evidence of acclimatisation less cogent and the conclusion that such an effect occurs somewhat more tentative.

It is clear that the rats in experiment 2 were more affected by hypoxia than those in experiment 1. On day 1 the 13% group of experiment 2 avoided far less than the comparable group in the first experiment. The 9% were initially as poor as in experiment 1 but fail to show any kind of improvement with repeated testing. The control groups in the two experiments were very similar in their avoidance performance so the poorer performance in the second experiment is not simply a consequence of physical disability in the cardiac puncture which was used.

At the time it was thought that the poorer performance of hypoxia of the rats in experiment 2 could be due to an anaemia from:

(a) drawing of blood in the pre-tests and/or
(b) impaired respiratory function consequent of the use of ether anasthetic in drawing the samples.

Subsequent experimentation showed that the rats in experiment 1 were exceptionally good in their tolerance of hypoxia and the performance of the rats in experiment 2 was only slightly poorer than other groups tested without prior drawing of blood. Hence one or both of these factors might have been operative but clearly the large differences between the effects of hypoxia in experiments 1 and 2 cannot be attributed solely to them.

Further examination is needed of the suggestion that rate of generation of red cells (Hemopoiesis) is increased by avoidance training and more directly by the electric shock this entails. Miale (1958) suggests that hemopoieses can be enhanced by stimulation of the adrenal cortex by A.C.T.H. The stress of shock is likely to stimulate the adrenal cortex. Among the substances released after such stimulation would be one which would stimulate hemopoiesis almost as a by-product of the general activation.

There is one point on which the evidence of increased hemopoiesis with shock is less cogent than might appear. In the two groups exposed to 9% oxygen with and without training the P.C.V. and Hemoglobin are higher in the former case, i.e. in those animals who shocked on every exposure. The same is true of the 21% oxygen groups but in this case the group given no shock also were not exposed to 13% oxygen for one day prior to the final blood samples being drawn. The 21% group given repeated shocks were given one such exposure to 13% O_2 the day before the final blood samples were drawn. If increased P.C.V. can occur within hours as a result of reduction in plasma volume (not hemopoiesis) (Van Liere & Stickney, 1963, p. 35), then the higher P.C.V. of the 21% group given repeated shocks might not be as a result of shock alone as the group given repeated shock also had one experience of hypoxia. In the 9% groups there is no such confounding of shock experience and hypoxia and here the group given repeated shocks does show higher P.C.V. apparently as a concomitant of repeated experience of shock.

It would appear that shock alone produced higher red cell volume but clearly more evidence would be needed to clarify the evidence given here.

CHAPTER VIII

EXPERIMENT 3

The experiment described here was an attempt to clarify and tidy up a number of points arising out of the two previous experiments. This involved a piece-meal approach with a series of discrete and often not well connected comparisons. A summary will be given of the questions on which information was thought to be needed.

1. It appeared that the drawing of blood samples before the experiment and/or the use of ether as an anaesthetic to do this may have exacerbated the effects of hypoxia and may have masked the protective effects of prolonged exposure to hypoxia.
2. In experiment 1 rats tested later in the three hour session on day 1 had been poorer at avoidance learning. This effect was more clearly shown throughout experiment 2 where animals were always tested in the same order on each day of testing. Such time effects tended to pile up in a way which was obscured in experiment 1 where the order of testing was changed daily. No clear explanation could be given for this phenomenon but it was clearly not an effect of hypoxia.

3. The direct test of acclimatisation seemed unsatisfactory. This involved testing rats in hypoxia on avoidance learning with and without prior exposure to hypoxia. Apart from suggestions that shock and hypoxia might produce better acclimatisation than hypoxia alone not enough data could be gathered in a single day of testing adequately to differentiate experimental groups on behavioural measures.
4. The suggestion that shock alone could give rise to higher indices of oxygen carrying capacity in the blood was partially in doubt. It involved the assumption that changes in such indices would not be produced by a single 3 hour exposure to hypoxia though this assumption had evidence to make it doubtful.

To attempt to deal with these problems a group of 50 male albino rats of 90 to 120 days of age was collected and a series of experimental groups was drawn at random from these rats. The groups were given various treatments but no blood samples were drawn until the completion of the experiment in an attempt to evaluate changes from normality in the blood picture produced by the experimental treatments.

The decline in performance within a session was attacked first. This effect was only found when the bag was closed off on the whole of one side by a wooden board. It was thought that the effect could be due to (a) a build up of carbon-dioxide within the box or (b) might be because the board placed the animals within holding cages in comparative darkness such that stray light from the testing box shone in the holding cages causing the rats to habituate to the warning light. One group of six rats was tested in normal air with a hole cut in the wooden wall at the level of the holding cages so that no gas build up could occur and yet still the decline in performance within the session was found. Another group of five rats was tested in the same condition but a partition was placed between the testing box and the holding cages such that no stray light from the box could shine in the cages. In this condition no deterioration within the session was found. Accordingly all the rest of the experiments were carried out using this partition but the 11 rats tested were left in their own cages and were used as a control group for the blood picture evaluations at the completion of the experiment some 25 days later.

Four other groups of rats were formed and tested on the easy shuttle avoidance used for all rats in experiment 1 and half the rats in experiment 2. The same apparatus and procedure was used as described for these experiments and the rats within a group were tested in the same order daily to check whether the decline in performance had been completely eliminated.

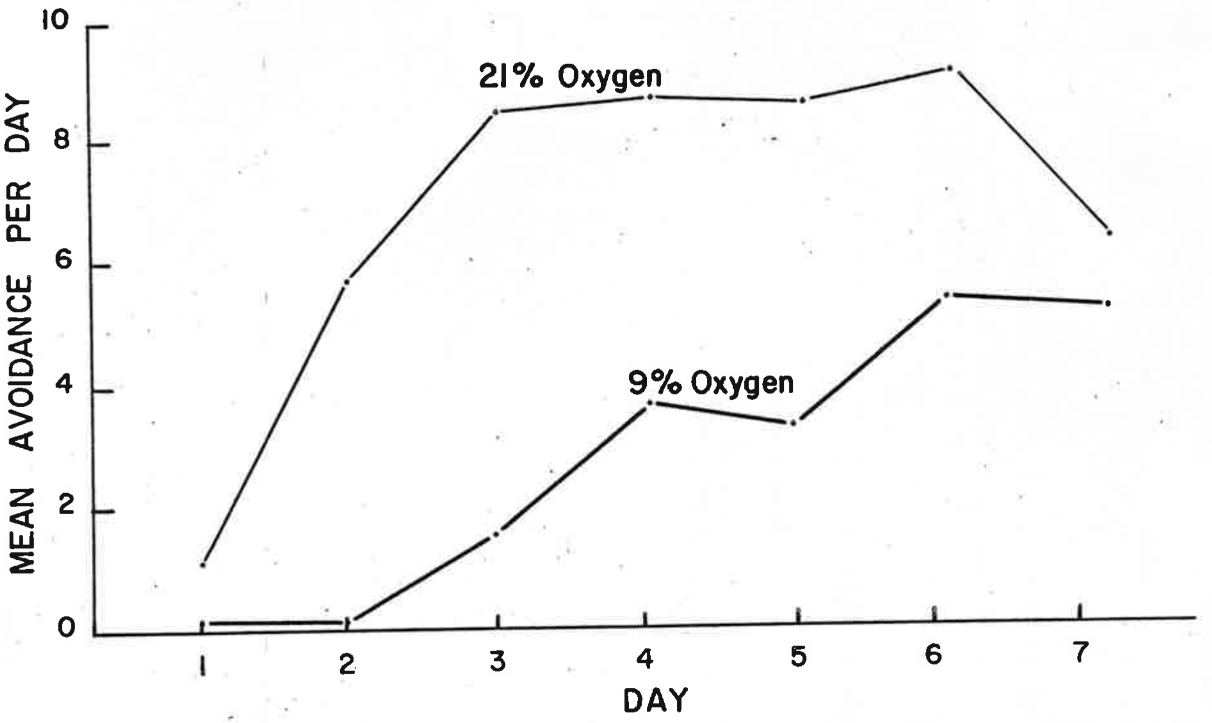
Group A and group B were trained on shuttle avoidance once every 3 or 4 days with no pretraining in shock escape. Group A was tested for 6 days in normal air and on the seventh day of testing were exposed to 9% oxygen. Group B were given 7 days training at 9% oxygen throughout. Group C were given 7 days pre-exposure to normal air without training, then they were trained to escape the shocks to a criterion of 8 escapes to a shock within 10 seconds and they were then tested on two successive days at 9% oxygen on avoidance learning. Group D received 7 days pre-exposure to 9% oxygen were given escape training in normal air and then tested on two successive days on shuttle avoidance. In this latter group only 5 rats were tested. The day after the final testing session for each group all the rats were weighed and blood samples were drawn using the technique described in experiment 2. PCV and haemoglobin determinations were carried out as in that experiment.

Results.

Avoidance Measures.

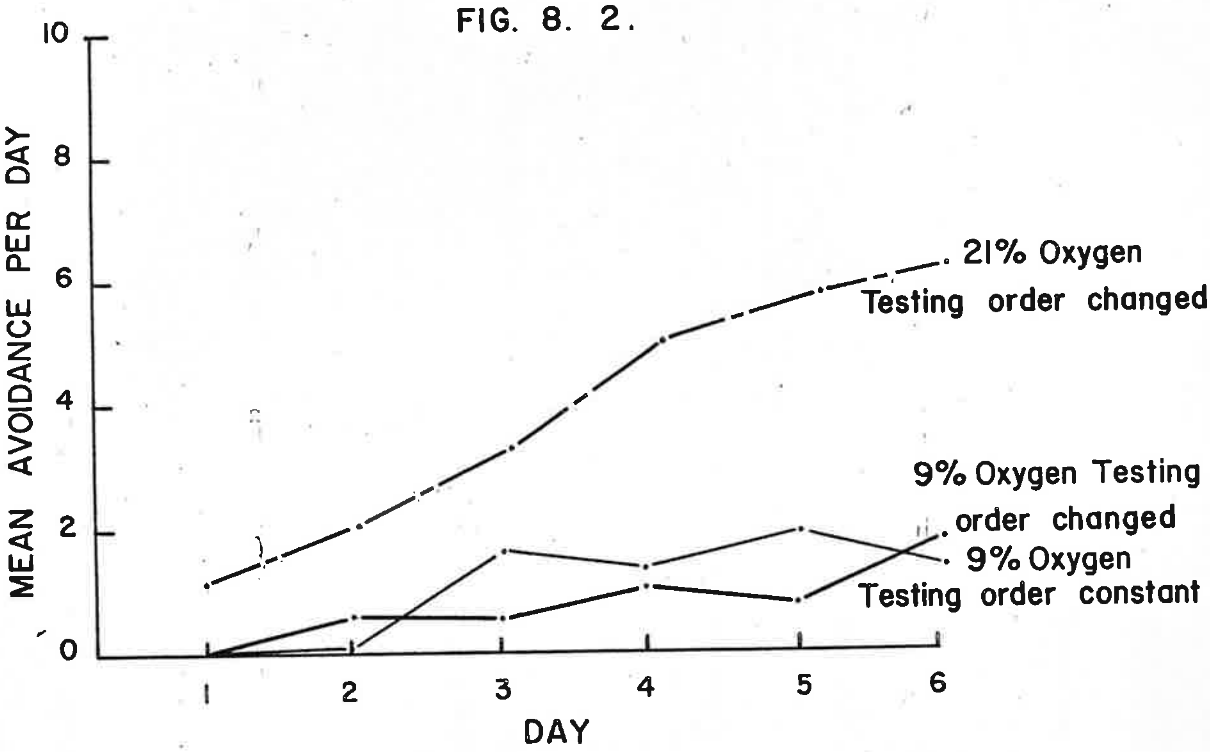
Groups A & B were treated similarly to the 21% and 9% group in experiments 1 & 2. Figure 8.1 shows the mean avoidance daily in these two groups for the 6 days of testing in normal air and 9% oxygen respectively and the results when both groups were tested at 9% oxygen. Even without prior escape training, by day 3 the control groups performance were better than that in experiments 1 or 2. This is the result of removing the habituation effects which had depressed the overall mean score in those experiments. The 9% group however, though better than the

FIG. 8. 1.



Mean daily avoidance in rats given repeated training at 21% & 9% Oxygen.

FIG. 8. 2.



Mean daily avoidance as related to oxygen concentration and order of testing.

comparable group in experiment 2, do not improve as much as in experiment 1. By day 5 their mean performance is 5.2 avoidances as against 8 avoidances of the 9% group in experiment 1.

TABLE 8.1

MEAN AVOIDANCE IN GROUPS TESTED AT 9% OXYGEN AFTER PRE-EXPOSURE TO 21% OR 9% OXYGEN

		Day 1	Mean	Day 2	Mean
Pre-exposure:	21%	0 0 7 0 5 0	2.0	0 0 9 1 0 0	1.7
	9%	0 0 1 0 0 -	0.2	0 0 9 2 0 -	1.8

The results for the pre-exposed groups are seen in Table 8.1. On the first day of testing the group pre-exposed to hypoxia was superior to the group who had not been pre-exposed though on day 2 the difference had disappeared. Inspection of the results of individual animals in Table 8.1 indicate that the differences in a predicted direction are due to the good performance of 2 animals one of whom failed to avoid at all on day 2. Clearly no statistical analysis could be carried out on such data.

On the whole the modal escape time was quicker on day 1 in the group given pre-exposure to hypoxia though the reliability of the difference cannot readily be estimated. On day 1 in both groups there was one animal which failed to escape the shock at all within 10 seconds. On day 2 this was true for 2 animals in each group suggesting that testing on successive days in hypoxia was considerably debilitating.

Animals Weight and Blood Picture.

TABLE 8.2

MEAN WEIGHT, P.C.V. AND Hb AS RELATED TO EXPOSURE TO HYPOXIA

Condition	Control No Hypoxia	Repeated Avoid Training 6 days 21% O_2 1 day 9% O_2	7days pre-exposure to 21% 2days @9%	7days pre-exposure to 9% 2days @9%	Repeated avoid t'g 7days @9%
Mean Wt. (Gms)	297.6	294.5	288.6	265.8	255.5
Mean P.C.V. (%)	43.0	42.9	44.1	45.9	44.3
Mean Hb. (%)	95.6	98.5	96.2	98.5	101.0

Table 8.2 shows the mean weight, PCV and Hb of the rats in each experimental group. The control group consisted of the rats tested once in normal air on shuttle avoidance some 25 days before.

In all three measures groups given 1-2 days at 9% oxygen are little different from control but the two groups with 7 or 9 days exposure are much reduced in weight, show remarkedly high Hb. and have the highest PCV though the groups given avoidance training for 7 days at 9% are not much higher than the group given only 2 days. Of the groups given repeated exposure to 9% oxygen the group given avoidance training on every 7 occasions are slightly lighter but show lower PCV and the same Hb. as the group given only 2 days avoidance training in 9 days of exposure to hypoxia.

Discussion.

It is clear that the care to exclude stray light from the holding cages prevents the habituation effects which depressed the level of performance of the control groups in experiments 1 & 2. However in spite of this the 9% oxygen group is poorer than in experiment 1 though better than experiment 2. The pre-treatment of anaesthetic and blood sampling must have made the groups in experiment 2 less able to tolerate hypoxia but the performance of the 9% group in experiment 1 is still by far the best in spite of any habituation effects. There are only two readily suggestible reasons for the markedly superior performance of this group over the 9% group in the present experiment. In experiment 3 there are still some signs that rats tested later in a session are poorer suggesting that within the 3 hour period the effects of hypoxia are cumulative. In experiment 1 rats were rotated so that rats might be tested first on one day, fifth on the next day, etc. If training early in a session means that rats are less hypoxic then they would have a greater chance of learning the avoidance and once having learned it under favourable conditions, perform better when more hypoxic. Hence rotation by order of testing would produce better overall performance. The other difference between experiment 1 and 3 is that in experiment 1 rats were pretrained to escape shock in normal air but this was not done in experiment 3. Although rats escape shock as quickly under hypoxia as in control it is possible that pretraining to escape produces some advantage when learning avoidance under adverse conditions.

The more direct test of behavioural adaptation between groups with and without pre-exposure to hypoxia produces results in day one in avoidance training similar to experiment 2 though the data is inconclusive. On day 2 one rat in the group given pre-exposure is poorer than on day one but other rats which showed no avoidance revealed more signs of debilitation than the group given no pre-exposure indicating that the stress of testing on successive days may be especially debilitating to rats who have lost more weight. Thus one must reject this repeated testing daily as a suitable demonstration of any adaptation effects using the behavioural measures.

The data on weight and blood picture changes suggest that under the conditions used here one or two days exposure to hypoxia had little effect on the indices of acclimatisation. However prolonged exposure to hypoxia was associated with lower weights and higher PCV and Hb indicating that these blood changes are not only produced in animals made somewhat anaemic at the outset of the experiment.

Experiment 4.

In the previous experiment the question was raised as to why the group under repeated avoidance testing at 9% oxygen in experiment 3 failed to improve as much as the similar group in experiment 1. This experiment was designed to test the alternative explanations put forward for this poorer performance: lack of prior escape training in normal air and/or testing of rats in the same order on each testing session.

The experiment was carried out in stages and when it became apparent that all the rats, even the control group, were poorer than in previous experiments some aspects of the proposed experiment were not carried out. However the data which was obtained provides some information to be included in the final interpretation of the results and is reported here. A group of 40 male albino rats were collected from the University animal house. Since the previous study had indicated that rats continually exposed to hypoxia may suffer a weight loss of 50 grams in 300, older and heavier rats were used in this experiment. These were 120 day old or more with weights from 350 to 570 grams with most between 400 and 450 grams.

Three groups of 6 rats were selected at random from the 40 rats and all groups were given training in escape avoidance in normal air to the criterion of 8 escapes to the safe side of the box within 10 seconds. The groups were then given separate treatments. Group 1 were given training once every 3 or 4 days on shuttle avoidance in normal air. The order of testing within a session was specified by an orthogonal latin square such that the position of testing for each rat was varied systematically on various days. Group 2 was treated in the same way as group 1 as regard the interval of testing and the rotation of order but the testing was carried out at 9% oxygen. Group 3 was also tested at 9% oxygen and the rats were tested in the same order every day.

All rats were weighed prior to the commencement of escape training and were weighed before and after each experimental session. In all other respects the procedures used were the same as in the previous experiment.

Results.

Figure 8.2 shows the mean number of avoidances per group. The control group performs much worse than any other previous control group and on day 5 were poorer than the 9% group of experiment 1. The two groups tested at 9% were poorer than the controls but no differences observable between the two of them. There is certainly no evidence that the group tested in the rotated order perform better. Again the results by themselves are not to be given much weight since in group 2 only 2 rats avoided at all whereas in group 3 only 3 avoided. In the control group all animals showed some avoidance of the shock.

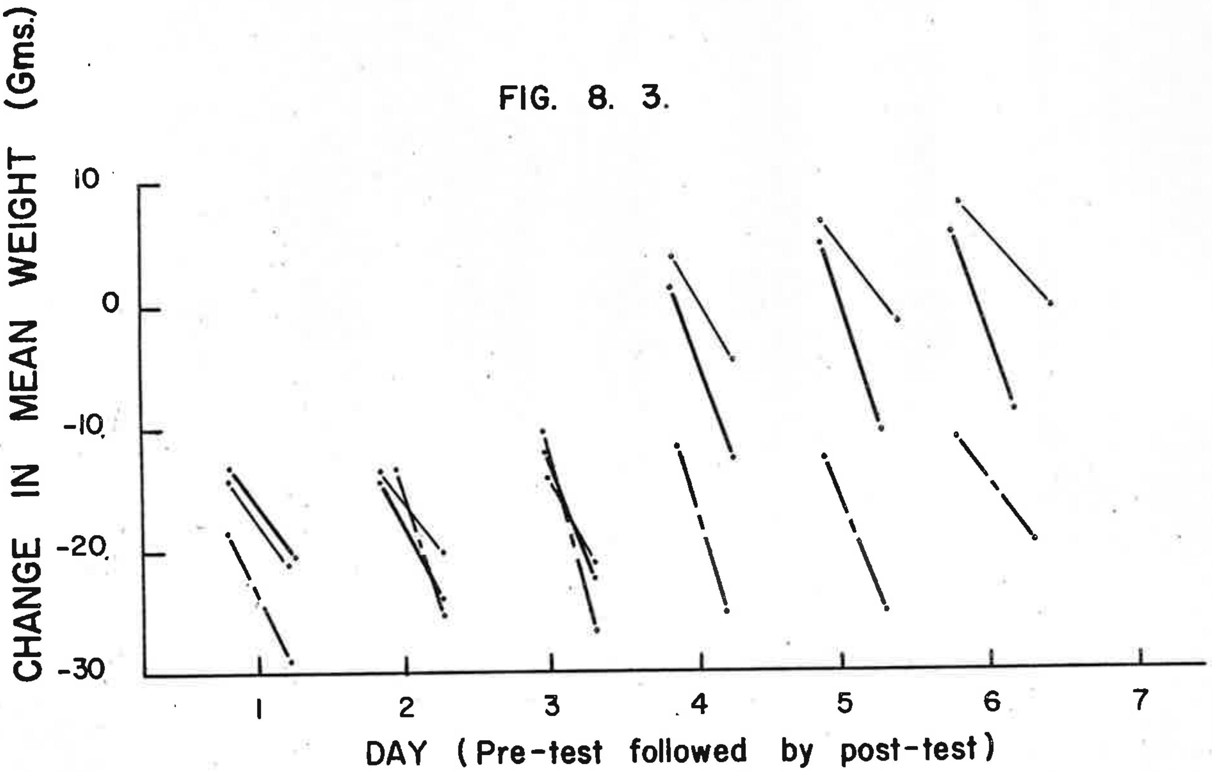
Fig. 8.3 shows the mean change in weight both before and after each day of testing relative to weights prior to the first escape training. In the hypoxic groups the weight reduction through time is much less than in experiment 3. In the group given rotated order of testing at 9% oxygen the initial weight loss is made up like the control group but this effect is not seen from the group given the same order of testing daily. The weight loss within each session is considerably greater in the two hypoxic groups.

<u>Discussion</u>.

Once again hypoxia has been shown to depress the learning of shuttle avoidance response. Attempts to discover whether rotation order of testing was beneficial in hypoxia were vitiated by the failure of any animals to learn the avoidance response as quickly as previous groups. The fact that the rotated group made up their weight losses like the controls would seem to be some evidence of this but no mechanism can be invoked to explain this though a gain in performance could be quite plausibly explained.

Animals tended to show an all or none response within the experimental session: animals who avoided at all tended to avoid the shock most of the time. This makes analysis difficult and means that for clear cut differences to be found between experimental groups fairly large numbers of animals need

FIG. 8. 3.



Changes in mean WT relative to pre-test level before and after each testing session at 21% & 9% Oxygen.

———— 21% Oxygen. Testing order varied

▬▬▬ 9% " " " "

— - — 9% " Testing order constant

to be used and a fair level of attainment of avoidance needs to be achieved. The response required for successful avoidance is a fairly gross motor response and it seems intuitively that successful learning would be correlated with level of general activity. It is true that in experiment 1 there was no within group correlation between general activity prior to shock and the level of avoidance attainment but this may be as a result of restriction of the range studied. Such lack of correlation within groups is often found when overall correlations exist (see Grice, 1966).

When trying to develop the shuttle avoidance technique the author used hyper-active young female rats and these were without doubt the easiest to train and even learned the avoidance without any shock being applied. Hence age and level of activity may be crucial variables determining the extent of hypoxia impairment of shuttle avoidance and the degree to which such impairment is overcome behaviourally through time. Such variables would be in addition to any possible strain differences which might occur when (as here) genetic factors are not constant. One specific factor related to this would be the adequacy of respiratory function in the animals and the degree to which they were infected with the specific pneumonic pathogens to which these animals are susceptible. The degree of difference in many physiological functions consequent on this factor has been examined using rats from the same animal house as used in this experiment (see Godwin, Fraser & Ibbotson, 1964). Clearly in experiments on hypoxia the direct consequences of these pathogens would be considerable and the variations between experiments on the effects of hypoxia may well be a direct function of such differences.

CHAPTER IX

EXPERIMENT 5 AND THE GENERAL SUMMARY OF THE FINDINGS OF THE RAT EXPERIMENTS

The evidence already reported indicated that there was impairment of shuttle avoidance learning at 9% O_2 but little effect at 17% and 13% O_2. At 9% O_2 the initial poor performance improved rapidly (Experiment 1), failed to improve (Experiment 2), or improved somewhat (Experiment 3). There was no doubt that hypoxia produced a deterioration but the question remained as to the extent of any concurrent acclimatisation. In physiological measures both Experiments 2 and 3 showed acclimatisation type changes but the behavioural evidence was equivocal. It appeared possible that the ability to learn the avoidance under stress could be a function of age: in younger animals with high level of loco-motor activity, the appropriate response (crossing from one side of the box to the other) is highly probable without any external stimulus and hence learning to associate the response to a light stimulus would be easier. Thus it is possible that under marginal conditions (as 9% O_2) small age differences could make a considerable difference.

Apart from age the other major factor thought likely at this stage to affect the extent of learning at 9% O_2 was the extent of pneumonia infection in the animals. The final experiment reported here was designed to examine these factors and to check on results previously obtained on the trend effects of hypoxia and physiological changes occurring with intermittent exposure.

A group of 70 male Albino rats was gathered in the University animal house. All the animals had been weaned within a single week. They were housed in 4 large cages and 2 groups of 24 were taken at random to be tested.

For one group testing commenced at 60 days of age and after the testing was completed the other group was tested, these latter animals being 90 days old at the commencement of testing.

Both 60 day and 90 day old groups were tested using the same procedures as in experiment 1.
4 groups were made up from each 24, one being repeatedly tested at one of the 4 O_2 concentrations used: 21%, 17%, 13% and 9%. As in experiment 1 each group was tested once every 3 or 4 days, in a 3 hour session. At the conclusion of the repeated testing, blood samples were drawn by cardiac puncture, using ether anaesthetic. The samples were drawn the morning after the last testing session and were immediately centrifuged to determine the P.C.V. This determination was carried out by the author as it could not conveniently be carried out by the staff of The Institute of Medical and Veterinary Science.

For the behavioural testing animals were pre-trained to a criterion of 8 escapes from shock within 10 seconds in normal air. They were then given 10 trials on each testing session with a 10 sec. warning light and 90 sec. inter-trial interval. Within each session the order of testing was varied following a Latin square design. Thus in all respects conditions were set which were thought to be most favourable for learning. Though pre-training on shock escape in normal air and rotation of order of testing had not clearly been shown to be advantageous in hypoxia as suggested in Chapter VIII, there was good reason for supposing they might be.

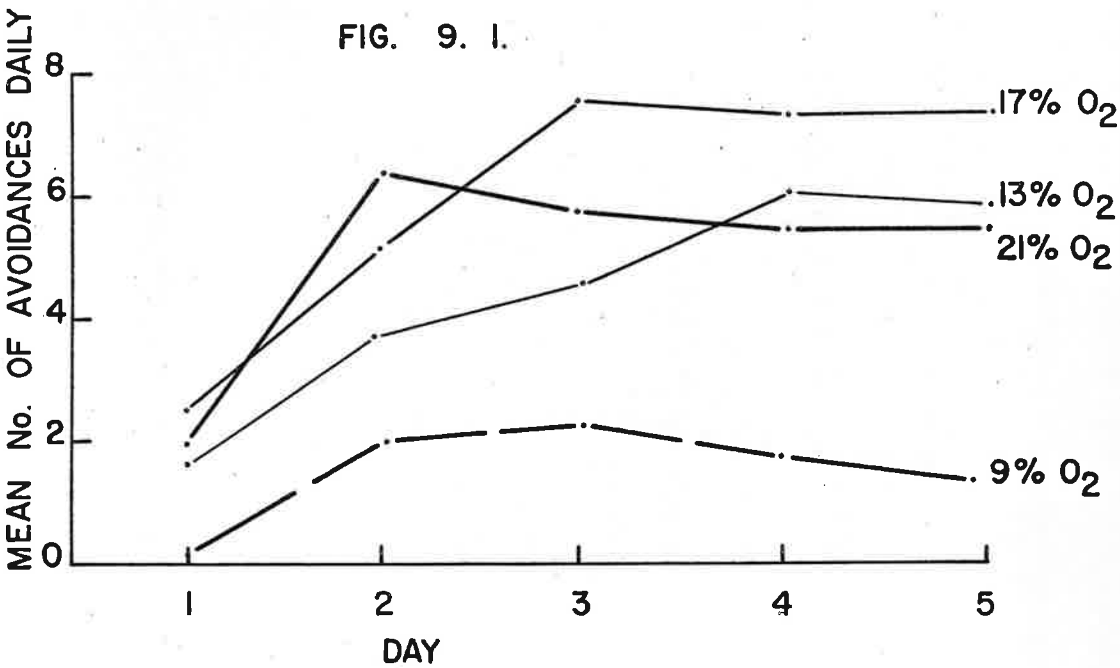
Results.

60 Day Old Group.

The mean level of spontaneous shuttling in the 5 mins. prior to the first shock of escape training was 12.25. Fig. 9.1 shows the mean daily avoidance over the 5 days of testing at the various oxygen concentrations. There is little or no evidence of impairment at 17% or 13% O_2, the 17% group performing better than the controls. The 9% O_2 group showed little avoidance learning at any time.

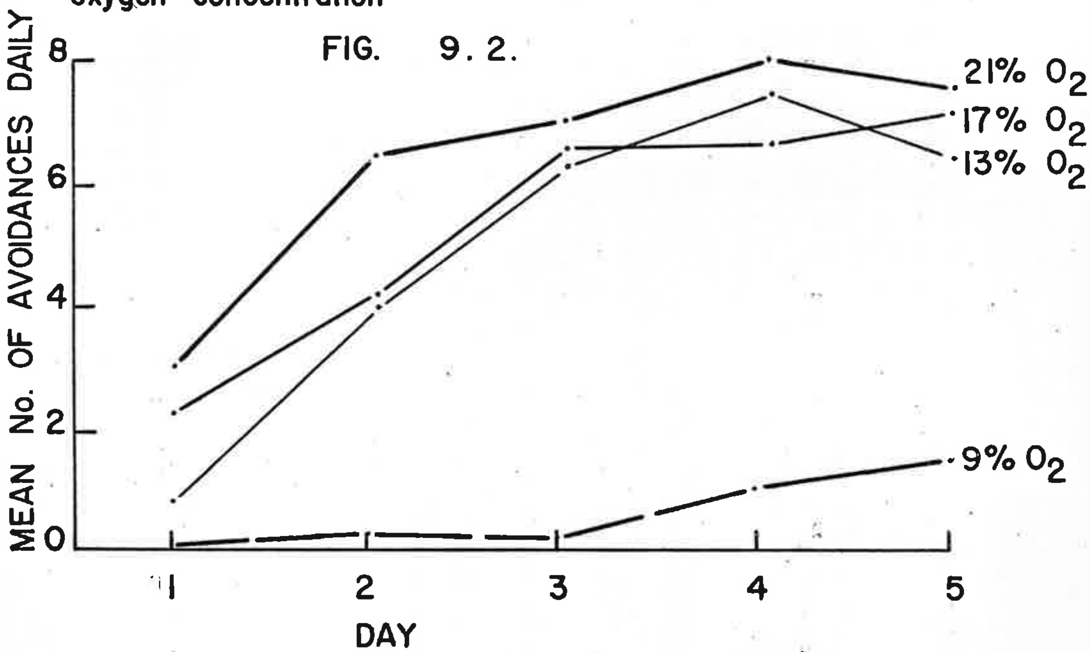
When the haematological determinations were carried out many of the blood samples were found to have haemolised. The plasma was red or pink and hence the measures of P.C.V. cannot be considered to be reliable. 2 animals from the 21% group and 2 from the 9% group were examined by Veterinary Patholo-

FIG. 9. 1.



Mean daily avoidance in 60 day old rats at 4 levels of oxygen concentration

FIG. 9. 2.



Mean daily avoidance in 90 day old rats at 4 levels of oxygen concentration gists of The Institute of Medical and Veterinary Science. Gross inspection revealed some deformation of the lung surface in the 9% rats and this was attributed to enlargement of the bronchioles, which was not seen in the control animals. One of these latter was found to have a large area of calcified pneumonia tissue in one lung. After histo-pathological investigation the Pathologist reported that all 4 rats showed marked and similar pneumonia.

90 Day Old Group.

The mean level of spontaneous shuttling in the first session was 11.0. F test of the difference between 60 Day and 90 Day Groups showed a value of 3.07 which has a probability somewhat higher than 0.10. Hence there is some evidence that the Older Group were less active, as expected. Fig. 9.2 shows the mean daily avoidance in the repeated testing. There is an even poorer performance at 9% O_2 than the 60 Day Old Group but with little sign of major impairment at 17% and 13%.

Determinations of P.C.V. were carried out and special care was taken to avoid haemolysis. Table 9.1 shows the mean P.C.V. for each group.

TABLE 9.1

MEAN P.C.V. FOR GROUPS GIVEN REPEATED EXPOSURE TO ONE OF FOUR OXYGEN CONCENTRATIONS

Oxygen	21%	17%	13%	9%
Mean P.C.V.(%)	46.5%	45.6%	45.9%	48.1%
N	5	6	6	6

A trend analysis of variance gave a F test for linear component of 2.87 (with 1 + 19 d.f. $p > .10$). The quadratic component F was 5.35 ($p < .05$) and the cubic component was negligible.

Discussion.

Comparison of Fig. 9.1 and 9.2 shows that there is little difference between 60 day old and 90 day old groups. The younger group showed slightly more locomotor activity in the testing box prior to the first experience of shock and on the whole their avoidance learning on hypoxia is slightly better. However, the difference is small and it seems obvious that small differences in age would not account for the wide variation found throughout this investigation on the learning performance of groups subjected to 9% oxygen.

The measures of Red Cell Volume once again give some evidence of physiological acclimatisation. The 21% oxygen group have a slightly higher P.C.V. than either 17% or 13% groups but the 9% have much the highest level. A simple interpretation would be that here only in the 9% group is there evidence of a real increase in P.C.V. consequent on exposure to hypoxia.

General Conclusions from the Animal Experiments.

It seems clear that shuttle avoidance is impaired by hypoxia but that the trend is an accelerating function of the decline in O_2 in the air breathed. As low as 13% O_2 not much impairment is noted though the rats were never quite as good at this level compared with the controls. Drawing of blood before testing commenced (using ether as anaesthetic) or using a more difficult avoidance task slightly increased the effects of this level of hypoxia. The effects at 9% O_2 are much more severe and more variable. In Experiment 1 by day 5 the mean number of avoidances per rat was 8 out of a possible 10 (N=6). In Experiment 2 where blood samples were drawn prior to the testing there was no avoidance learning by day 5 (N=3). In Experiment 3 the rats had no blood sample taken but also had no initial training at escaping the shock in normal air and here the mean number of avoidances on day 5 was 3.4 (N=6). In Experiment 4 with pre-training in shock escape the mean number of avoidances on the same day was 1.3 (N=12). In the final experiment the comparable figure was 1.5 (N=12).

Hence in the case of 39 rats initial learning of shuttle avoidance at 9% O_2 was always poor compared with the controls. In 6 rats performance improved rapidly, and improved somewhat in 6 more. The rest showed little or no learning with repeated testing.

The results of Experiment 1 with the rapid improvement could be dismissed as an oddity and a general statement made that hypoxia has a small effect on avoidance learning down to 13% O_2 but that at 9% O_2 the effects are profound and prolonged. However the suggestions from the behavioural data of Experiment 1 that some physiological acclimatisation had taken place, were confirmed by physiological measures taken in Experiments 2, 3 and 5.

Hence the question must be left open as to how prolonged is the impairment consequent on exposure to 9% O_2. The weight of the evidence from all 5 experiments considered together argues for impairment throughout the experimental testing. However the groups tested in the various experiments were small and results vary a great deal between groups. In Experiments 1 and 5 the rats were given virtually identical treatment but the results of the 2 groups exposed to 9% O_2 vary greatly. This variation would seem to be much too large to be mere random variation in small samples drawn from a single population. Given what is known of the poor respiratory function of these animals (see Experiment 5) one can only presume that there is some powerful extraneous factor affecting the results and suggest that this factor is the degree of pneumonia. Very much post hoc one would have to suggest that the animals in Experiment 1 were for some reason less infected.

Clearly development of this work would involve much more strict control of genetic factors in general and pneumonia infection in particular. Only in this way can adequate prediction be made of the degree of hypoxic impairment. Such a program would be an ambitious one involving considerable expenditure and several years work involved in setting up an isolated and self contained rat breeding section.

For the present one can conclude that the trend of the effects of hypoxia on shuttle avoidance learning in the rat fit quite closely to the 'traditional' view of the effects of hypoxia outlined in ChapterI. That is: hypoxia has little effect up to a fairly severe level of hypoxia and beyond this the impairment is very marked.

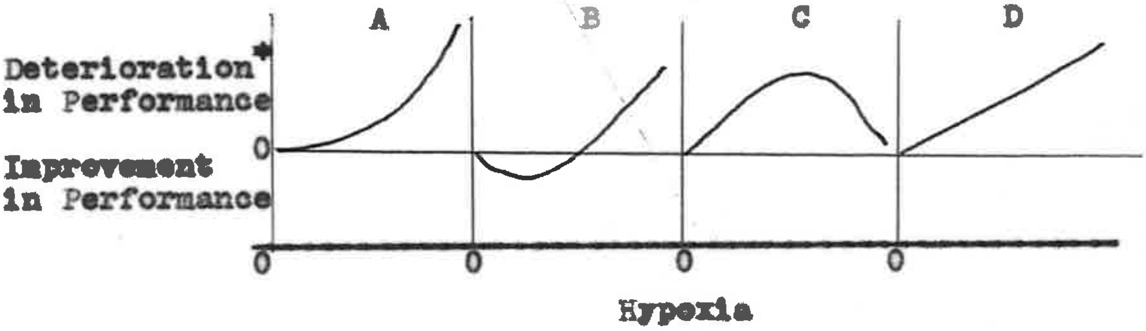
CHAPTER X

GENERAL CONCLUSIONS

Investigations reported in this thesis represent an attempt at a new approach to the psychological study of the effects of hypoxia. Tasks used have not previously been used with hypoxia and the basic experimental design (different subjects in different levels of hypoxia) has not often been employed. The general purpose of the research was exploratory activity over a wide field, but certain general statements can be made in the light of the evidence available.

The use of techniques of investigation from the field of aging seems to have been fruitful. In both dichotic listening (Chapter II) and translations from stimulus to response (Chapter III), the initial investigations borrowed heavily from the research on aging. In successive experiments the work was guided more towards the study of hypoxia in itself but both tasks seem sensitive to the effects of hypoxia and seem well suited to a continuing analysis of the site and nature of the changes occurring under hypoxia. The only lack of success in this respect was the use of discrimination card sorting, which seemed to show little clear-cut or interpretable change in hypoxia. It was not possible to make a direct comparison of the effects of hypoxia and aging, as had been envisaged at the outset, because of the complex and unexpected nature of the hypoxic effects found. However, it should be noted that useful lines of investigation were opened up with the initial starting point of aging. The information reduction task (Chapter V) which seems to offer a remarkably efficient means of study of impairment under stress arises out of translation processes study but has not been used in aging studies. The animal shuttle avoidance studies were developed directly from the hypoxic literature and the general conclusions drawn from it of the processes principally sensitive to hypoxia.

In the introduction note was made of what would be expected from the literature regarding the trend of deterioration with increasing hypoxia.



It was stated that Graph A would be the classical view of the changes in performance with hypoxia backed by physiological evidence of the trend of oxygen saturation in blood with increasing hypoxia. Graph B is the general shape found by some studies in neurophysiology of single nerves, studies in conditioned and unconditioned reflexes in animals and some sensory threshold studies in humans. In fact, in this investigation the translation processes tasks showed results as in Graph C and the dichotic listening and information reduction tasks produce results as in Graph D. Only in the rat studies was the expected picture found similar to Graph A.

Why then the conflict between much of the evidence here and previous work? The more cognitive tasks used have shown linear deterioration under hypoxia without any of the saving at low altitude expected from Graph A. The tasks used here were of proven sensitivity, the experimental design was designed to maximise the chances of detecting any changes in hypoxia. Furthermore, the subjects were generally given no chance to practise the tasks used in normal air before being exposed to hypoxia. Such practice appears to bestow considerable protection against impairment and is a procedure which has usually been used in experiments where results like Graph A are found. It might, therefore, be suggested that cognitive capacity is reduced progressively from ground level up but that at low levels of hypoxia such reduction is very easily masked. It is possible that testing subjects within a few minutes of being exposed to hypoxia maximises the chances of detecting mild impairment. This point will be dealt with below but it should be noted that such acute testing as used here has not been a feature of many investigations in this field.

This statement of the trend of hypoxia requires further qualification when one considers the reliable reversable effect in hypoxia (as shown in Graph C) found in the tasks involving light cancelling. It could be suggested that above 10,000 feet the physiological protective mechanisms have associated with them some increased arousal in the body which confers protective effects shown in tasks without too heavy a cognitive load. This is possible, but here the difficulty is that such effects have never been shown before in hypoxia. It may be that the sensitivity of the design and techniques have shown behavioural changes stemming from physiological changes which might have been missed in other experiments. However, the physiology of the subjects tested here is, by definition almost, very much more similar to that of subjects in other experiments than is the psychological make-up and more especially the difference in the psychological setting. Hence the psychological situation becomes a likely candidate to explain the differences.

The acute testing over thirty minutes to sixty minutes of naive subjects was a feature of these experiments which is relatively novel. The experimental assistants employed in the investigations wore oxygen masks as did the experimenter throughout all testing sessions. Even these people reported some apprehension at being locked inside a large metal tank so presumably the same feelings must have been shared by the subjects. Hence the results reported here may truly be the results of the interaction of two stresses: anxiety alone in the ground level groups and anxiety plus hypoxia in the hypoxic groups. In the animal experiments such extra factors would not be expected to be of importance, especially in view of the more prolonged testing, and here the more 'traditional' picture of the effects of hypoxia was found.

On the basis of this conclusion one might hesitate to generalise the findings of these investigations to other testing and performance situations but the degree of generality is an empirical question with information available here on profitable techniques and procedures to use.

The general conclusion drawn from the effects of length of exposure to hypoxia is that subjects tested after ten minutes in hypoxia were poorer than those tested after forty to fifty minutes. This was odd and unexpected and goes against the general view of progressive deterioration with time in hypoxia. Such progressive deterioration is readily observed in levels of hypoxia in which eventual complete collapse will occur and it has been shown at lower levels. It is true that the exposure times used here were quite short and in the long term the more normal progressive deterioration might be seen. It is possible that the time intervals involved may show the development of some short term physiological energising response which is reflected in behaviour. However, from the time span involved it is as likely, if not more likely, that at the longer exposure intervals the subjects have become more accustomed to the testing situation and hence less apprehensive.

The consideration of the degree of specificity of the results obtained here involves many factors on which no more than speculation can be provided. It seems reasonable to conclude however that hypoxia does produce effects at fairly mild levels of stress and that some tasks are more useful than others in this study. Further the sensitive experimental designs employed may produce their own problems in interpretation though they are sensitive to small changes in cognitive function. Because of their sensitivity they may be affected by anxiety which, in certain tasks, may interact with hypoxia to give quite complex trends.

APPENDIX 1.

TESTS OF STATISTICAL SIGNIFICANCE

The classical theory of statistics in psychology is that outlined and largely developed by Fisher (1960). The approach is one of inductive inference where, on the basis of information from an experiment on a random sample, probability statements are made about the effects of the experimental treatment in the population from which the sample is drawn. The process consists of setting up a null hypothesis that the experimental treatment has no effect. This null hypothesis is the basis of all experimental inference and should be formulated in advance of the experiment. Fisher says that it is never proved or established but it is possibly disproved in the course of experimentation. If it is disproved then the alternative hypothesis is accepted, that the experimental treatment does produce a real difference. As for the level of disproof of the null hypothesis it is suggested that "it is usual and convenient for experimenters to take 5% level as a standard level of significance." In this way anything accepted as significant indicates a real effect and seldom will claims be made for experimental effects which do not stand up to repeated testing (type one errors). As for what Fisher calls "errors of the second kind", i.e. accepting the null hypothesis when it is false "this has no meaning with respect to simple tests of statistical significance".

In recent years there have been a number of criticisms of this approach and various alternatives have been suggested. There are a number of specific objections but they all stem from one fundamental one that this approach is quite at variance with the methods of scientific investigation. Luchins & Luchins (1965), in dealing with the general logic of thinking, point out that the logic of discovery is far removed from the logic of proof. As a result the null hypothesis often has to be invented post-hoc for publication of experiments whose sole surpose was to find "what happens if". Hays (1964) deals with this topic of "testmanship" and suggests a slight softening of the classical approach by using a three choice decision on the null hypothesis: accept, retain with doubt or reject. Edwards _et al_ (1963) suggest a more radical approach where experimental evidence is added to prior probabilities or expectations so that a new set of probabilities are arrived at, using Bayes' theorem. In this way, no hard and fast decision is ever made but a view is produced of what the world is probably like. Hays (1964) suggests that the difficulties with this approach are twofold: the prior probabilities are often not quantifiable and also psychology seems not to be ready for such a radical change though there is much to commend it as being closer to the actual practice of research.

The Fisher logic gives a false air of precision to experimentation where any result with a probability of 5% or less is "real" but one with a probability of 5.5% is not. The Bayesian approach of Edwards <u>et al</u> (1963) seems to be in difficulties over the false precision involved in attempting to quantify prior probabilities though the actual consequences of this difficulty are not as drastic as the all-or-none of the Fisher approach. The irrelevance of such precision is suggested by Edgington (1966) who shows how seldom in psychology samples can be considered random, and thus inference beyond the results for the sample can be made but such inference is non-statistical. When it is remembered how much results obtained are dependent on the experimenter who did the experiment (Kintz <u>et al</u> 1966, Rosenthal 1966, Rosenthal 1967), consideration of 5% or 6% would appear to be "straining at gnats".

Bakan (1966) has reviewed the difficulties and distortions of the Fisher approach which he points out is designed for the one-off experiment with no prior evidence on the phenomenon in question. One of the difficulties he suggests with significance testing is that publication of information is too much dependent on such significance levels. This inflates the number of type one (false rejection of the null hypothesis) errors in the literature. In a thesis more freedom is allowed than generally given by journal editors and therefore the practice followed throughout this one is essentially pragmatic and

Bayesian without the exact probabilities. It is, in fact, the normal practice in experimental research away from the artificial conventions of journals.

Levels of probability are quoted with the statistical analyses. In general no result with a probability of greater than 10% is given much credence. However, in assessing the meaning of experimental data interpretation is made on the basis of plausibility of the effects from previous knowledge and from prior experimentation. Further, significance levels are placed in context of the power of the test of statistical significance. Hence a result with a high probability by chance using a test with few degrees of freedom leads to a high probability of false acceptance of the null hypothesis. Such a result is not necessarily given less credence than an acceptably significant result from a test of much higher power. Hence, not only significance level but also the size of the effect is taken into account in such a way that no F ratio greater than 2.5 is ignored and no F ratio less than 2 is given much attention. In such cases the experimental treatment would seem to contribute no more to the variance than random variation on its own.

In this way, no decision is ever finally made, which is the case in most scientific investigations. Evidence is collected and evaluated, more evidence is added and evaluated, statements are made of what seems to be the case, and some general qualification is made of the degree of confidence to be ascribed to these statements. Hence no statistical decision is made and probability values are treated as statistics describing the area of confidence of the results. Such a procedure has no rigorous rationale but it is a true reflection of the way that investigations of this kind proceed. As Luchins & Luchins (1965) point out, many areas of rigorous mathematics have been carried out for a long time without an adequate "meta-theory", and no apology is necessarily needed for such a lack.

APPENDIX 2.

DISCRIMINATION CARD SORTING AND AGE

In experiment A of Chapter V it was found that there was little effect of hypoxia in the discrimination card sorting task as described by Crossman (1955). What difference there was lay in the opposite direction from that described for aging by Crossman and Szafran (1956): with increasing difficulty sorting times increased more in the hypoxic group though this group was slightly quicker at the easiest task. Crossman and Szafran (1956) reported that all the subjects were slower over all than young adults though the difference was greater with the easier discrimination tasks.

Results reported by Crossman and Szafran are at odds with the bulk of the findings in age that in older subjects response times are slower over-all and this slowing may be constant at all levels of difficulty or may be more marked in the more difficult discriminations or choice situations (Welford 1962). The level of times taken in the aging study were quite different from those found in the hypoxia experiment: in Crossman and Szafran (1956) the time per card for young subjects at one versus four dots discrimination was 0.8 seconds and for eight dots versus ten dots was 1.0 seconds. In the decompression chamber a group of young male adults took an average of 0.9 seconds for one versus four and 2.1 seconds for eight versus ten dots discrimination.

For these reasons it seemed that some attempt should be made to establish the effects of aging using the cards and following procedure of the hypoxia experiment. The procedure used and followed as closely as possible was that described by Crossman (1955) which appears not to have been varied in the aging study though few details are given there.

Letters were written to graduates of Adelaide University who graduated before 1935, asking them to take part in an experiment involving comparison between older graduates and present students on a card sorting task. From some thirty letters sent ten replies were received and these people were tested on the card sorting task. Of the ten subjects, five were females and ages ranged from 54-65 years.

For the comparison five male and five female psychology students aged 19-20 years also did the card sorting task. These subjects took part in the experiment in partial fulfilment of a course requirement and hence could hardly be regarded as such ready volunteers as the older graduates, though the nature and purpose of the experiment was explained to them.

The procedure was similar to that described in Chapter V. Four packs of forty cards each were made up with packs containing equal numbers of two denominations of three millimetre diameter, black dots spread haphazardly over the face of an otherwise blank playing card. The packs consisted of the following denominations: one or four dots, six or twelve dots, eight or twelve dots and eight or ten dots. Subjects were handed a well-shuffled pack and asked to hold them face down, to turn them over one at a time and sort them into two piles according to the number of dots on each card. They were told to do the task as quickly as they could but to try not to make more than one or two mistakes per sorting. Subjects did two blocks of trials each consisting of one run through each of the four levels of difficulty. After a short rest subjects did one more block consisting of one trial at each of the four tasks and then were given three successive trials at each level of difficulty. Interspersed with these final trials subjects were asked three times to sort a pack into two piles by alternation, placing the first card on one pile, the second card on another pile, the third card on the first pile and so on. This latter was an attempt to measure any individual or group differences in speed of manipulation of the cards. Sorting times were recorded on a hand-held stopwatch to the nearest one-tenth of a second. The order of presentation of tasks was varied for each subject for each block of trials and systematically varied between subjects, using orthogonal latin squares.

Results.

As in the hypoxia experiment few errors were made in sorting so results have been analysed solely in terms of the time taken by each subject in each group to sort each pack of cards. The times taken on the first three blocks of trials were analysed along with the mean of the last three trials where subjects had three attempts at each level of difficulty before moving on to the next.

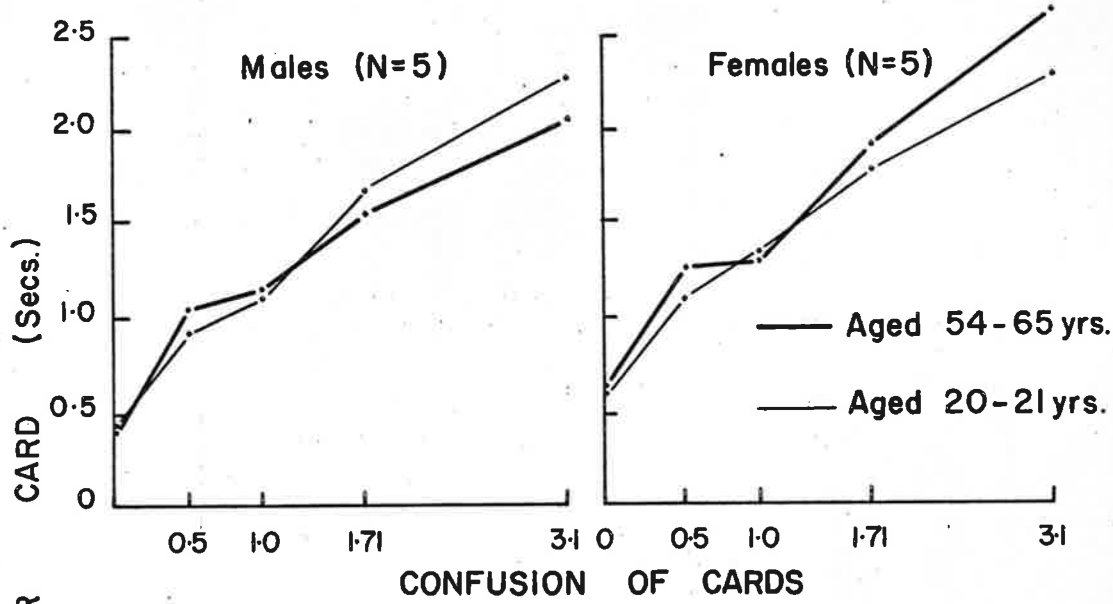
Analysis of variance was carried out on the data for a two-by-two factorial design with two age levels and two sexes and within and between group comparisons made of the level of difficulty and practice effects of four separate trials at each level of difficulty. The within group variance was approximately twice as great in the older group and the individual variation by level of difficulty was similarly higher though in neither respect was there any difference by sex. Differences of variance of this magnitude are considerable but where there are equal numbers in the sub-groups, the bias in probability estimation is fairly small (see Lindquist 1953) and a full analysis was therefore carried out. Table A.3.19 of the Statistical Appendix shows the results of this analysis. The only sizeable difference in overall scores lies in the slower performance of the female subjects though even here the probability is greater than 10%. As in the hypoxia experiment Crossman's (1955) confusion function accounts for virtually all the variation in levels of difficulty. Neither age nor sex show any sign of interaction with difficulty but there is a sizeable interaction of (linear) confusion by sex by age. Figure A.2.1 shows this effect. In the females the traditional picture of the effects of age are found: the young are slightly quicker at one-four (70 m.sec.) and very much quicker at eight-ten (380 m.sec.). In the males the reverse effect is found though the effects are much less marked. Young males are quicker at the easier task but slightly slower at the more difficult. It should be noted that there is no difference by age by alternation times though there is by sex. The general level of times taken in this experiment is quite close to those found in the young adult males on normal air tested in the decompression chamber.

Discussion.

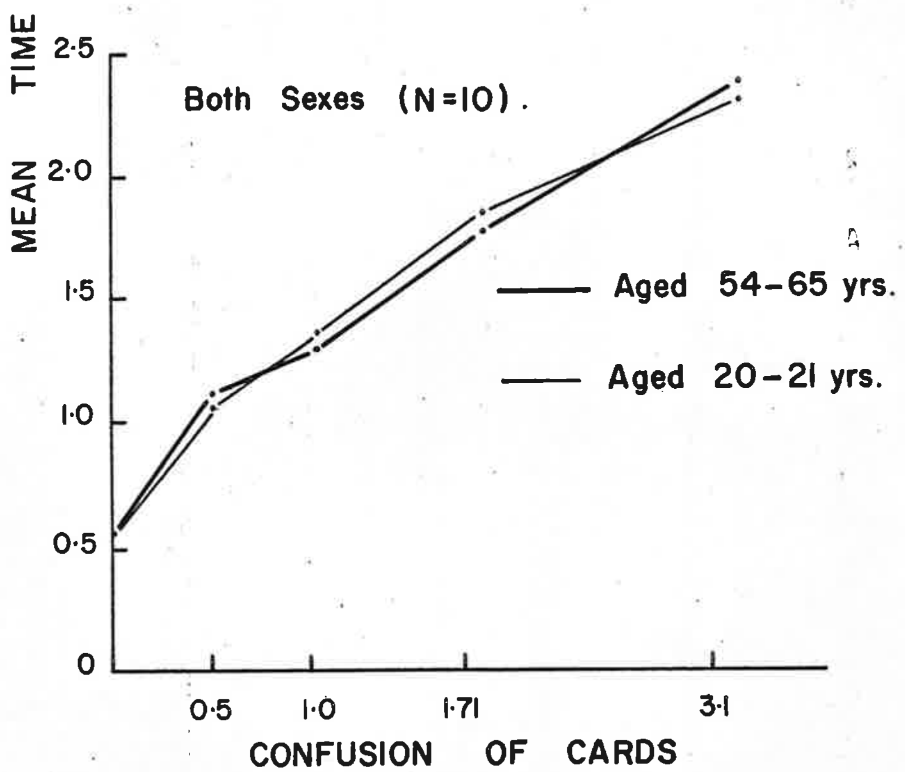
As in the experiments on the effects of hypoxia on discrimination card sorting, there is little evidence here of any simple and externally consistent account of the effects of aging. Even if there were, considerable qualifications would have to be made of the interpretation in view of the differences between groups which is confounded with age differences.

From observation in the experiment it appeared that the older males were competing against their younger counterparts so as to be highly motivated.

FIG. A. 2. I.



Discrimination card sorting. Mean time per card for 2 age levels in both sexes.



They were told the purpose of the experiment was to compare older and younger people of university level. The element of competition was not stressed and often attempts were made to dissuade subjects from this view but nonetheless this clearly had an effect on performance. Among the older female subjects this motivation was less obvious and the prime motive in offering to act as subject seemed from general interest and a desire to help. Of the five elderly females, three were retired, which is not true of any of the males of comparable age and on the whole the retired ladies were much the slowest.

Among the younger subjects, the female subjects were slightly slower overall. This probably represents no fundamental sex difference but is a response to the particular experimenter since it has been consistently found throughout the work reported in this thesis that females were slower in all tasks, a difference which is almost certainly not universal.

Relating these considerations to the findings of differing effects of varying levels of difficulty to age levels according to sex, the conclusion which seems to be most plausible, almost in spite of some of the evidence, is that older subjects are in general slower at the card sorting task and this slowing is greater at more difficult tasks. It is suggested that where the reverse occurs it is because of an element of extra-motivation which can readily lead to quicker times in more difficult tasks. No matter how hard the subjects try they cannot increase the sorting time on one versus four by more than a few seconds, over forty cards, but on the eight versus ten task a reduction of ten or fifteen seconds could well be expected if the subject tries harder.

This conclusion is based on casual observation of the subjects but has received confirmation obliquely from some unpublished work done in the department of Psychology at Adelaide University by another staff member. She compared adult university students with ten or twelve year old school children on the discrimination card sorting task and found the children slower overall but especially slow in the more difficult tasks. In both respects, with twelve subjects per group the differences were highly reliable statistically. In tests of psycho-motor skill aging often reflects the same changes in reverse as those occurring up to maturity and thus it seems likely that in discrimination card sorting the true effects of age using the general techniques outlined are the opposite to those outlined by Crossman and Szafran (1956). The question then arises as to how the difference in results has arisen but clearly more direct empirical test of the effects of aging on discrimination card sorting would be required before the more theoretically oriented question is dealt with.

APPENDIX 3

STATISTICAL APPENDIX

TABLE A.3.1.

CHAPTER II EXPERIMENT A. DIGIT SPAN & DICHOTIC LISTENING. ANALYSIS OF VARIANCE OF THE EFFECTS OF HYPOXIA, TEST-RETEST AND NUMBER OF DIGITS IN A LIST.

Digit Span

Effect	D.F.	Var.Est.	F
Hypoxia (H)	1	20.45	2.04
Within H	20	10.04	
Test-Retest (T)	1	1.15	
H x T	1	1.97	
Within x T	20	3.34	
Number (N)	3	329.35	67.91 (C)
H x N	3	4.50	
Within x N	60	4.85	
T x N	3	2.16	
H x T x N	3	2.89	
Within x T x N	60	3.89	

C: $.01 > p$

TABLE A.3.1. (<u>Cont</u>.)

Effect	D.F.	Dichotic 1st Half Var.Est.	Dichotic 1st Half F	Dichotic 2nd Half Var.Est.	Dichotic 2nd Half F
Hypoxia (H)	1	69.89	2.68	191.02	5.30(B)
Within H	20	26.08		36.01	
Test-Retest (T)	1	18.62	3.41(A)	20.40	7.81(B)
H x T	1	23.56	4.32(A)	.77	
Within x T	20	5.46		2.61	
Number (N)	4	580.30	108.2 (C)	201.10	34.1 (C)
H x N	4	3.16		3.03	
Within x N	80	5.36	1.63	5.89	
T x N	4	8.64	1.13	7.92	2.21(A)
H x T x N	4	5.99		.57	
Within x H x T	80	5.31		3.59	

A: $.1 > p > .05$ B: $.05 > p > .01$ C: $.01 > p$

TABLE A.3.2.

CHAPTER II EXPERIMENT B. DICHOTIC LISTENING. ANALYSIS OF CO-VARIANCE WITH ADJUSTMENT FOR AGE AND PRE-TEST DIGIT SPAN

		First Half Dichotic		Second Half Dichotic	
Effect	D.F.	Var.Est.	F	Var.Est.	F
Hypoxia	3	59.51		21.0	
Linear	1	3.59		70.69	2.03
Quadratic	1	129.26	1.34	85.56	2.45
Cubic	1	96.83			
Within H	26				

No F Ratio attains level where p .10.

<u>Within Groups Correlation</u>.

	First Half	Second Half
With Age	r = 0.234	r = 0.335
With Digit Span	r = 0.306	r = 0.734

TABLE A.3.3.

CHAPTER II. EXPERIMENT C. DICHOTIC LISTENING. FIRST HALF LIST ANALYSIS OF VARIANCE

Effect	D.F.	Var.Est.	F
Hypoxia (H)	2		
Linear	1	24.81	
Quadratic	1	19.60	
Exposure (E)	1	244.02	3.95 (A)
H x E	2		
Linear	1	26.56	
Quadratic	1	51.35	
Subjects Within	24	61.78	
Noise/Quiet (N)	1	777.60	93.72 (C)
N x H	2	2.63	
N x E	1	13.07	1.58
N x H x E	2	17.02	2.06
N x Within	24	8.28	
Test/Retest (T)	1	32.28	5.76 (B)
T x H	2	0.63	
T x E	1	26.65	4.76 (B)
T x H x E	2	0.26	
T x Within	24	5.60	
Before/After (B)	1	322.02	36.47 (C)
B x H	2	1.98	
B x T	1	36.81	4.17 (A)
B x H x T	2	24.21	2.74 (A)
B x Within	24	8.83	

TABLE A.3.3. (Cont.)

Effect	D.F.	Var. Est.	F
N x T	1	0.42	
N x T x H	2	1.28	
N x T x E	1	33.75	4.07 (A)
N x T x H x E	2	8.07	
N x T x Within	24	8.28	
N x B	1	29.40	8.72 (C)
N x B x H	2	4.77	1.42
N x B x E	1	11.27	3.34 (A)
N x B x H x E	2	1.25	
N x B x Within	24	3.37	
T x B	1	15.00	1.22
T x B x H	2	16.74	1.36
T x B x E	1	1.67	
T x B x H x E	2	7.35	
T x B x Within	24	12.27	
Residual	30	262.41	

A: $.1 > p > .05$ B: $.05 > p > .01$ C: $.01 > p$

TABLE A.3.4.

CHAPTER II EXPERIMENT C. DICHOTIC LISTENING. SECOND HALF LIST. ANALYSIS OF CO-VARIANCE. ADJUSTMENT FOR PRE-TEST DIGIT SPAN. ADJUSTED DEGREES OF FREEDOM.

Effect	D.F.	Var. Est.	F
Hypoxia (H)			
Linear	1	349.79	4.36 (B)
Quadratic	1	8.15	
Exposure (E)	1	69.21	
H x E	2		
Linear x Linear	1	283.89	3.54 (A)
Quadratic x Linear	1	54.59	
Subjects Within	23	80.31	

Within Groups Correlation = 0.449
Regression = 1.44

A: $.1 > p > .05$ B: $.05 > p > .01$

TABLE A.3.5.

CHAPTER II EXPERIMENT C. DICHOTIC LISTENING. SECOND HALF LIST. ANALYSIS OF VARIANCE. RAW SCORES.

Effect	D.F.	Var. Est.	F
Hypoxia (H)	2		
Linear	1	273.00	2.83
Quadratic	1	7.25	
Exposure (E)	1	207.20	2.15
H x E	2		
Differences in Linear	1	486.51	5.05 (B)
Differences in Quad.	1	119.01	1.23
Subjects Within	24	96.38	
Noise/Quiet (N)	1	1105.10	79.17 (C)
H x N	2	19.68	1.41
E x N	1	30.10	2.16
H x E x N	2	9.11	
N x Within	24	13.96	
Test/Retest (T)	1	148.84	9.75 (C)
H x T	2	30.71	2.01
E x T	1	2.20	
H x E x T	2	4.26	
T x Within	24	15.26	
Before/After (B)	1	110.70	21.05 (A)
H x B	2	13.68	2.60
E x B	1	.20	
H x E x B	2	5.31	
B x Within	24	5.26	

TABLE A.3.5. (Cont.)

Effect	D.F.	Var. Est.	F
N x T	1	0.50	
H x N x T	2	14.68	1.45
E x N x T	1	7.72	
H x E x N x T	2	0.99	
N x T x Within	24	10.09	
N x B	1	0.10	
H x N x B	2	10.53	2.19
E x N x B	1	24.66	5.14 (B)
H x E x N x B	2	9.78	2.03
N x B x Within	24	4.80	
T x B	1	10.84	2.06
H x T x B	2	9.92	1.89
E x T x B	1	7.01	1.33
H x E x T x B	2	9.02	1.71
T x B x Within	24	5.26	
Residual	30	71.82	

A: $.1 > p > .05$ B: $.05 > p > .01$ C: $.01 > p$

TABLE A.3.6.

CHAPTER III EXPERIMENT A. ANALYSIS OF EFFECTS OF 4 LEVELS ON PRESSURE ON 3 LIGHT-CANCELLING TASKS. CO-VARIANCE ADJUSTMENTS FOR AGE AND PRE-TEST SIMPLE LIGHT CANCELLING

	Analysis of Variance			Analysis of Co-Variance		
	D.F.	Mean Square	F	D.F.	Mean Square	F
Hypoxia (H)	3			3		
Linear	1	40.88	6.08(B)	1	47.43	8.37(C)
Quadratic	1	48.51	7.20(B)	1	27.64	4.88(B)
Cubic	1	0.08		1	1.81	
Within Groups	28	6.79		26	5.66	
Task (T)	2	4419.16	660.5(C)			
H x T	6	3.57				
T x Within Groups	56	6.69				

Within Groups Correlations Age r = -0.45
Pre-Test r = 0.23

B = .05 > p > .01 C = .01 > p

TABLE A.3.7.

CHAPTER III EXPERIMENT B. REACTION TIME AND MOVEMENT TIME. 3 LEVELS OF PRESSURE BY 2 AGE GROUPS. CO-VARIANCE ADJUSTMENT FOR PRE-TEST SIMPLE R.T. AND M.T.

		Reaction Time		Movement Time	
	D.F.	Adj.Mean Square	F	Adj.Mean Square	F
Hypoxia	2				
Linear	1	2376.97		1908.1	4.0(A)
Quadratic	1	5810.75	3.94(B)	64.0	
Age (A)	1	261.9		88.13	
H x A	2				
Diff.in Linear	1	3347.50		2101.91	4.41(B)
Diff.in Quad.	1	16918.40	1.15	651.80	1.37
Within Groups	23	14750.30		476.81	
Within Groups Correlation		r = 0.571		r = 0.570	

A = .1 〉 p 〉 .05 B = .05 〉 p 〉 .01 C = .01 〉 p

TABLE A.3.8.

CHAPTER III EXPERIMENT B. REACTION TIME. HYPOXIA BY AGE IN RELATION TO CHOICE, WIDTH OF KEY AND DISTANCE OF KEY.

	D.F.	Mean Square	F
Hypoxia (H)	2	56,255.36	2.71 (A)
Age (A)	1	56,376.67	2.72
H x A	2	20,704.07	
Within	24	20,713.16	
Choice (C)	1	94,024.01	62.5 (C)
C x H	2	753.31	
C x A	1	15,030.41	9.68 (C)
C x H x A	2	656.00	
Within	24	1,549.98	
Width (W)	1	437.01	
W x H	2	1,892.86	
W x A	1	6,825.21	2.55
W x H x A	2	205.26	
Within	24	2,677.20	
Key (K)	3	1,299.01	4.47 (C)
K x H	6	135.16	
K x A	3	220.69	
K x H x A	6	355.44	1.22
Within	72	290.51	

TABLE A.3.8. (Cont.)

	D.F.	Mean Square	F
C x W	1	118.01	
C x W x H	2	274.31	
C x W x A	1	81.67	
C x W x H x A	2	665.17	
Within	24	1,010.99	
C x K	3	417.72	2.29 (A)
C x K x H	6	336.81	1.84
C x K x A	3	278.29	1.52
C x K x H x A	6	133.86	
Within	72	182.7	
W x K	3	43.11	
W x K x H	6	150.94	
W x K x A	3	6.50	
W x K x H x A	6	125.78	
Within	72	184.06	

B = .05 $\rangle$ p $\rangle$ .01 C = .01 $\rangle$ p

TABLE A.3.9.

CHAPTER III EXPERIMENT B. MOVEMENT TIME. HYPOXIA BY AGE BY EFFECTS OF KEY DISTANCE AND KEY WIDTH.

	D.F.	Mean Square	F
Hypoxia (H)	2	1626.39	2.40
Age (A)	1	53.49	
H x A	2	1778.95	2.62 (A)
Within Groups	24	677.02	
Width (W)	1	6900.47	196.9 (C)
W x H	2	53.52	1.53
W x A	1	61.71	1.58
W x H x A	2	159.01	4.54 (B)
Within x W	24	35.03	
Distance (D)	3	6957.86	205.9 (C)
D x H	6	39.17	1.44
D x A	3	27.12	
D x H x A	6	29.83	
Within x D	72	33.79	
W x D	3	13.64	
W x D x H	6	66.27	2.88 (B)
W x D x A	3	14.05	
W x D x H x A	6	14.66	
Within x W x D	72	23.05	
Total	239		

C = $p < .01$ B = $.05 > p > .01$ A = $.1 > p > .05$

TABLE A.3.10

CHAPTER III EXPERIMENT C. REACTION TIME AND MOVEMENT TIME. EFFECTS OF ALTITUDE AND DURATION OF EXPOSURE. CO-VARIANCE ADJUSTMENT FOR PRE-TEST SIMPLE R.T. AND MOVEMENT TIME.

		Reaction Time		Movement Time	
	D.F.	Mean Square	F	Mean Square	F
Hypoxia (H)	2				
Linear	1	0.0		0.1	
Quadratic	1	53.83	6.22(B)	46.34	7.4 (B)
Time (T)	1	6.11		19.02	3.04
H x T	2				
Diff.in Linear	1	10.89	1.26	6.81	1.1
Diff.in Quad.	1	2.42		82.24	13.13(C)
Within Cells		8.66		6.26	
Within Cells Correlation		r = 0.321		r = 0.427	

$B = .05 > p > .01$ $C = .01 > p$

TABLE A.3.11.

CHAPTER III EXPERIMENT C. REACTION TIME. HYPOXIA BY AGE IN RELATION TO 4 REPLICATES OF 3 TASKS ON 10 KEYS. TIMES TRANSFORMED TO NATURAL LOGS.

	D.F.	Mean Square	F
Hypoxia (H)	2	28.04	3.13 (A)
Time (T_1)	1	3.49	
H x T	2	12.98	1.45
Within	24	8.955	
Task (T)	2	145.58	51.78 (C)
T x H	4	1.74	
T x T_1	2	3.31	1.16
T x H x T_1	4	2.43	
Within x T		2.85	
Key (K)	9	0.129	
K x H	18	0.171	1.21
K x T_1	9	0.188	1.33
Within x K	216	0.141	
Replicates (R)	3	1.133	1.92
R x H	6	2.68	4.55 (A)
R x T_1	3	0.633	1.07
R x H x T_1	12	0.795	1.35
Within x R	72	0.589	
T x K	18	0.284	1.99
T x K x H	36	0.090	
T x K x T_1	18	0.123	
T x K x H x T_1	36	0.108	
Within x T x K		0.143	

TABLE A.3.11 (Cont.)

	D.F.	Mean Square	F
T x R	6	0.470	
T x R x H	12	0.210	
T x R x T_1	6	1.145	1.98
T x R x H x T_1	12	0.358	
Within x T x R			
K x R	27	0.242	1.38
K x R x H	54	0.123	
K x R x T_1	27	0.090	
K x R x H x T_1	54	0.197	1.13
Within x K x R	648	0.175	
Residual	1614		
Total	3600		

A: $.10 > p > .05$ C: $.01 > p$

TABLE A.3.12

CHAPTER III EXPERIMENT C. MOVEMENT TIME. HYPOXIA BY AGE IN RELATION TO 4 REPLICATES OF 3 TASKS ON 10 KEYS. TIMES TRANSFORMED TO NATURAL LOGS.

	D.F.	Mean Square	F
Hypoxia (H)	2	19.60	2.67 (A)
Time (T_1)	1	15.78	2.14
H x T_1	2	12.57	1.71
Within Groups	24	7.34	
Task (T)	2	634.8	296.9 (A)
T x H	4	2.79	1.31
T x T_1	2	0.02	
T x H x T_1	4	1.63	
Within x T	48	2.138	
Key (K)	9	6.27	18.16 (C)
K x H	18	0.432	1.25
K x T_1	9	0.197	
K x H x T_1	18	0.513	1.49 (A)
Within x K	216	0.345	
Replicates (R)	3	7.480	22.06 (C)
R x H	6	0.268	
R x T_1	3	0.293	
R x H x T_1	12	0.238	
Within x R	72	0.339	

TABLE A.3.12 (Cont.)

	D.F.	Mean Square	F
T x K	18	3.177	10.56 (C)
T x K x H	36	0.353	1.17
T x K x T_1	18	0.300	
T x K x H x T_1	36	0.405	1.35 (A)
Within x T x K	432	0.301	
T x R	6	0.950	3.13 (C)
T x R x H	12	0.193	
T x R x T_1	6	0.322	
T x R x H x T_1	12	0.411	1.35
Within x T x R	144	0.304	
K x R	27	1.315	5.81 (C)
K x R x H	54	0.174	
K x R x T_1	27	0.406	1.80 (C)
K x R x H x T_1	54	0.226	
Within x K x R	648	0.226	
Residual	1614		
Total	3600		

A: $.1 > p > .05$ B: $.05 > p > .01$ C: $.01 > p$

TABLE A.3.13

CHAPTER IV. ANALYSIS OF VARIANCE OF ADDITION AND CLASSIFICATION TASKS. 3 LEVELS OF PRESSURE AND 2 TIMES OF EXPOSURE.

Effect	D.F.	Mean Square	F
Hypoxia (H)	2		
Linear	1	192.2	8.67 (C)
Quadratic	1	12.5	
Time (T_1)	1	67.5	3.05 (A)
T x H	2	0.77	
Within Cells	24	22.16	
Task (T)	1	388.80	28.69 (C)
T x H	2		
Diff. in Linear	1	28.80	2.13
Diff. in Quad.	1	3.75	
T x T_1	1	93.63	6.91 (B)
T x H x T_1	2		
Diff. in Linear	1	28.8	2.13
Diff. in Quad.	1	16.02	1.18
Within x T	24	13.55	
Replicate (R)	1	0.83	
R x H	2	14.16	1.91
R x T_1	1	0.53	
R x H x T_1	2	14.56	1.97
Within x R	24	7.38	
T x R	1	0.03	
T x R x H	2	18.26	2.12
T x R x T_1	1	4.80	
T x R x H x T_1	2	8.33	
T x R x Within	24	8.63	
Total	119		

A = $.1 > p > .05$ B = $.05 > p > .01$ C = $.01 > p$

TABLE A.3.14

CHAPTER V. DISCRIMINATION CARD SORTING EXPERIMENT A.
STATISTICAL ANALYSIS OF 4 LEVELS OF DIFFICULTY
REPEATED 4 TIMES AT 2 LEVELS OF ALTITUDE

	D.F.	Mean Square	F
Hypoxia (H)	1	1063.34	
Within H	22	2861.81	
Difficulty (D)	3	50285.47	101.7 (C)
Confusion Regr.	1	148038.30	299.5 (C)
Residual	2	1414.06	2.86 (A)
D x H	3	512.10	1.04
Diff. in Confusion	1	817.4	1.65
Within x D	66	494.3	
Replicates (R)	3	2741.85	29.79 (C)
R x H	3	22.76	
R x Within	66	92.04	
R x D	9	211.70	3.84 (C)
R x D x H	9	33.40	
R x D x Within	198	55.20	
Total	383		

A: $.1 > p > .05$ B: $.05 > p > .01$ C: $.01 > p$

TABLE A.3.15

CHAPTER V. EXPERIMENT B. ANALYSIS OF VARIANCE AND COVARIANCE. DISCRIMINATION CARD SORTING AT 3 LEVELS OF ALTITUDE IN 2 AGE LEVELS.

	D.F.	Mean Square	F	Adj.Mean Square	F
Hypoxia (H)	2				
Linear	1	908.2		45.0	
Quadratic	1	1739.1		193.0	
Age (A)	1	583.1		0.0	
H x A	2				
Diff. in Lin.	1	338.7		0.0	
Diff. in Quad.	1	3744.2		1714.0	2.58
Within	24	1532.16		663.4	
Difficulty (D)	1	236498.5	319.2	224.9	
D x H	2	1603.1		381.5	
D x A	1	51.06		143.0	
D x H x A		1997.2		869.0	1.71
Within	24	741.0			
Replicate (R)	3	420.64	6.15		
R x H	6	25.61			
R x A	3	74.73	1.09		
R x H x A	6	69.84			
R x Within	72	68.43			
R x D	3	75.01	1.09		
R x D x H	6	17.41			
R x D x A	3	45.86			
R x D x H x A	6	54.39			
R x D x Within	72	68.81			
Total	239				

TABLE A.3.16

EXPERIMENT 2. ANALYSIS OF VARIANCE ON AVOIDANCE PERFORMANCE AT 21% OR 9% WITH 1 OR 6 DAYS AVOIDANCE TRAINING.

	D.F.	Mean Square	F. Ratio
O_2 Concentration	1	0.0	
Days of Training	1	5.4	1.53
Interaction	1	18.9	5.37 (B)
Residual	14	3.52	

TABLE A.3.17.

EXPERIMENT 2. TREND ANALYSIS OF CHANGES PRE-TEST TO POST-TEST IN RED CELLS (P.C.V.) AND HEMOGLOBIN (Hb.) IN BLOOD.

		P.C.V.		Hb.	
	D.F.	Mean Square	F	Mean Square	F
O_2 Concentration					
Linear	1	25.2	3.37(A)	138.7	3.37(A)
Quadrate	1	2.0		.1	
Cubic	1	3.2		11.7	
Residual	20	7.92		41.17	

A: .1 〉 p 〉 .05 B: .05 〉 p 〉 .01 C: .01 〉 p

TABLE A.3.18.

EXPERIMENT 2. ANALYSIS OF VARIANCE OF P.C.V. AND Hb. CHANGES AT 21% OR 9% O_2 WITH 1 OR 6 DAYS OF AVOIDANCE TRAINING.

		P.C.V.		Hb.	
	D.F.	Mean Square	F	Mean Square	F
O_2 Concentration	1	37.7	10.69(C)	165.4	6.56(B)
Days of Training	1	14.7	4.16(A)	117.1	4.64(B)
Interaction	1	15.0	4.27(A)	2.0	-
Residual	20	3.52		25.2	

Probability Levels.

A = $.1 > p > .05$ B = $.05 > p > .01$ C = $.01 > p$

TABLE A.3.19.

ANALYSIS OF VARIANCE. DISCRIMINATION CARD SORTING AT 2 AGE LEVELS IN BOTH SEXES.

Effect	D.F.	Mean Square	F
Age (A)	1	59.9	
Sex (S)	1	8303.8	2.87
A x S	1	1408.3	
Within A x S	16	2892.5	
Difficulty (D)	3		
Confusion	1	120484.5	349.9 (C)
Residual	2	919.3	2.67
D x A	3	92.2	
D x S	3	26.7	
D x A x S	3		
Con. x A x S	1	1975.5	5.73 (B)
Resid. x A x S	2	109.4	
Within x D	48	344.3	
Replicate (R)	3	4937.0	
R x A		58.5	
R x S		188.4	1.71
R x A x S		66.8	
Within x A x S		110.3	
D x R		321.7	4.59 (C)
D x R x A		87.7	1.25
D x R x S		36.7	
D x R x A x S		19.2	
Within x D x R		70.1	

B: $.05 > p > .01$ C: $.01 > p$

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