LOW LEVEL HYPOXIA - THE CASE FOR ITS RECOGNITION

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"The minimum altitude at which cognitive and psychomotor performance becomes significantly impaired has been, and remains, a controversial issue with important implications for flight safety."[1]

INTRODUCTION

"Mild" hypoxia, or as the Air Safety Investigators often call it, "Pilot Error", has been recognised as a hazard from at least the time of World War 1. Unfortunately, there was, and still is, considerable disagreement on how much of a hazard mild hypoxia can be. Today, most pilots accept that hypoxia may have some affect on crew performance, but certainly not below 10,000 feet (3,000 m), because the regulations permit "normally aspirated" operation up to this level. Many also believe recovery from hypoxia occurs on descent. Fatigue, including hypoxia induced fatigue, is accepted as a normal part of flying.

There is plenty of anecdotal evidence that flight crew make errors in the air that they would never make on the ground.

So as not to embarrass anyone else, I will have to use my own examples, all in situations that occurred at altitudes well below 10,000 feet.

1 The first example is on a flight test for initial issue of an Instrument Rating.

A Departmental Examiner was seated in the right hand seat.

I completed the NDB and ILS approach procedures without problem, there was only a simple VOR approach at Mangalore to finish.

With the Approach Plate open in front of me I entered the holding pattern by turning the wrong way.

I didn't realize the error until the examiner told me on the ground, after engine shutdown.

2 The second example occurred on approach to Sydney, at 3000 feet in a Cessna 310R, after a flight from Coolangatta at 8000 feet. A warning horn sounded. A check of airspeed and undercarriage ruled out stall and gear warnings. As it was not the time or place for detailed investigation, I continued the

approach, hoping that I would be able to handle whatever was about to happen. On the landing roll, the left engine stopped. Then I remembered. I had forgotten to change tanks from auxiliaries back to mains after the mandatory 3 hours! Potential double engine failure. Later, when told about this, two very experienced senior pilots admitted having double engine failures when they began flying a 310R.

3 The third example occurred above Adelaide in Cessna 182 in heavy traffic. Control carefully instructed a left turn onto a heading 270 degrees different, then watched because they knew that I was going to turn right.

4 Other examples also point to a similar problem. Travelling as an airline passenger to China during the 1980's, I would take contracts and documents in the plane, with the intention of using the eight or nine hours on the flight to work on them. It was always too hard, and I never got anything done.

You can probably add some that got plenty of publicity, and heaps that didn't.

MINIMUM OXYGEN REQUIREMENTS

The minimum oxygen content allowed in the workplace at sea level by the British Health and Safety Executive and the Australian National Occupational Health and safety Commission is 18%, compared the oxygen content equivalent to 15% at sea level in a commercial aircraft cabin.[2]

As noted in the Winder and Balouet paper at this symposium, the percentage concentration of oxygen does remain unchanged at altitude, at about 20.9%, but the actual amount of oxygen in the same volume of air decreases as the pressure drops with altitude. Atmospheric pressure at sea level is about 760 mm. Hg. with a corresponding partial pressure of oxygen of 159 mm. Hg.

The minimum O_2 concentration for work, noted above, of 18%, is equivalent to 136 mm. Hg. A minimum oxygen partial pressure of 118 mm Hg. (equivalent to an altitude of about 8000ft/2500 m is usually maintained in commercial aircraft cabins. Civil Aviation Order 20.4 permits flight crew to operate in an oxygen partial pressure of 109 mm. Hg. (10,000 ft/3050 m.), and for up to eight hours!

Laboratory research, with controls, into low level hypoxia has in the past produced mixed results. A subject's performance in an already learned task is less affected by hypoxia than in performing a new task.[3] The problem has always been that the subjects have to be shown what to do before the test. Then it is no longer new. The response and tolerance of individual subjects varies , and subjects usually seem to be 18 to 31 year old, fit and male.

There has been a steady stream of papers on the effects of low level hypoxia over the last 20 years.[1,3,4,5] There is enough evidence to suggest a re-evaluation of the altitudes or the criteria requiring the use of supplemental oxygen.

In summary, these papers are saying:

- There is variability in the effect of altitude on blood oxygen saturation level, or SaO2, between people, and in the same person depending on his condition and state of arousal, and variability in effect of SaO2 on cognitive, memory, decision making performance, and on the delay in reacting.[1,3,5]
- Saturation levels of oxygen (SaO_2) levels at 8,000 feet are conventionally accepted as being 90%. Testing indicates this is mean only for exposure of half an hour, with variation from 85% to 93% going down to 80% when you doze off.[6]
- No strong evidence appears for any particular level for which supplemental oxygen should be required.
- Highly variable responses and tolerances to hypoxia indicates a conservative approach to the use of supplemental oxygen.
- "...hypoxia can selectively affect the two components of an observer's decision making behaviour - their sensory capability, and their preference (or, bias) for making one decision over another."[4]
- Task learning under hypoxic conditions (8000 feet) was impaired. Poor performance continued on return to normoxic conditions. By contrast tasks learnt at sea level conditions appear to be performed better under hypoxic conditions.[3]
- Signal detection tests show response times slower at 7000' than sea level.[4]
- The magnitude of the effect is dependent on SaO_2 history - that is, the time that the subject has been at altitude. Recovery of cognitive function particularly, takes time.[1] This is similar to the situation in sports medicine called Oxygen Debt.
- Hypoxia subject "often unaware of the occurrence of symptoms, even though objective physiological indicators clearly point to a hypoxic state". Symptoms that are observed often attributed to other causes.[3]
- "Low oxygen tension profoundly disturbs cerebral functioning."[1]
- "Arterial oxygen tensions tend to fall after the fourth decade."[7]

- Exercise or workload lowers SaO2 level.
- Smokers more susceptible to hyperventilation, and performed slower and less accurately.[7]
- There was a case for different altitudes for supplemental oxygen.[8]
- Consumption of 50 g of alcohol is reported to lower SaO2 by about 8% at 9000 feet and raise $SaCO_2$ by 5%, but not at sea level.[9] Irritability and aggression are common symptoms of hypoxia or anoxia, and suggest a physiological basis for the phenomenon known as "air rage".)

FAA CAMI SIMULATOR RESEARCH

In April 1997, the FAA Office of Aviation Medicine, Civil Aeromedical Institute published a report looking at simulator performance under mild hypoxic conditions.[1]

This study compared the performance in simulated cross-country flights, of ten general aviation pilots under mild hypoxic conditions, and ten others maintained at sea level conditions.

The Figures below are reproduced with the kind permission of Dr Tom Nesthus.

Figure 1 shows the blood saturation, measured by a pulse oximeter, of oxygen in pilots in response to increase altitude under simulated conditions. The effect of altitude on blood oxygen saturation level was to reduce it from about 99% saturation at sea levels, to around 96% at 8000 feet.

Figure 1: Blood Oxygen Saturation and Altitude

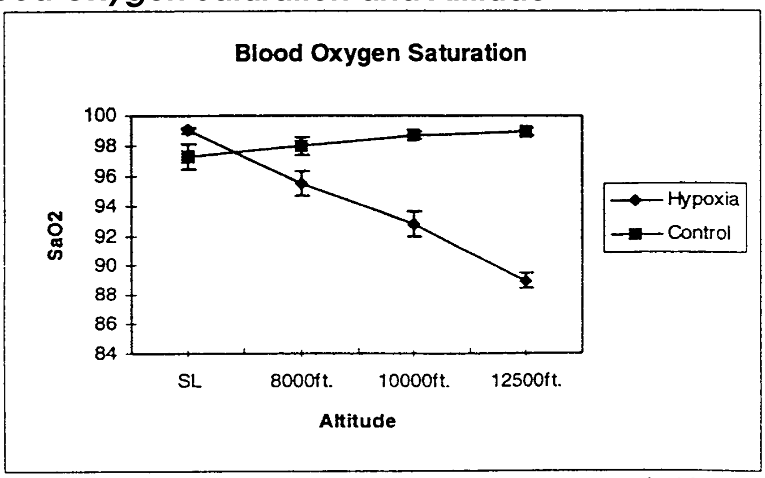
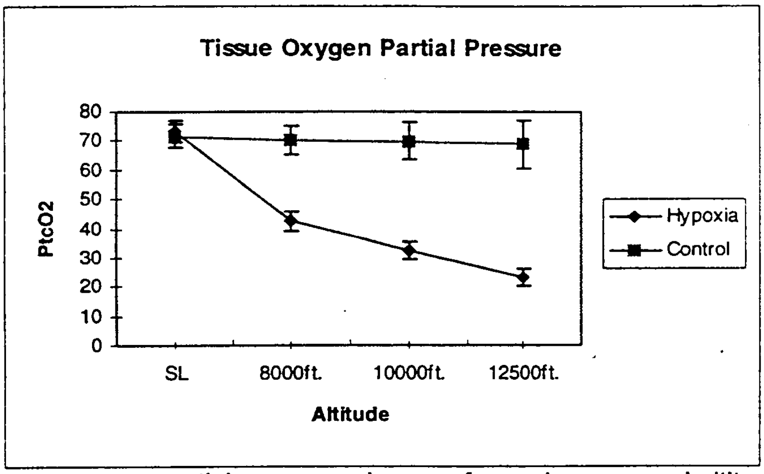


Figure 2 shows the tissue partial pressure of oxygen in pilots measured using a Radiometer (TCM-3). There is an even more striking effect of altitude on tissue oxygen saturation, where the tissue oxygen partial pressure falls from about 73 mm. Hg to at sea level to about 43 mm. at 8,000 feet.

Figure 2: Tissue Oxygen Partial Pressure and Altitude



Therefore, while blood oxygen saturation is reduced a little at quite low altitude, tissue oxygen may be at levels that could cause tissue ischaemia.

Other physiological parameters were also affected. Tissue Carbon dioxide saturation ($SaCO_2$) falls (see Figure 3, overleaf), and heart rate rises with altitude (see Figure 4, overleaf). However, these changes are small.

Figure 3: Blood Carbon dioxide Saturation and Altitude

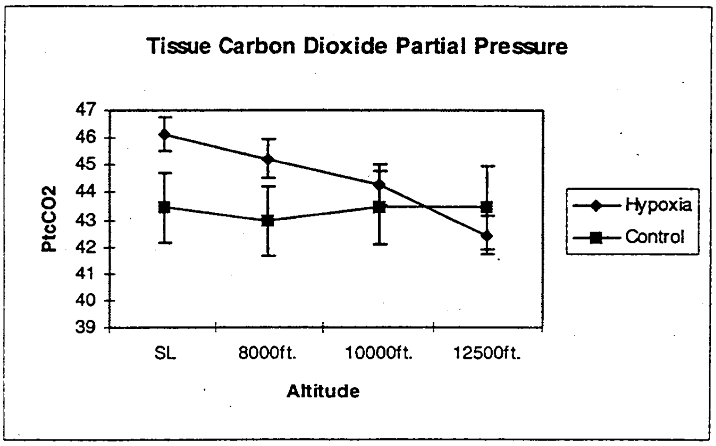
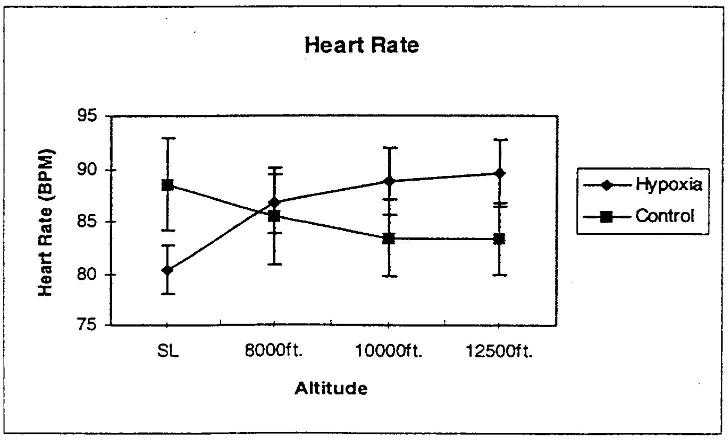


Figure 4: Heart Rate and Altitude



While the changes in Figures 3 and 4 may not be significant, the decrease on tissue CO_2 partial pressure, along with the increase in heart rate (and probably respiration rate, which was not measured) suggests an increased susceptibility to hyperventilation.

Of importance to aviation safety was that effect of altitude on the numbers of errors made (see next pages). The number and type of procedural errors observed was affected by altitude (see Figure 5), as were the procedural errors at different altitudes (see Figure 6) and procedural errors for each phase of flight (see Figures 7 and 8). Hypoxic conditions are observed to cause an increase in procedural errors in virtually all cases of Figure 5, and all cases in Figures 6 and 7. Further, the number of errors during descent (Figure 7) is especially noteworthy. This is a particularly important part of flight, and one in which errors must be minimised.

The simulation trial was held over four days, and the number of procedural errors was he highest on day 1. However, the number of errors in the Hypoxia group remained high over the four day period (Figure 8).

Figure 5: Total number of procedural errors by error category and level of O_2

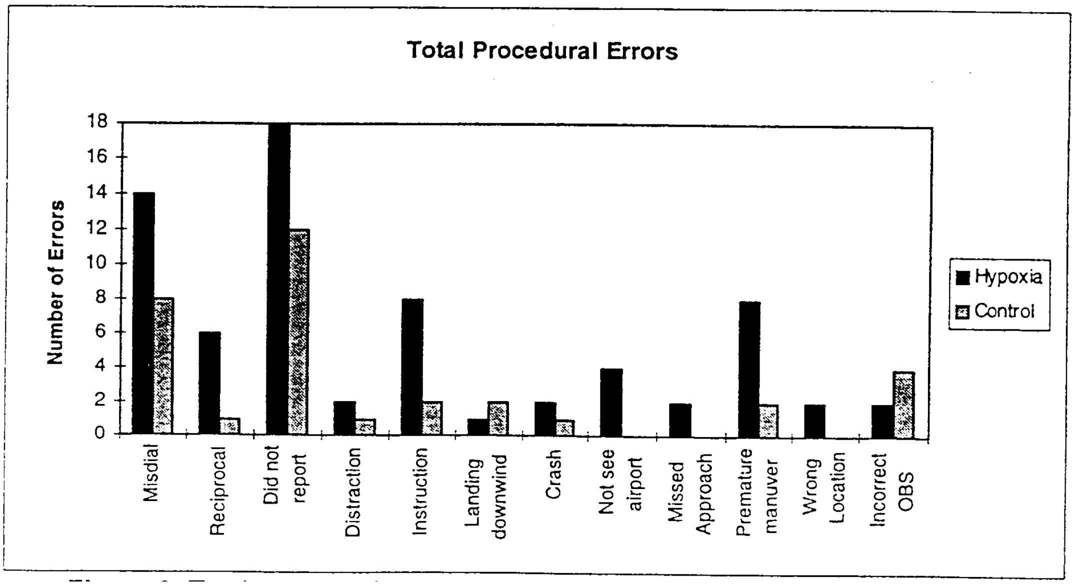


Figure 6: Procedural errors at different altitudes

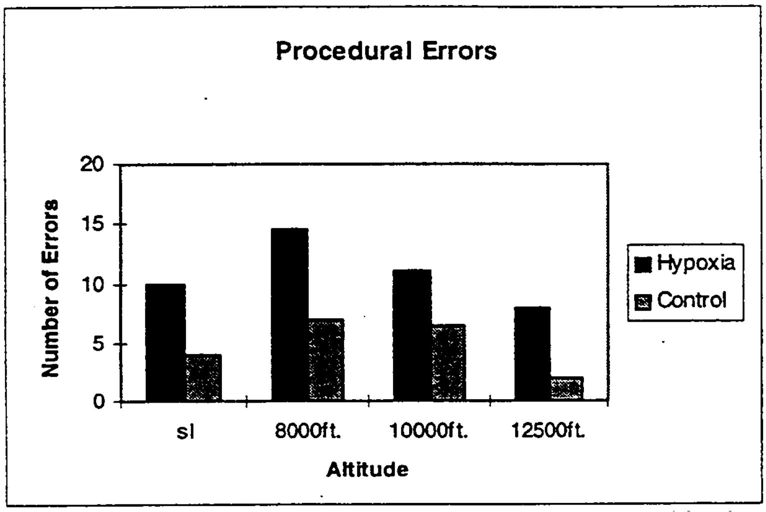


Figure 7: Procedural errors at Different Cruise Segment

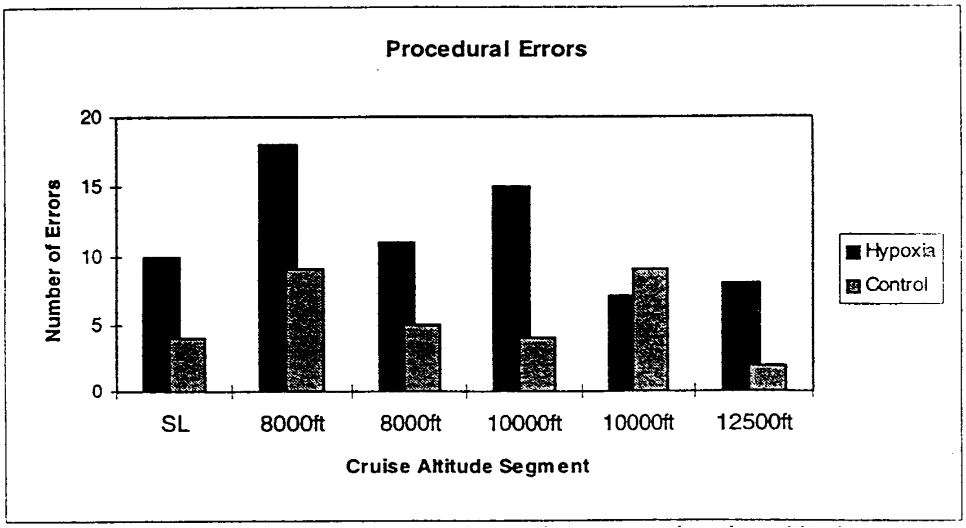
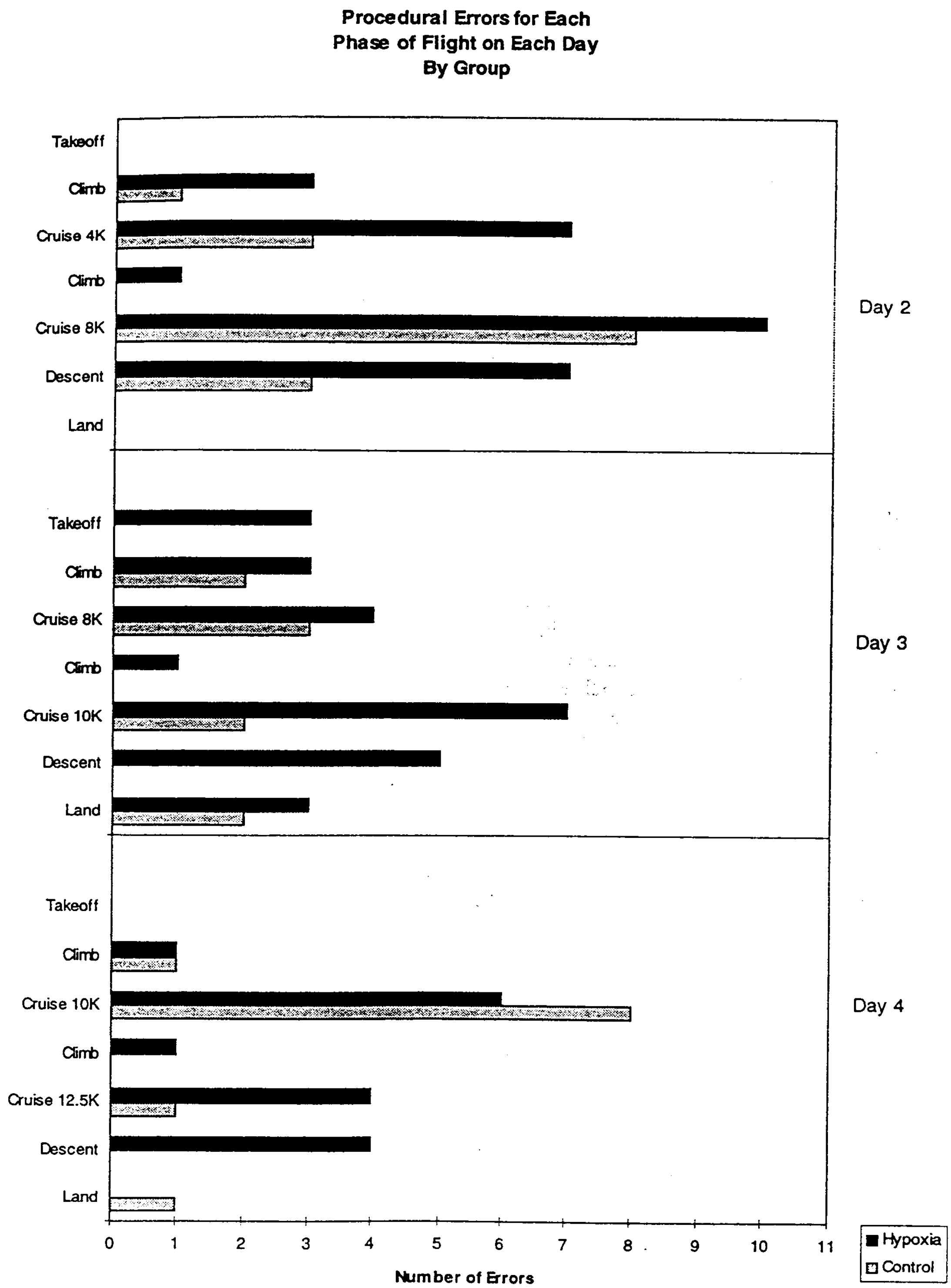
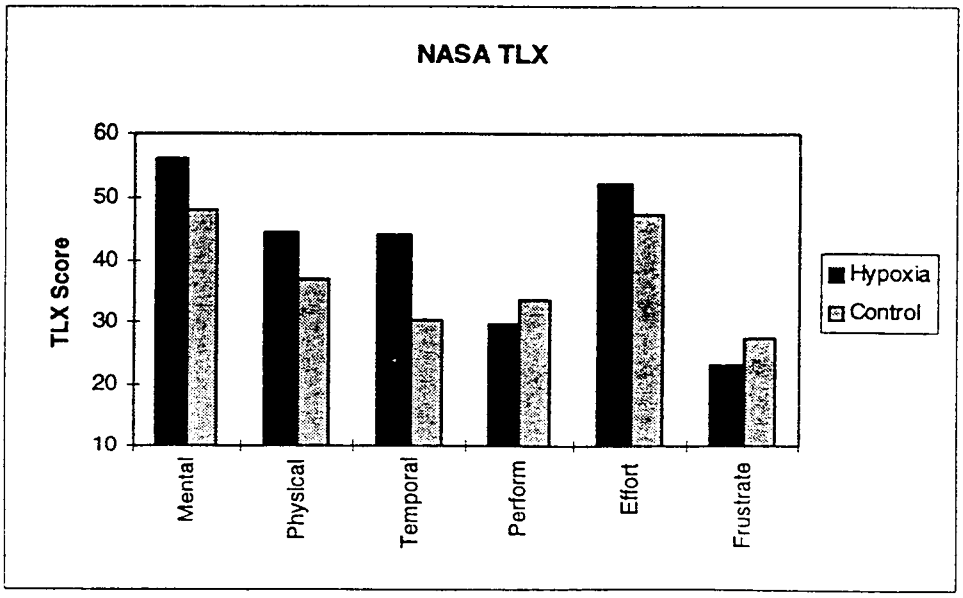


Figure 8: Procedural errors on the phase of flight and the different days of the Simulation



It is also quite notable that the pilot's perception of their workload (as measured by the NASA TLX workload score) was also affected by hypoxia (see Figure 9. The differences in mental, physical and temporal workloads are especially revealing.

Figure 9: Perception of Workload and Hypoxia



MY OWN OBSERVATIONS OF USING A LOW FLOW OF SUPPLEMENTAL OXYGEN ON FLIGHTS BELOW 10,000 FEET

I have experienced extreme fatigue on and following general aviation flights at even moderate altitudes. This fatigue is noticeably absent following flights on supplementary Oxygen.

I often experience "furry" vision following night flights (dark adaptation is one of the first neurological functions to be impaired during hypoxia). However, night vision is sharp and clear following flights on oxygen.

In a trial of IR student performance, the instructor set up a particular dual Navigation Exercise with the student breathing 0.3 l/min of supplementary oxygen, below 10,000 feet. The student believed his performance was no different to usual, but instructor reported student's taking control of flight rather than his previous tendency to look for guidance and assurance.

CONCLUSIONS

Hypoxia needs to be recognized as a significant safety consideration below 10,000 feet.

There doesn't appear to be any particular cut-off level for where benefit can be provided by the use of supplementary oxygen.

Because of the responsibility carried by the air-crew, it is reasonable to expect that all measures would be taken to ensure that they do not have impairment of performance. This suggests that keeping them at the blood oxygen saturation at sea level is an important goal.

Hypoxia should not be dismissed as a minor nuisance. Some means of measuring O_2 saturation in flight, such as a pulse oximeter, should be available. This gives a crew a more objective indication of their condition.

Particular attention also needs to be given to the crew condition during the descent and approach, considering the time taken to recover normal cerebral functions following a period at altitude.

If crew are to operate at some level of hypoxia, their tasks must not be too taxing so that they are less affected, or must be sufficiently well learned as to be automatic.

It would be expected that training would be more efficient conducted in sea level conditions. This suggests a greater role for simulator rehearsal in flight training, prior to carrying out the exercise in the air.

6.1 REFERENCES

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