EXPOSURE TO MILD HYPOXIA AND IMPLICATIONS FOR DECISION MAKING

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Abstract

Eight healthy male subjects were required to make speeded responses to the Manikin task and to complete a flight simulation instrument landing task during prolonged exposure to a partially oxygen-deficient environment (mild hypoxic hypoxia).

The subjects were exposed, in a hypobaric chamber, to experimental conditions at altitudes of Sea Level, 6,000ft, 8,000ft, 10,000ft, and 14,000 ft. All subjects served as their own controls.

The individual variability of physiological responses to the hypoxic insult, reported by other researchers, was confirmed. Accuracy on the Manikin was adversely affected by decreasing blood oxygen saturation. Changes in blood oxygen saturation were not correlated with reaction time on the Manikin task or any dependent variables on the Flight Simulator task. Implications for skill-based and rule-based decision-making in gliding and the use of supplementary oxygen are discussed.

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INTRODUCTION

The absence of an adequate supply of oxygen to the tissues is termed *hypoxia*. Glider pilots, like all humans, are vulnerable to the effects of oxygen deprivation and severe or acute hypoxia nearly always results in a rapid deterioration of body functions. The cells of the brain are particularly sensitive to a lack of oxygen. *Hypoxic hypoxia* occurs when breathing air due to the reduction in the partial pressure of oxygen as atmospheric pressure decreases with increasing altitude. It is caused by the absence of an adequate supply of oxygen in arterial and capillary blood.

Oxygen is transported between the lungs and the tissues by haemoglobin molecules in the blood. The combination of haemoglobin and oxygen is a loose and reversible bond allowing haemoglobin to pick up and unload oxygen according to the metabolic need and demand. The *percentage saturation of arterial haemoglobin* (SaO_2) describes the ratio of oxyhaemoglobin molecules to the total number of haemoglobin molecules available to bind with oxygen. This is also referred to as *blood oxygen saturation*.

An individual exposed to hypoxic hypoxia, at about 10,000 ft, experiences a reduction in their SaO_2 level from a sea level value of about 98% to a value of approximately 92% to 93%. In response to this relatively mild insult, the respiration and cardiac rates increase slightly. These physiological responses continue as altitude increases. Breathing air at 25,000 ft results in a doubling of the heart rate and an increase of 40 to 60% in the respiratory rate. For a normally healthy person, these responses provide a measure of protection up to about 13,000 ft for periods of less than 60 minutes.

The physiological effects of hypoxia are well understood in terms of gaseous exchange, times of useful consciousness and physical reactions, and excellent summaries are available in the literature (e.g., Ernsting, Nicholson & Rainford, 1999). The full range of accepted visual, general physiological, and neuro-muscular symptoms induced by hypoxic hypoxia is detailed in Table 1. The altitude at which significant effects of hypoxia occur can be lowered by a number of factors. Physical activity, extremes of temperature, and anxiety all increase the body's demand for oxygen and hence its susceptibility to hypoxia. Carbon monoxide inhaled in smoking and certain medications can also reduce the oxygen-carrying capacity of the blood and magnify the effects of hypoxia.

Table 1 Physiological and psychological effects on humans exposed to hypoxic hypoxia

Visual	General	Neuro-muscular
Decrease in colour perception	Euphoria	Clumsiness
Decrease in peripheral awareness	Task fixation	Fine tremor
Decrease in acuity	Personality changes	Slurring of speech
Dimming	Fuzziness (not dizziness)	Slow movements
	Amnesia	Hypoxic 'flap'
	Lethargy	
	Mental confusion	
	Sensitivity to cold or heat	
	Cyanosis	
	Loss of self criticism, judgement	

As altitude increases, the various symptoms are accentuated and the time required for their onset reduces. A summary of specific cognitive effects and their trigger altitudes, as detailed by Ernsting et al. (1999), is shown in Table 2.

Table 2 Cognitive effects of acute hypoxic hypoxia and the altitudes at which they can be expected to occur

Altitude (feet)	Effects of Exposure
Above 5,000	Light sensitivity of the dark-adapted eye affected
Above 8,000	Short- and long-term memory affected
Above 10,000	Complex hand-eye co-ordination affected Performance on previously learnt coding and conceptual reasoning tasks affected
Above 12,000	Performance on pursuit motor tasks affected Choice reaction time on well learned tasks affected
Above 15,000	Fine hand tremor reduces ability to make precise adjustments
Above 16,000	Simple reaction time increased

While the effects of unprotected exposure to high altitudes are both rapid and harmful, the research on the effects of hypoxic hypoxia on humans at altitudes up to 15,000 ft is much less precise. Henderson, McCarthy & St George (1995) proposed that the failure to find consistent effects of hypoxia on performance, in this area of research, might be due to one or more of the following confounding variables:

1. The use of naive subjects with no previous exposure to hypoxia in a hypobaric chamber where their ignorance creates apprehension (Berkun, Bialek, Kern & Yagi, 1962; Denison, Ledwith & Poulton, 1966; Ledwith, 1968 and 1970; Crow & Kelman, 1969 and 1973; Fiorica, Burr & Moses, 1971; Green & Morgan, 1985; Schlaepfer, Bärtsch & Fisch, 1992).

2. The variability of experimental altitudes achieved utilising gas mixtures to simulate the reduced partial pressures of oxygen at altitude (e.g. Denison et al., 1966; Cahoon, 1970; Fiorica et al., 1971; Billings, 1974; Fowler, Paul, Portier, Elcombe & Taylor, 1985; Fowler, Elcome, Kelso & Porlier, 1987; Schlaepfer et al., 1992; Farmer, Lupa, Dunlop & McGowan, 1993; McCarthy, Corban, Legg & Faris, 1995; McCarthy, Hill & Legg, 1995).

3. Individual variations in the physiological response to hypoxia. The critical independent variable being the 'effective' altitude of the subject, as measured by SaO_2, rather than their 'nominal' altitude measured by the altimeter (Fowler et al., 1985; Knight, Schlichting, Dougherty, Messier & Tappan, 1991; Paul & Fraser, 1994; Cottrell, Lebovitz, Fennell & Kohn, 1995; McCarthy, Hill & Legg, 1995). In addition, few experiments have measured individual subject SaO_2.

4. The use of tasks with little relevance to those performed in the aviation environment. Those that have used tasks such as 2D tracking and monitoring (e.g. Figarola & Billings, 1966; Chiles, Iampietro, Higgins, Vaughan, West & Funkhouser, 1971; Collins, Mertens & Higgins, 1985) have shown conflicting results.

The aim of the present study was to determine the effects on the performance of pilots during prolonged exposure to a partially oxygen-deficient environment (mild hypoxic hypoxia). The specific issues identified above related to experimental designs in previous research investigating the effect of exposure to mild hypoxia. This study sought to manage each of these design issues by using experienced subjects, inducing the hypoxic insult in a hypobaric chamber, using individual SaO_2 levels as the independent variable, and by incorporating a piloting task.

Measures of Dependent Variables

Two tasks were used for this study, the first being the Manikin figure task incorporated in the Walter Reed Performance Assessment Battery, which has been used to study the effects of sleep deprivation, circadian disrhythmia, heat stress, physical fatigue, and hypoxia (Thorne, Genser, Sing & Hegge, 1985). The Microsoft Flight Simulator Version 5.0 software provided the subjects with a simulated Instrument Landing System (ILS) approach. This was the same task used by Rasmussen &

Hasbrook (1972) to investigate pilot performance on an ILS task during successive in-flight simulated instrument approaches.

The Manikin Task

Since 1966 a number of researchers have used a Manikin figure, as shown in Figure 1, to investigate the effects of hypoxia on cognitive performance (e.g., Denison, et al., 1966; Fowler et al., 1985; Farmer et al, 1993; Paul & Fraser, 1994). The task was devised by Benson and Gedye (1963) to test the ability of pilots to orientate themselves with respect to an external visual reference system.

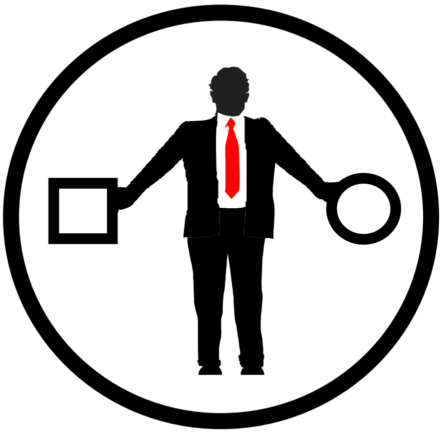

Figure 1 The Manikin Figure shown in the upright orientation. The border and hand-held symbols may be either coloured or, as shown, a circle or square. The shape of the surrounding border determines which is the correct stimulus. The subjects are required to identify the hand in which the stimulus is being held.

Previous researchers have used Reaction Time (RT) as the dependent variable and the accuracy of responding has rarely been considered. The required responses to this task can be viewed as a signal-detection task. Signal-detection theory assumes that the subject has two possible responses - one when the required stimulus is present and an alternative response when the stimulus presented is not the required stimulus. There are, therefore, four possible responses: (a) a *Hit* - the correct selection of the required response when the target stimulus is present; (b) a *False Alarm* - an incorrect selection of the required response in the absence of the target stimulus; (c) a *Miss* - the incorrect selection of the required response in the presence of the inappropriate stimulus; and, (d) a *Correct Rejection* - the correct selection of the alternative response when the stimulus presented is not the required stimulus.

The Manikin task required the subjects to respond with the selection of *Left* or *Right* via a computer keyboard. For this research, a ‘Hit’ was, arbitrarily, assigned as being the correct selection of ‘Left’ when the stimulus (the target symbol) was in the Manikin’s left hand. Consequently the correct selection of ‘Right’ was defined as a ‘Correct Rejection’. The four possible signal-detection events are shown in Figure 2.

		RESPONSE	
		LEFT (Press ‘V’ Key)	RIGHT (Press ‘M’ Key)
STIMULUS	Target Symbol in Manikin Left Hand	Hit (H)	Miss (M)
	Target Symbol in Manikin Right Hand	False Alarm (FA)	Correct Rejection (CR)

Figure 2 Matrix of possible signal-detection responses to the Manikin task

The frequencies of these four events are determined by two factors: how good the subject is at the task; and, their disposition towards a particular response. The sensory ability of the subject and the distinctiveness of the stimulus influence the first factor. The second factor is influenced by the rewards or penalties for responding correctly or incorrectly, and the relative frequency of presentation of the stimulus. Signal-detection theory separates an individual’s performance into two distinct measures: (a) *Stimulus discriminability*, which is a measure of accuracy; and (b) *Response bias*, which is a measure of the extent to which the subject favours one response over another independently of the sensory evidence provided. Davison and Tustin (1978) derived the measure of discriminability used in this research. As the probability of the presentation of ‘left’ or ‘right’ was set at .5 in this study response bias (log *b*) was not included as a dependent variable as it was not manipulated. A response-bias free measure of discriminability (log *d*) is given by:

$$\log\ d = .5 \log \left(\frac{H \times CR}{M \times FA} \right) \tag{1}$$

The Flight Simulator ILS Task

The dependent variables obtained from the Flight Simulator task all involved measures of the subject's ability to maintain the position of the 'aircraft' within vertical altitude and heading limits at a target airspeed. The nature of the ILS task is such that it could be expected that sinusoidal error responses would be evident. A mathematical measure of the deviations, assuming a balanced sinusoidal flightpath was achieved, would therefore result in the sum of the errors being zero. In similar experiments, using data derived from aircraft tracking tasks, (Hasbrook & Rasmussen, 1971; Rasmussen & Hasbrook, 1972) absolute values were measured for all dependent variables to provide a model of the actual performance achieved. Chiles et al. (1971) also used absolute measures for their dependent variables on a tracking task. As a result, absolute values were also measured for all dependent variables obtained on the Flight Simulator ILS task in this experiment.

METHOD

Subjects

Eight volunteer subjects were drawn from amongst Royal New Zealand Air Force (RNZAF) pilots as they were familiar with the hypobaric chamber, had been exposed to hypoxia indoctrination training in the chamber, were trained to recognize the dangers of hypoxia, and were all experienced with exposure to prolonged mild hypoxia. The subjects were required to be physically fit, non-smokers, not on medication, and were required to abstain from alcohol for 48 hours prior to each experiment and to report any abnormal sleep patterns.

Apparatus

The hypoxic condition was induced by exposing the subjects to reduced atmospheric pressure in the hypobaric chamber at the RNZAF Auckland Aviation Medicine Unit facility. This procedure ensured that the subjects were physically exposed to the combination of reduced atmospheric pressure and hypoxia, and avoided the restrictions associated with the use of masks for breathing. The pressure demand oxygen system fitted to the chamber was isolated from the external supply to minimize the risk of free oxygen leaking into the chamber. Four roof-mounted fans provided ventilation of the main compartment.

The Walter Reed Manikin program ran on an IBM compatible DSE 386 25 MHz processor with a 35 cm SVGA monitor. An Adventech PCL-830 timer card was added to the computer to provide the timing accuracy required for the software package.

The ILS task was proprietary Microsoft Version 5.0 Flight Simulator software. The software was installed on an IBM compatible 486 DX2 66 MHz computer and the imagery displayed on a Phillips 50 cm monitor. Control inputs for the aircraft were provided through a proprietary Flightmaster control device comprising a yoke-style control column, rudder pedals, a rotary elevator trim switch, and a single lever throttle. The flight profile and aircraft configuration of each approach was recorded using the Microsoft *video record* software option for subsequent analysis.

A Nellcor N-200E Pulse Oximeter, using a ten to fifteen second averaging time, was used to provide non-invasive and continuous measures of functional oxygen saturation of arterial haemoglobin. The Nellcor D2-25 adult oxygen adhesive transducer sensor was attached to the little finger on the subject's non-preferred hand and was protected from external illumination by multiple layers of black stocking material.

The researcher was protected from hypoxia by the use of the Mountain High Equipment and Supply Company Model A-1 analogue computer electronic oxygen delivery system. This system provided a pre-determined bolus of oxygen with each breath and minimized the possibility of a subject being exposed to oxygen-enriched air because of the proximity of the researcher at any time during the experiment.

The composition of the free chamber air was assessed using a Datex Oscar$_{oxy}$ SCO-123 monitor. The sampling line was positioned above the computer workstations. The chamber ventilation fans were operated as necessary, during periods when subjects were not engaged in a task, to maintain the chamber temperature between 20^0C and 22^0C.

Procedure

Training was conducted in the hypobaric chamber and was completed on the day immediately prior to the first day of experiments for each subject.

The subjects were exposed to five experimental conditions at chamber altitudes of 500 ft (Control condition), 6,000 ft, 8,000 ft, 10,000 ft and 14,000 ft. Fifteen minutes was provided for the ascent followed by fifteen minutes rest after the altitude had been established to allow for physiological accommodation prior to the presentation for any tasks. The 14,000 ft condition was used primarily to provide SaO_2 data prior to a descent to the 10,000 ft condition. The subjects were not aware of the actual chamber altitude.

A repeated measures design was used with subjects serving as their own controls. The sequence in which the tasks were presented was repeated every two hours. Three blocks of tasks were completed in the Control, 6,000 ft and 8,000 ft conditions, and two blocks of tasks in the 10,000 ft condition.

SaO_2 levels for each subject were monitored to enable individual responses to the hypoxic insult to be assessed. Arterial blood samples were taken while the subjects were stable at a chamber altitude of 10,000 ft to provide a baseline physiological measure of 'effective' altitude to be determined relative to the 'nominal' altitude of the hypobaric chamber.

The potential effects of fatigue were reduced; the chamber was quiet and vibration free, the experimental conditions were completed between the hours of 8 am and 5 pm and subjects completed no more than three experimental conditions on consecutive days.

The Manikin Task

The Manikin task was presented on a computer screen with a figure inside either a green or red square, and holding a green or red square in either the left or right hand. The figure was randomly presented in one of four orientations: front-on upright or inverted, and rear-view upright or inverted. The subjects were instructed to respond as quickly and as accurately as possible. The subject initiated the commencement of each block of 264 trials. After each response the screen was blanked for 300 msecs and then the next figure was presented.

Subjects were given immediate feedback after each trial with the word ‘Correct’ or ‘Error’ being displayed on the screen as appropriate and were provided with an on-screen display at the completion of each block showing the number of trials of the task that had been completed, the percent correct and the mean RT. The dependent variables recorded for the Manikin task were the RT for all responses and the value for log d (accuracy), computed in accordance with Equation 1.

The Flight Simulator ILS Task

The Flight Simulator instrument landing task was based on the Instrument Landing System (ILS) approach on runway 28 Left at San Franciso using the Learjet 35 aircraft. The subjects were given control of the aircraft in stable flight at an altitude of 3,000 ft, 20 nautical miles from the runway, with the autopilot engaged. The approach was conducted with no external imagery visible through the aircraft 'windscreen'. The subjects were required to fly the approach accurately down to the minimum published altitude for the ILS approach of 200 ft above ground level. At this point the subjects were required to pause the program, not land the aircraft.

Control of the aircraft configuration was through the keyboard with the appropriate keys acting as toggle switches. Labels placed on the keys identified the control function of each key.

The dependent variables recorded for the ILS task were aircraft altitude, heading, vertical speed, and indicated airspeed. The value for each dependent variable was extracted at 0.1 DME intervals from 15 DME to the point at which the simulator was put on hold.

RESULTS

Physiological Measures

A Pearson product-moment correlation was conducted on the arterial blood data. The arterial blood samples showed a significant correlation with the digit oximeter readings (r (4) = .954, $p < .05$). The manual readings and oximeter readings were also significantly correlated (r (4) = .970, $p < .05$). These correlations provided confidence that the values of SaO_2 obtained during this study were valid. Arterial blood samples were only obtained from four subjects due to the other subjects experiencing physiological problems during the blood extraction, including one who fainted.

Individual effective altitudes, as defined by the SaO_2 levels, varied considerably from the nominal chamber altitude. For example, at the 14,000 ft nominal chamber altitude, the effective physiological altitude of subject 3 was about 17,000 ft and that of subject 6 about 12,000 ft, but a one-way ANOVA test, to consider between-subject differences, was not significant (F = 0.811, MSE = 18.16). A non-parametric trend test

(Kendall, 1955) showed that the SaO_2 levels decreased significantly as the nominal altitude of the chamber was increased ($n = 8$, $k = 5$, $z = 6.41$; $p < .01$).

In addition, a significant Pearson product-moment correlation was found between the SaO_2 after the chamber had been stable at altitude for 10 minutes and the SaO_2 during the first experimental task ($r\ (30) = .946$, $p < .01$). This provided evidence that the subjects were physiologically stable prior to testing commencing. The SaO_2 values, for each subject at each nominal altitude are shown in Figure 3.

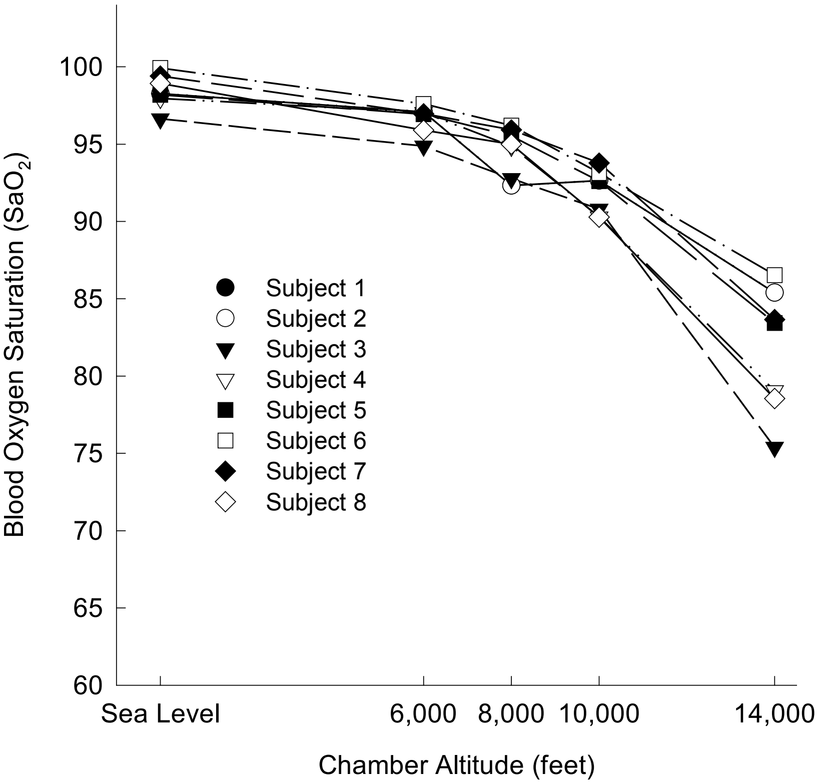

Figure 3 Individual mean blood oxygen saturations as a function of chamber altitude

Measures of Dependent Variables

Pearson product-moment correlations were conducted to investigate the effect of SaO_2 on performance. The data from four conditions; Control, 6,000 ft, 8,000 ft, and 10,000 ft, was included in these analyses. The Pearson product-moment correlation yielded a significant correlation between SaO_2 and accuracy (log *d*) on the Manikin task ($r\ (32) = .465, p < .01$) as shown in Figure 4. Reaction Time was not significantly correlated with SaO_2 ($r\ (32) = .274, p > .05$), and so is not plotted.

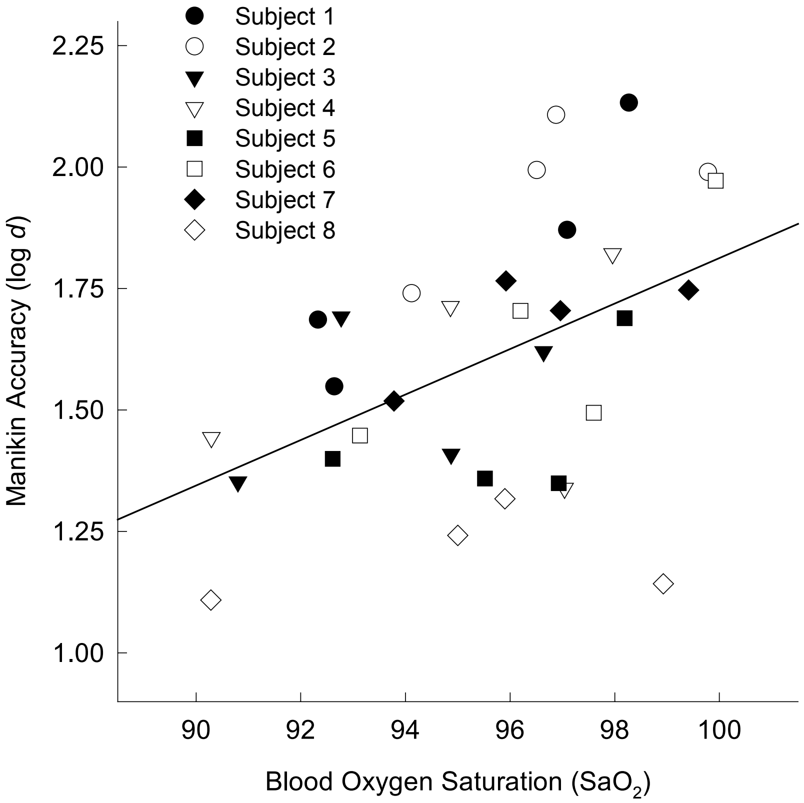

Figure 4 Accuracy (log *d*) for individual subjects and the correlation between subjects, as a function of blood oxygen saturation

The grouped results for the Flight Simulator ILS task dependent variables, by experimental condition, are provided in Table 3. There were no significant correlations between SaO_2 and the Flight Simulator ILS task dependent variables.

Table 3 Group means and standard deviations for Flight Simulator ILS task as a function of the experimental condition

Dependent Variables		Condition Control *n = 9*	 6,000-ft *n = 9*	 8,000-ft *n = 9*	 10,000-ft *n = 6*
Altitude (ft)	*M*	83.70	85.88	88.14	80.65
	SD	45.15	43.97	62.56	39.26
Heading (^{o})	*M*	1.10	1.22	1.08	1.14
	SD	0.47	0.72	0.46	0.46
Vertical Speed (ft/min)	*M*	330.32	365.80	336.18	325.31
	SD	134.62	139.44	122.65	99.49
Air Speed (knots)	*M*	7.13	8.49	6.53	7.31
	SD	8.04	8.05	8.87	7.59

Environmental Factors

The measured percentage of oxygen in the chamber air remained at 21%. The mean overall temperature in the main compartment of the hypobaric chamber was 21.6^{o}C with a *SD* of 1.22^{o}C. The mean temperature gradually increased during each experimental condition, rising by an average of 2.5^{o}C over the period.

DISCUSSION

Physiological Responses

The digit transducer sensors and NELLCOR N200-E pulse oximeter equipment provided accurate predictions of the level of SaO_2 at a chamber altitude of 10,000 ft when compared to the values of saturation obtained from the analysis of arterial blood samples. The significant correlation of oximeter and arterial blood SaO_2, at 10,000 ft, made it reasonable to assume that the oximeter values obtained throughout each experimental condition were valid.

The subjects were drawn from military aircrew and all had experience of acute hypoxic symptoms during their RNZAF training while being exposed to known altitudes of 20,000 ft and 25,000 ft. The use of experienced and knowledgeable subjects avoided the difficulties identified by previous researchers regarding naive subjects possibly experiencing apprehension and anxiety while in the hypobaric chamber. There was no overt evidence that the subjects were apprehensive or anxious in the hypobaric chamber during testing. The stability of the blood oxygen saturations prior to the commencement of testing supports the contention that the subjects were not apprehensive.

The initiation of the exposure to hypoxic hypoxia through the use of a hypobaric chamber avoided the difficulties identified by Colrain (1988) and Ernsting et al. (1999) regarding the breathing difficulties induced by the use of masks. The use of a hypobaric chamber to induce the hypoxic insult also ensured that the subjects were physiologically immersed in the reduced atmospheric pressure and exposed to an identical environment.

The range of saturations obtained in each condition (Figure 3) show similar results to those obtained by McCarthy, Corban, Legg & Faris (1995), McCarthy, Hill & Legg (1995) and documented by Cottrell et al. (1995). This variability in individual response leads further evidence to the fact that the “effective altitude”, proposed by Fowler et al. (1987), and as measured by the level of saturation, may be more relevant to the effect of the hypoxic insult on individual performance than the actual environmental altitude.

The variation in individual SaO_2 responses lends evidence to concerns raised in regarding the actual altitudes achieved in previous research where measured values of SaO_2 differed from the intended test altitude. Between-subjects differences in blood oxygen saturation were, however, not significant, and the non-parametric trend test showed that the SaO_2 values decreased with increasing altitude.

Measures of Dependent Variables

Accuracy on the Manikin task (measured by the discriminability function log *d*) reduced with decreasing blood oxygen saturation as shown in Figure 4. This figure also shows the individual variability of responses but the significant relationship between SaO_2 and accuracy is evident. This suggests, as a result of the significant tendency for SaO_2 values to decrease with increasing altitude, that accuracy on the Manikin task would also decrease if measured against altitude. However, as the intention of this study was to consider SaO_2 as an independent variable, the relationship of accuracy and nominal chamber altitude was not explored.

The resulting decreased accuracy with decreased blood oxygen saturation, with no change in RT, adds to the body of conflicting literature regarding the effects of mild hypoxia at intermediate altitudes. The reduced accuracy supports the findings of Denison et al. (1966) and McCarthy, Corban, Legg & Faris (1995).

The lack of any detectable change in performance, over blood oxygen saturation, on the Flight Simulator dependent variables is consistent with the findings of Collins et al. (1985) who reported no effect of altitude on a tracking task performed at 12,500 ft. In contrast Chiles et al. (1971) reported increased errors on a tracking task at 14,000 ft when combined with an arithmetic task. However, direct comparisons with these studies must be treated with some caution as SaO_2 values were not measured for the subjects in these studies.

The dependent variables on the Flight Simulator ILS task were, effectively, all measures of accuracy. The more accurately the subject managed the simulated approach the smaller the deviations one would expect to observe for each of the dependent variables. The absence of any effect of the hypoxic conditions on accuracy on the ILS task contrasts with the significant reduction in accuracy on the Manikin task with decreasing blood oxygen saturation. This raises the question as to the exact cognitive requirements of the ILS task compared to the Manikin task.

The management of an aircraft flying an instrument approach falls into the category of a *skill-based behaviour* (Rasmussen, 1983). Performance is governed by stored patterns of pre-programmed instructions. In this case, for example, if the aircraft is above the glideslope then well-practiced control inputs are made to pitch the nose of the aircraft down to increase the rate of descent and return to the glideslope.

The task of managing the flight path of the flight simulator aircraft requires spatial orientation and judgement. The accurate performance of this task requires concentration and practice. The subjects were familiar with the task from their flying training and it is suggested that the required elements of the task, especially the assessment of the subtle changes of control required to manage the flight path, were being performed at the skill level. The results of this research suggest that behaviour, at the skill-based level, is not affected by exposure to hypoxic conditions resulting in decreased SaO_2 values in the order of 90 – 94%. This is consistent with the results reported by Collins et al. (1985) and Rasmussen & Hasbrook (1972), when the only task that was being performed was a tracking task.

Rasmussen (1983) also proposed the category of *rule-based behaviour* where the solutions to familiar problems are governed by stored rules of the type “if (state) then (action)”. Errors at this level are typically associated with the misclassification of situations or stimuli leading to the application of the wrong rule as a response. This follows signal-detection theory rationale where the selection of a response requires a decision as to the presence or absence of a stimulus. It is suggested that the Manikin task, requiring the correct recognition of spatial orientation and the matching of the stimulus shape to the Manikin’s hand, to enable a correct response, could be described as a rule-based task. Accuracy on the Manikin task, by comparison to the Flight

Simulator ILS task, was more sensitive to the effects of blood oxygen saturation. The results from this study suggest, therefore, that tasks requiring rule-based behaviour, such as the Manikin, are more appropriate for the investigation of the subtle effects of hypoxia on cognitive performance in the aviation environment.

Rasmussen (1983) also proposed a third level of behaviour – *knowledge-based behaviour* where conscious analytical processes must be used, in conjunction with stored knowledge, to solve novel situations. It is suggested that the Manikin task does not require this level of cognitive functioning.

Performance on the dependent variables was unlikely to have been affected by environmental factors. There was no evidence of any increased percentage of oxygen in the chamber and the temperature of the chamber environment was appropriate for the type of tasks being completed. Industry standards vary, but Bell (1974) notes that, in the United States, optimal temperatures for workers undertaking light work lie within the range 20°C to 22°C, while in the United Kingdom an air temperature of 19.5°C to 20°C is suggested as suitable for clerical workers.

Implications for Gliding

The finding that a skill-based task, the simulation of an instrument landing task, is not affected by exposure to acute mild hypoxia producing SaO_2 saturations generally equivalent to an altitude of 10,000 ft, suggests that the existing requirement that supplementary oxygen be used above 10,000 ft may be appropriate for the basic tasks of flying a glider. However, the demands of competitive flying require that constant decision-making also occur (Moffat, 1974). These decisions will involve the application of rule-based behaviours and even knowledge-based behaviours.

Consequently, the requirement to ensure that glider pilots are functioning at a sufficiently competent level must be based on their ability to perform rule-based and knowledge-based decision making. When the implication for decision making is combined with the now, well documented, variability in individual response to a hypoxic insult, the results of this study suggest that competitive glider pilots should consider using supplementary oxygen at altitudes significantly below 10,000 ft in order to maintain a high level of blood oxygen saturation to improve their rule- and knowledge-based decision making abilities.

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