AN ASSESSMENT OF DETERIORATION OF COLOUR VISION, CONTRAST SENSITIVITY AND PHORIAS AS A RESULT OF HYPOXIA IN PERSONS RESIDENT AT ALTITUDE

BY

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DEDICATION

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ABSTRACT

The altitude at which oxygen supplementation should commence to be administered to aircrew in South Africa, flying in unpressurised aircraft, is 12,000 feet. Above that altitude it is considered that significant effects of reduced tissue oxygen content (hypoxia) become manifest. It has been shown that vision is particularly sensitive to hypoxia, and is commonly the first system affected. There was concern that there might be subtle visual effects due to relative hypoxia at 12,000 feet, which might not be obvious to aircrew, but which could affect flight safety. If this were so, the level for commencement of oxygen supplementation might have to be lowered.

To assess this situation three important parameters of vision, namely, colour vision, contrast sensitivity, and the presence of phorias (potential squint), were selected for study.

37 healthy volunteers, in small groups, had these parameters assessed at ground level in an altitude chamber at the Institute for Aviation Medicine, Lyttleton, South Africa. They were then taken to simulated altitudes of 8,000 feet and 12,000 feet. Sufficient time was allowed at each altitude for physiological adaptation, and the visual parameters reassessed. Oxygen saturation of tissues was also measured to confirm relative hypoxia at altitude.

Statistical analysis of the visual parameters concluded that there were no clinically significant deleterious effects, due to relative hypoxia, on the visual parameters studied, at a simulated altitude of 12,000 feet, and that there was no indication, therefore, to lower the existing threshold for oxygen supplementation from 12,000 feet.

It is recommended that further work be done to detect any cumulative effects of prolonged flight at 12,000 feet and also to repeat the work with aircrew based at sea level. Such personnel would not have the small degree of physiological adaptation existing in those resident at the altitude of Pretoria, and might, theoretically, be more susceptible.

OPSOMMING

Suurstofaanvulling vir Lugbemanning wat met vliegtuie sonder kajuitdrukbeheer vlieg, is verpligtend bo 12,000 voet bokant algemene seevlak. By daardie hoogte word aanvaar dat betekenisvolle effekte van verminderde weefselsuurstofkonsentrasie manifesteer (hipoksie). Dit is aangetoon dat visie besonder sensitief is vir hipoksie, en dat dit oor die algemeen die eerste funksie is wat geaffekteer word.

Die moontlikheid van subtiele visuele disfunksie as gevolg van relatiewe hipoksie op 12,000 voet wat nie so ooglopend vir lugbemanning is nie en dus ‘n vliegveiligheidsrisiko mag wees, was rede tot kommer. Indien dit wel die geval is, sou die vlak vir verpligte suurstofaanvulling verlaag moes word.

Ten einde bogenoemde situasie te evalueer, is drie belangrike parameters van visuele funksie geselekteer vir verdere studie, naamlik: kleurvisie, kontras sensitiwiteit en fyn oogspier koördinasie (forias).

Sewe-en-dertig gesonde vrywilligers is in klein groepe vir bogenoemde funksies op grondvlak in ‘n dekompressie-tenk by die Instituut vir Lugvaart-geneeskunde, Lyttelton, Suid-Afrika, getoets.

Daarna is hulle in dieselfde dekompressie-tenk op gesimuleerde 8,000 voet en 12,000 voet hoogtes bo seevlak vir dieselfde funksie getoets. By elk van die twee hoër hoogtes is genoeg tyd toegelaat vir fisiologiese adaptering voordat die visuele parameters weer getoets is.

Weefseloksigenasie is ook terseldertyd by die verskillende hoogtes bo seespiëel gemeet om relatiewe hipoksie-vlakke te bevestig.

Statistiese analise van die visuele parameters het bevestig dat daar geen klinies betekenisvolle agteruigang van visuele vermoëns op 12,000 voet was nie.

Daar was geen sterk aanduiding om die bestaande regulatoriese drumpelwaarde vir aanvullende suurstofvoorsiening aan lugbemanning van vliegtuie sonder kajuitdrukbeheer van die huidige 12,000 voet te verlaag nie.

Dieselfde eksperiment behoort egter ook herhaal te word by ‘n dekompressie-kamer fasiliteit wat op seevlak geleë is. Sulke lugvaartpersoneel wat by die see woon, het nie die geringe graad van fisiologiese adaptasie-voordeel wat die het wat woon by, byvoorbeeld, die Pretoriase hoogte bo seespiëel nie en kan in teorie dus meer vatbaar vir hipoksie wees.

Dit word verder aanbeveel dat verdere soortgelyke werk gedoen word om die moontlike kumulatiewe effekte van verlengde vlugte by 12,000 voet te meet.

CHAPTER 1

1.1 INTRODUCTION AND BACKGROUND

1.1.1 HYPOXIA

A requirement for adequate brain sensory and motor function is an adequate oxygen supply, delivered to the tissues via the respiratory and circulatory systems. A reduction in tissue concentrations of oxygen (hypoxia) causes impairment of body systems and functions. This becomes more marked with greater reduction of oxygen, and some tissues and organs are more sensitive to oxygen reduction than others (see below).

In view of this, oxygen supplementation is necessary in aircrew at certain altitudes, unless the crew members are functioning in the adequately oxygenated microclimate of a pressurised aircraft. In these circumstances the cabin altitude is kept at about 8,000 feet, or even lower, irrespective of the aircraft's actual altitude.

1.1.2 CURRENT REGULATIONS FOR OXYGEN SUPPLEMENTATION

International rules and conventions are such that aircrew are required to commence oxygen supplementation, in unpressurised aircraft, at altitudes above 10,000 to 12,000 feet (feet is usually the standard international measurement of altitude). Various countries have different commencing altitude thresholds within this band. In South Africa 12,000 feet is used. Investigation as to why this has been chosen reveals little evidence as to why this particular altitude has been selected, but it has been passed from generation to generation. An assumption is sometimes made that flying at 12,000 feet will safely clear the highest mountains in South Africa, i.e. the Drakensbergs, whereas 10,000 feet has less of a safety margin. The supposition may be that the short time necessary at that altitude in order to clear the peaks does not justify the use of oxygen. As the literature review below will indicate, the levels chosen are based on experimental work conducted mainly in the 1920s and 1930s. The evidence for the appropriateness of this is rather vague, and some of the experimental methods are somewhat dubious. It was noted that the effects of hypoxia begin at lower altitudes than the threshold level chosen, but that, in practice these remain "acceptable" up to the recommended units. There has been little challenge to this, and the designated limits for oxygen commencement have been passed down over many years, being generally accepted without much question. It is interesting to note that U.S. Army aircrew, because of combat requirement in non-pressurised helicopters, are allowed to ascend to 14,000 feet without oxygen, in case of tactical necessity, in combat [1]. This altitude may not be maintained longer than thirty minutes, implicitly recognising the effects of hypoxia at that altitude.

1.1.3 VISUAL EFFECTS OF HYPOXIA

It will be seen in the literature review that aspects of vision are amongst the first of the body functions to be affected by low levels of circulating oxygen (hypoxia). The use of aircraft is rapidly expanding in South Africa, and this includes significant numbers of unpressurised aircraft. Safe flying, particularly in poor visibility conditions, over mountain ranges, requires high altitude flying. In the light of these factors interest was expressed in determining whether the present recommendation of oxygen supplementation above 12,000 feet was appropriate. The significant number of aircraft incidents and accidents in South Africa added impetus to this.

1.1.4 SUGGESTION FOR INVESTIGATION

Since vision is affected early in a hypoxic situation, it was considered that this would be a sensitive area for detecting early signs of hypoxic effects. It is also a very important, indeed crucial, aspect of pilot function. Consideration was given as to whether, at 12,000 feet, there might be subtle effects, due to relative hypoxia, on pilot vision, which might not be obvious to aircrew, but which were adversely affecting flight safety. It was therefore decided to assess aspects of vision in the altitude chamber at the Institute for Aviation Medicine at Lyttleton, near Pretoria. This is a facility owned and operated by the South African Military Health Service of the South African National Defence Force and for the benefit of the Civil Aviation Industry in Southern Africa in general.

1.1.5 CONSIDERATIONS OF AIRCREW RESIDENT AT ALTITUDE

Aircrew permanently resident in the Johannesburg/Pretoria area have, like all inhabitants of these areas, already adjusted to living at some degree of altitude (5,000 to 5,500 feet), but it was not known if this element of adaptation would have any effect on the development of hypoxic effects in aviation. The visual parameters, defined below, which were selected for investigation, were colour vision, contrast sensitivity and the development of phorias. It was felt important to investigate this area of flight physiology in order to determine whether the current South African regulations requiring oxygen supplementation above 12,000 feet were appropriate, or should be altered to a lower altitude.

1.1.6 ETHICAL AND SANDF APPROVAL

This project was approved by the South African Military Health Service (Letter SG(2)/R/202/3/7 dated 30 July 1999), (Annexure A) and the ethics committee of the University of Pretoria (Letter 24/98 dated 25 February 1998), (Annexure B).

CHAPTER 2

2.1 REVIEW OF LITERATURE

2.1.1 RELEVANT PAPERS

Literature review has revealed surprisingly little with regard to the topics under study. Some of the original literature is quite old, but reveals acute clinical, scientific and observational capability.

The classical original paper is that of Wilmer and Berens [2], published in 1918, when powered flight had only been in existence for a few years. It is a remarkable piece of work for the time. The authors describe various visual effects at varying altitudes from 5, 000 to over 20,000 feet. This work was conducted by the U.S. military in a low pressure chamber, a form of which existed even in those days. The hypoxia of altitude could therefore be simulated. Disturbances of vision as a result of hypoxia were found. These were mainly between 15,000 and 20,000 feet. They were noted as affecting stereoscopic vision, pilot reaction time, field of binocular vision and eye muscle balance (early evidence of phoria). Also affected were field of vision, retinal detection and sensitivity, eye accommodation, convergence, intra-ocular tension, colour vision. Many of these visual parameters were, clearly, adversely affected by hypoxia, the greater the degree of hypoxia, the greater the degree of abnormality. Significantly, all the deleterious effects were rapidly corrected by the administration of oxygen.

It was apparent, therefore, that even in the early days of powered flight, vision was significantly affected by hypoxia.

The next stimulus to scientific investigation in this area occurred during World War Two. The leading aviation medicine writer of this period was R.A. McFarland of the United States. In a classic paper published in 1941[3] he indicated that much of the experimental work on vision and altitude had not been particularly well conducted. By performing more exact experiments he was, nevertheless, able to confirm much of Wilmer and Berens' work. He further refined the effects of hypoxia on visual functions. This included deleterious effects on visual sensitivity, colour vision, light sense and dark adaptation, contrast discrimination, visual acuity, visual fields, accommodation and convergence and ocular movement co-ordination. He also indicated that the contrast sensitivity work done hitherto was inadequate.

In 1946 Hecht *et al* [4] published a paper concerning anoxia and brightness discrimination. This demonstrated that deterioration in contrast discrimination begins at low altitudes and is definite at 8,000 feet.

In 1971 McFarland [5] published another classic paper in aviation medicine. In summarizing the state of the art he presented a wealth of scientific information, including the fact that studies had confirmed that oxygen is required at altitudes above 10-12,000 feet for prolonged flights. He also indicated that the effects of altitude are accentuated by alcohol and that the carbon monoxide effects from smoking can lower the ceiling at which altitude effects begin. It is well known in aviation medicine that there is a range of individual differences in respect of tolerance to hypoxia. Factors influencing this include general physical condition, infection, tiredness, alcohol and tobacco, hypoglycaemia, respiratory depressants, extremes of temperature, G-force effects, physical effort and vibration. Some of these were commented upon in the remarkable paper by Wilmer and Berens (1918) mentioned above.

Also in 1971, Ernest and Krill [6] drew attention to the psycho-physiological aspects of the effect of hypoxia on visual function. They confirmed deleterious effects on retinal function as a result of hypoxia, and also reported the interesting observation that hyperventilation, commonly as a result of anxiety or stress, may cause an elevation in the subject's haemoglobin oxygen saturation, along with hypocapnia and alkalosis, and that this can compromise visual performance.

Kobrick [7] had, in 1970, demonstrated the effects of hypoxia on colour sensitivity zones at various altitudes, the lowest altitude at which effects were encountered being 13,000 feet. Smith *et al* [8], in view of contradictory results regarding the effects of hypoxia on colour vision, reassessed this in 1975, utilising the FM 100 Hue test. This is a sensitive test of colour discrimination. They confirmed the deleterious effects of hypoxia on Hue test performance, especially under conditions of reduced illumination.

Kobrick *et al* [9] (1984) confirmed deleterious effects of hypoxia on night vision and Vingrys and Garner [10] (1987) demonstrated loss of colour vision affecting both red-green and blue-yellow discrimination at 12,000 feet. Further evidence of the adverse effects of hypoxia on green-red colour vision was produced by Richalet *et al* [11] in 1988, using a portable anomoloscope, an extremely sensitive colour vision assessment instrument.

By contrast, in 1995 Yap *et al* [12] demonstrated insignificant changes in spatial and temporal contrast sensitivity, central visual field thresholds and dazzle recovery time, with respect to simulated altitudes of 7,000 and 12,000 feet in an altitude chamber. They also indicated the importance, in these types of experiments, of maintaining an experimental subject for at least 15 minutes at any test altitude, to allow for equilibration of ambient and blood gas levels, before commencing visual testing.

Also in 1995, Davis *et al* [13] published a paper concerning visual performance of military pilots using tactical night vision aids in military aircraft, particularly army helicopters, operating at altitudes which resulted in degrees of hypoxia. They pointed out that the work of M^cFarland, Hecht and others (see above) had demonstrated degradation of visual performance in conditions of hypoxia, especially under low illumination circumstances, and that contrast sensitivity may decrease by as much as 50% under low illumination. They found that, at 12,000 feet, in a chamber, there was some diminution in visual acuity, but no diminution in contrast sensitivity.

2.1.2 INTERPRETATION OF LITERATURE

In reviewing the literature it is evident that hypoxia has been shown to affect colour vision and, in some work, contrast sensitivity. There is, however, some argument as to the altitude at which these effects develop. There is further uncertainty as to whether contrast sensitivity is affected by moderate hypoxia or not. It is interesting to note that there is remarkably little about the effects of hypoxia with regard to phorias. (the potential to develop squints under certain circumstances) The early work by Wilmer and Berens (1918), as mentioned above, does mention the development of ocular muscle imbalance as a result of hypoxia, and this could be interpreted as referring to phorias. Little has been published since, on this matter.

In perusing the relevant articles, several points emerged. Remarkably, in some of the experimental work described, very small numbers of subjects were used, the smallest numbers being two, the average six to eight, and the maximum 26. In addition, some of the experimental hypoxia was achieved by means of breathing hypoxic levels of oxygen from a mask. This is not greatly accurate, being subject to leakage, possible abnormal breathing patterns and other factors. In addition, the altered atmospheric pressure levels, as experienced at altitude, or in an altitude chamber, are not operative. Scientific accuracy and statistical significance of some of this work would, therefore, be questioned today, although it was landmark work at the time.

2.1.3 CONCLUSION

Literature review, therefore, suggests that there is a requirement for a controlled trial, with sufficient numbers of subjects, in a controlled altitude chamber, under standardised conditions, in order to further assess the effects of hypoxia on visual parameters.

CHAPTER 3

3.1 OBJECTIVE

The objective of this project is to determine if there is significant deterioration of colour vision, contrast sensitivity and the development of phorias in aircrew, due to the effects of hypoxia, when flying in unpressurised aircraft at an altitude of 12,000 feet. Implicit in this is a determination, therefore, as to whether the current South African regulations, requiring oxygen supplementation in such aircrew, from 12,000 feet upwards, are appropriate.

3.2 NUL HYPOTHESIS

The nul hypothesis is, therefore, that there is not a significant deterioration of colour vision, contrast sensitivity and phorias, due to hypoxia, in unpressurised aircraft at an altitude of 12,000 feet.

3.3 STUDY DESIGN

3.3.1 STUDY OUTLINE

The chosen visual parameters, e.g. colour vision, contrast sensitivity and phorias are of particular importance in the aviation environment, and changes in these could have subtle effects on performance, not necessarily noted by the aircrew, unlike more gross impairments of vision, which are more likely to declare themselves to the aircrew, and receive corrective action, e.g. descent to lower altitude or oxygen supplementation.

Colour vision is important in discerning signals and aircraft identification symbols. It is also important in interpreting computerised navigational displays, map symbols, flares and lights. Contrast sensitivity is important in spotting other aircraft against various backgrounds and in varying degrees of illumination. It is also important in discerning ground objects against various backgrounds. The transition of a phoria (latent squint) into a squint, with functional effects, could affect visual capacity, including focusing. In the same way that alcohol can induce a squint (cross-eyed inebriate) there is the possibility that the effects of hypoxia could adversely affect ocular muscles, producing a similar effect. As discussed in the literature review [2], there is some evidence that hypoxia affects all these parameters, but the evidence is conflicting. Altitudes predisposing to deleterious effects are not clear and some of the experimental work done in the past has not been performed with currently acceptable scientific and statistical standards. Of particular relevance was the small numbers of subjects used in much of the experimental work.

It was therefore decided to utilise around 40 subjects, 37 eventually being selected. This was a number significantly greater than previously reported in the literature, and was considered by the statisticians to be sufficient for validity.

The subjects were South African Military Health Service Medical Special Forces soldiers or South African Air Force members, all of whom had high standards of medical fitness, equivalent to aircrew.

The visual parameters for assessment were to be measured at ground level, 8,000 feet and 12,000 feet in an altitude chamber, to see if any changes occurred. A test level at 8,000 feet was suggested by the statisticians as a standardisation and control element.

3.3.2 STUDY TYPE

This was a double blind crossover trial with randomisation of exposure order, with blinding of the observer and subjects. The subjects were their own controls.

3.4 ETHICAL CONSIDERATIONS

The maximum altitude experienced by the subjects in the chamber was 12,000 feet, as is current practice in South African and international aviation. All subjects were healthy volunteers, and they were informed in detail about the experiment. An appropriate consent form was developed, discussed and completed for each subject (Annexure C). In this form, the project was explained, exclusions were indicated, the assessment methods were explained, any likely physiological effects discussed. The voluntary nature of the subject and the right to withdraw at any time, without prejudice, was explained. Confidentiality of subject data was also assured.

The project was approved by the ethics committee of the University of Pretoria, by Headquarters, South African Military Health Service and Headquarters, South African Air Force.

All subjects were members of units accustomed to flying and some were military parachutists.

Oxygen and advanced life support equipment were in the chamber during the entire experiment. The medical observer, trained in emergency procedures, was in the chamber throughout the experiment.

The subjects were, in fact, in the same situation as pilots flying at 12,000 feet every day in South Africa, and this was not perceived as being hazardous in any way.

3.5 TERMINOLOGY

COLOUR VISION - The ability to determine standard colours in presented standard patterns and images.

CONTRAST SENSITIVITY - The visual capacity to differentiate, effectively, objects at various contrast thresholds, that is to say, with variations of lightness and darkness in the same field. This is assessed in respect of black and white, not colour.

PHORIA - Extra-ocular eye muscle imbalance and co-ordination impairment, measured in vertical and horizontal planes when the ability to focus is suppressed.

ALTITUDE CHAMBER - A large chamber, able to seat 12 or more subjects, which can be sealed, and by means of oxygen, air and pressure variations, can be adjusted to produce simulated altitudes of various levels. It is in regular use to familiarise aircrew with different altitude circumstances. With increase in altitude there is reduction in ambient pressure, therefore, the altitude chamber is a hypobaric chamber, as opposed to the hyperbaric chamber which is used to apply oxygen under pressure to tissues and to induce favourable gas gradients. This is used in the treatment of divers "bends" and several other clinical conditions. The altitude chamber is displayed in illustrations 1,2,3.

ILLUS 1 – ALTITUDE CHAMBER – GENERAL VIEW

ILLUS 2 – ALTITUDE CHAMBER – ENTRANCE

ILLUS 3 – ALTITUDE CHAMBER – OPERATOR STATION

3.6 MEASURING INSTRUMENTS

(a) <u>OXYGEN SATURATION</u> – <u>PULSE OXIMETER.</u> A non-invasive instrument which measures the oxygen saturation of the blood by means of photocolorometric analysis of the pulse beat in peripheral small vessels. The analysing sensor is applied to the tip of a finger. The oxygen saturation of the blood, as a percentage, plus the pulse rate, is read off directly.

The pulse oximeter was:-

Nonin Medical Hand Held Pulse Oximeter Model 8500,
Nonin Medical, Plymouth MN, USA (Illus. 4)

(b) <u>COLOUR VISION</u> – 1. <u>ISHIHARA PLATES.</u> A system of suitably coloured blots in patterns, which display standard images (e.g. numbers). These can be detected by those with normal vision. Subjects with abnormal colour vision discern other patters. This is a means of detecting major colour vision discrepancies, and is the standard colour vision screening test.

The plates are:-

Tests for Colour Blindness,
S. Ishihara,
Kanehara Shuppan Co. Ltd,
Tokyo, Japan (Illus. 5)

2. <u>ANOMALOSCOPE.</u> A more sensitive instrument which requires subjects to match projected colour images by manual colour adjustment.

The Anomaloscope was:-

Neitz Anomaloscope OT – II
Neitz Company,
Japan (Illus. 6)

(c) <u>CONTRAST SENSITIVITY</u> – <u>VISION CONTRAST TEST SYSTEM.</u>

A wall chart system which assesses contrast sensitivity by the perception of black and white patterns mixed into various shades of grey at different densities, sizes and angles.

The system was:-

Vision Contrast Test Systems.

Dayton, Ohio, USA (Illus. 7)

(d) <u>PHORIA</u> – <u>STEREO OPTICAL VISION TESTER.</u> (Orthorator)

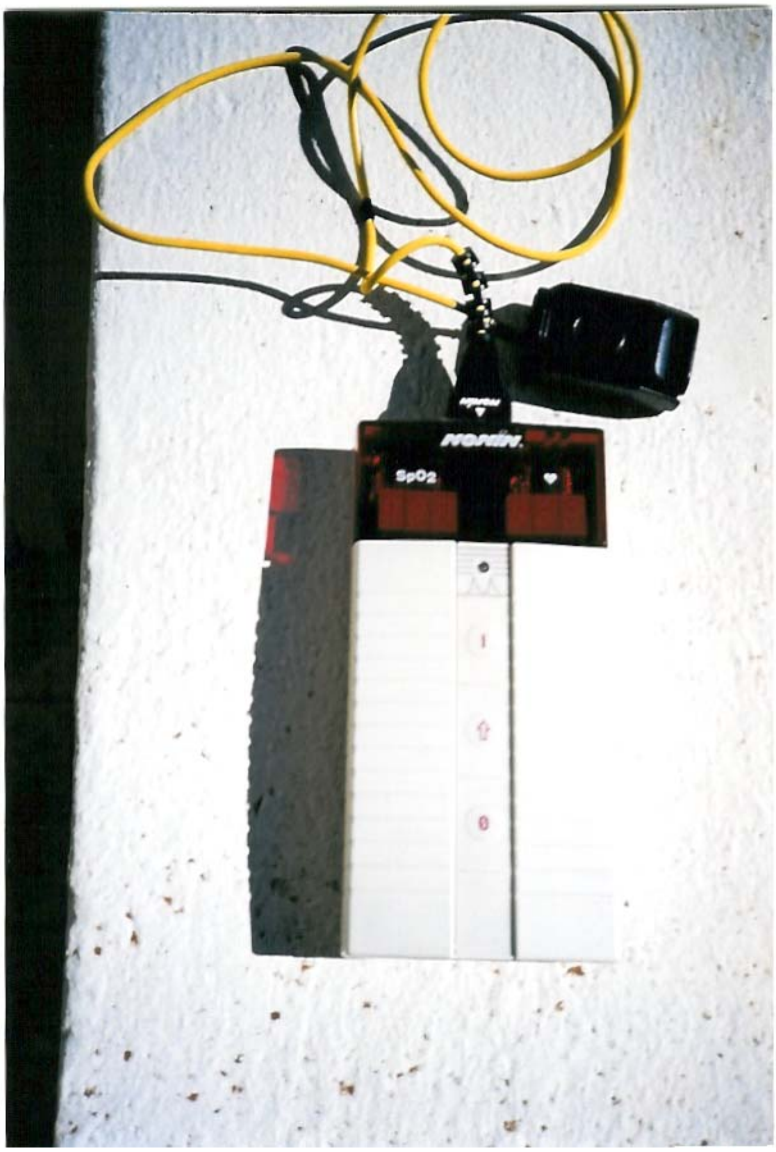
An electronic assessment apparatus for the detection of phorias, which functions by stressing visual muscle co-ordination, by removing focus and measuring extra-ocular muscle imbalance and co-ordination impairment.

The Orthorator was:-

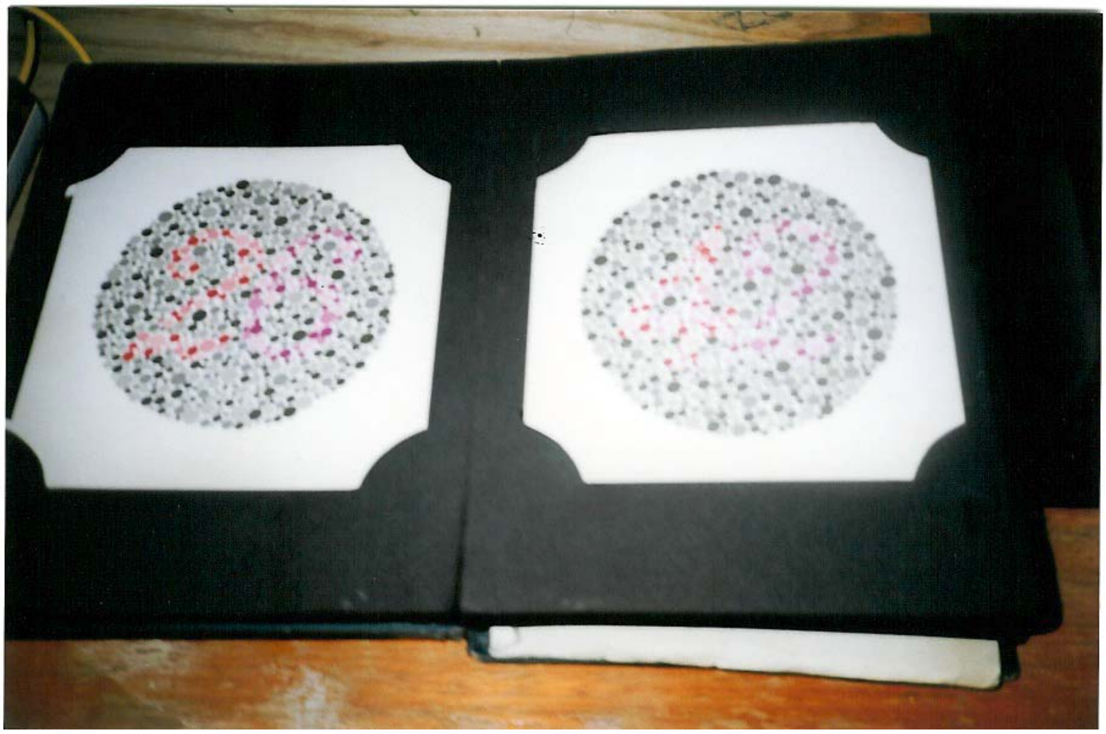
Stereo Optical Vision Tester.

Stereo Optical Co. Inc.,

Chicago, USA (Illus. 8)

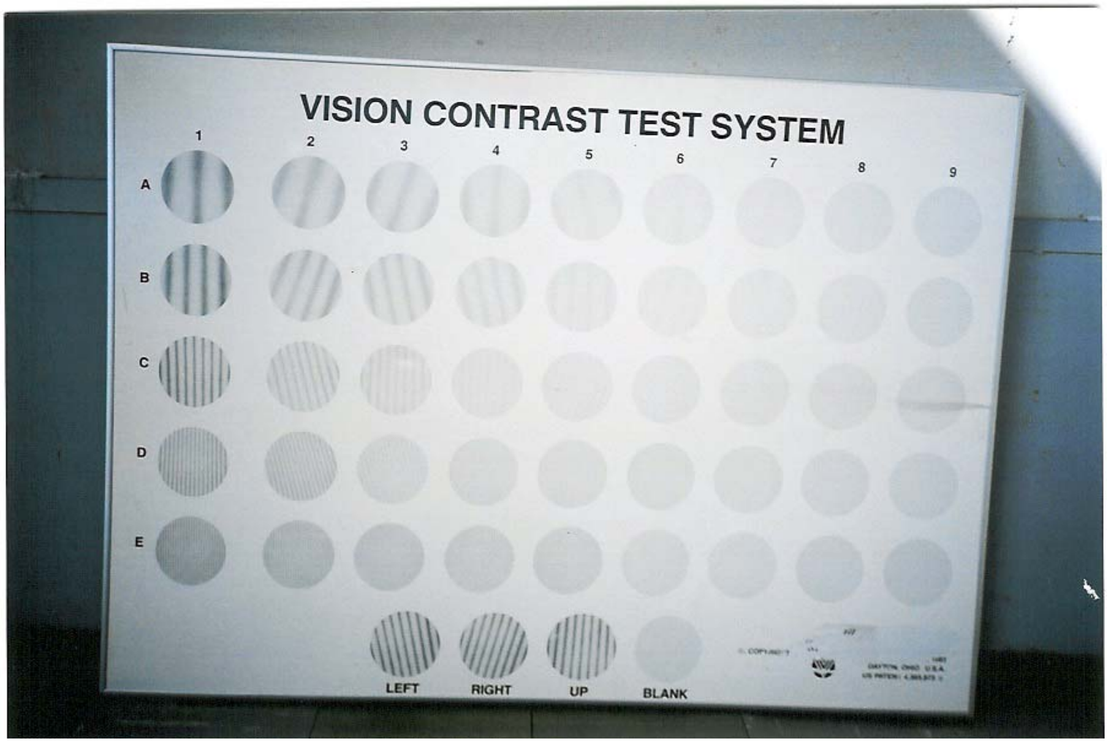


ILLUS 4 – PULSE OXIMETER



ILLUS 5 – ISHIHARA PLATES

ILLUS 6 – ANOMALOSCOPE



ILLUS 7 – VISION CONTRAST TEST SYSTEM

ILLUS 8 - ORTHORATOR

CHAPTER 4

4.1 METHODS AND MATERIALS

4.1.1 SUBJECTS

Participating in the study were 37 healthy military volunteers, all serving with the South African National Defence Force. Most were in the South African Military Health Service, but four were in the South African Air Force. Due to the logistic impossibility of obtaining current flight crew for the study (only four Air Force subjects) it was decided to utilise medical soldiers of the airborne and special forces medical unit colocated at the Institute for Aviation Medicine. These were very fit soldiers who were certainly up to aircrew fitness standards, and were well disposed towards aerospace medicine research. They were accustomed to flying, and several were parachutists. There were 31 males and 6 females. Of the group, 12 were European, 24 were African and one was coloured.

4.1.2 EXCLUSION CRITERIA

Exclusion criteria for the study were:-

1. Visual correction (spectacles, contact lenses, surgical correction)
2. Presence of eye pathology
3. Presence of upper respiratory tract infection, particularly if unable to clear ears. This could make the chamber experience, with alteration of air pressure and volume, uncomfortable or painful
4. Out of geographical test area, at a different altitude, in the preceding 10 days. Subjects had adapted physiologically to the relatively high altitude of the local area, and, for standardisation, it was considered that this should not be disturbed
5. History of fits. It is known that a tendency to fits can be exacerbated by hypoxia
6. On medications

It was, therefore, attempted to standardise as much as possible. All had been assessed by their units as having normal colour vision.

4.1.3 SUBJECT PREPARATION AND CONSENT PROCEDURE

All subjects completed a subject identification and profile form (Annexure E), and this was discussed with each subject. Whether the subject smoked or not was captured, for interest. All subjects were assessed for capacity to clear ears, with otological inspection, while exhaling against resistence, used as necessary.

The full experiment was discussed in detail with each group of subjects, the consent form explained, completed and signed. One copy was retained for the experiment documentation, and a second copy was given to each subject.

The exact nature of the trial was explained to each subject, including the relevant physiology, and the objectives of the study. A description was given of the instrumentation to be used, and the detail of the ascent, simulated altitudes and descent given, including likely effects on ears, breathing and pulse. Background noise due to the ingress and egress of air was explained, as well as the reduction of temperature in the chamber at altitude. Subjects were reassured regarding the simplicity of the experiment and that no invasive procedures, e.g. needle sticks, would be performed on them. The safety aspects were emphasised, and it was explained that resuscitation equipment and oxygen supplementation were instantly available in the chamber. The subjects were urged to relax and enjoy the experience, and all questions were answered to their satisfaction. Subjects were further reassured by means of informing them that the medical observer recording performance would be in the chamber under exactly the same circumstances as themselves.

4.1.4 SAFETY PRECAUTIONS:

The observer had advanced life support training, and emergency equipment in the chamber included supplementary oxygen, airway management equipment, intravenous fluids, ECG/Defibrillator, suction equipment, advanced life support drugs.

4.1.5 VISION TESTING METHODS AND MEASUREMENTS

A table was placed at the end of the altitude chamber furthest from the door. On it were placed the Ishihara Plates book, the anomoloscope and the orthorator. The contrast sensitivity chart was placed against the wall of the chamber furthest from the door, the subject reading it standing with his or her heels up against the lip of the entrance door. The distance from the reading point to the chart was 2,40 metres. Supplementary illumination for the Ishihara plates, was provided, as is common practice, by positioning an overlying lamp. The luminescence in the chamber was provided by the inbuilt fluorescent light system. This was measured by the Photometry and Radiometry Department Council for Scientific and Industrial Research, and was considered adequate at all altitudes. A full report on chamber luminosity is included. (Annexure E)

The luminosity, distances and optical considerations were assessed by an external authority, Dr A Uvijls, from the Ophthalmology Department of the University of Ghent, in Belgium. All were deemed satisfactory.

4.1.6 NON VISUAL MEASUREMENTS

To determine the functional degree of hypoxia during visual testing, the pulse oximeter was applied to the index digit of each subject at the different altitudes, thereby recording the percentage oxygen saturation of the blood at the different altitudes. The same instrument also measured the pulse rate.

The chamber operator recorded altitude, barometric pressure and temperature inside the chamber, ensuring standardisation. (Annexure F)

4.1.7 EXPERIMENTAL CONDUCT AND PROCEDURES

This study was based on repeated measurements, with each subject acting as his/her control.

Considerable time was taken beforehand in briefing the subjects, ensuring exclusion criteria were implemented, and in familiarising the subjects with the vision testing equipment. This was in order to eliminate "learning curve" effects in using the equipment. To this end, all subjects were instructed on the equipment, in the chamber with the door open, until they were competent in the use of that equipment.

All equipment was placed in a standard fashion in the chamber, and was not moved throughout the study. The medical observer remained in the chamber throughout. It was considered that the medical observer should not breathe oxygen during the phase of relative hypoxia in case leakage from the mask altered the oxygen concentration in the chamber. One medical observer was utilized for the whole experiment, in order to ensure standardisation. The observer had advanced life support training, and emergency equipment in the chamber included supplementary oxygen, airway management equipment, intravenous fluids, ECG/Defibrillator, suction equipment, advanced life support drugs.

Subjects were tested individually by sequential rotation through all the tests. Thus, testing of any individual was spread out over the whole test period, rather than one subject having all his/her tests at the beginning of the test period and another at the end. By this means greater standardisation could be achieved.

Groups of subjects were usually in fours, occasionally threes, due to availability or if exclusion criteria were invoked.

When the various tests and pieces of equipment had been explained and the subjects had practised all procedures, the visual parameters were assessed and recorded at ground level, in the chamber, with the door open.

The sequence of events for each subject was as follows:-

1. The subject was shown the Ishihara plates, and required to identify all the images (Illus. 9). This was a functional assessment of colour vision.
2. The subject's colour vision was further tested by utilising the anomaloscope. In this test the subject looks through the lens, seeing a circle divided into an upper and lower hemi-sphere. By means of two knobs, the colours of the upper and lower hemispheres are adjusted so that they match, the whole sphere now being uniformly coloured. The figures representing the adjustment of the upper (red/green) and lower (yellow) knobs are read separately from the side of the instrument. For standardisation, the lower knob was left at about 17 (average "normal") so that candidates concentrated mainly on matching the upper hemisphere to the lower (Illus. 10)
3. Candidates then moved to the orthorator for phoria testing. This consisted of two tests. In test 1 the candidate, on looking into the instrument, was presented with a series of numbered vertical white lines, each with a short "hockey stick" horizontal component at the top. There was also a horizontal red line. The subject was required to read out the number of the white line in which the horizontal red line coincided with the horizontal part of the white line. In test 2 the candidates could see a line of horizontal numbered white dots. There was also a vertical white arrow. The subject was required to read out the number of the white dot, which seemed to stand out predominantly and at which the arrow was pointing. These tests can determine the presence of a phoria (Illus. 11).

4. The candidate then stood with his/her heels against the lip of the door and read off the contrast sensitivity chart (Illus. 12). This had a series of five lines of circles, numbered A,B,C,D,E from top to bottom. Each circle was numbered 1 to 9 from left to right. The system comprises a series of circles, each one containing contrasting dark and light stripes of varying boldness. They were tilted either to the left, right, up or were blank. The circle contrasts were most prominent on the left, progressively becoming more difficult to determine on traversing to the right. Subjects were required to read each line, starting from the left, and stating whether each circle was "up", "left", "right" or "blank". On each line the furthest circle to the right that the subject could progress to in identification was recorded. This gave a measurement of visual contrast capability.

5. The subject then had the pulse oximeter attached to the right index finger, when seated, and the percentage oxygen saturation and pulse rate were measured.

Each subject was tested in this way, in sequence. The Ishihara test plates were utilised first, then the anomaloscope, the orthorator, and, lastly, the contrast sensitivity test. The sequence was then repeated, with each subject being re-tested in the same order. The Ishihara Plate test, being a gross assessment test, was not repeated. The anomaloscope test is very subjective, and a small movement of the knob can make a relatively large change in the figures. This test was, therefore, sequentially repeated a third time to give a greater spread of measurements for averaging.

When the base line assessments were completed at ground level the completed forms were passed out of the chamber to the statisticians, who were acting also as external observers and for quality assurance, as well as timekeeping. They were outside the chamber, observing activities through the observation windows, and also monitoring the chamber operator. Thus the baseline measurements were not available to the medical observer or subjects in the chamber.

ILLUS 9 – SUBJECT IDENTIFYING ISHIHARA PLATES

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ILLUS 10 – SUBJECT UTILISING ANOMALOSCOPE

ILLUS 11 – SUBJECT UTILISING ORTHORATOR

ILLUS 12 – SUBJECT UTILISING VISION CONTRAST TEST SYSTEM

4.1.8 ALTITUDE TESTING

After the ground level tests were completed, the chamber was sealed, and was pressurised to altitude. Pressurisation was to a simulated altitude of 8,000 feet and 12,000 feet. Which altitude was achieved first was selected randomly by the chamber operator, so that the medical observer in the chamber did not know which had been selected. During ascent to altitude the subjects were checked for adaptation, principally any discomfort in the ears. The chamber operator standardised pressure and temperature in the chamber. On achieving the first altitude, a period of 20 minutes was allowed before re-testing visual parameters. This was to allow the body physiology to adapt to the new altitude. During this time subjects sat quietly, and were not allowed to read, thereby eliminating any visual effects which that might or might not produce. No food or drink was consumed, and, of course, smoking was completely banned. Subjects had been allowed to utilise toilet facilities and partake of normal refreshments before sealing the chamber.

After the 20 minutes, vision tests were repeated in exactly the same way, and in the same sequence. On completion of testing, the medical observer sealed the results in an envelope, so that these were not available to him for the remainder of the tests. On completion of tests the chamber was pressurised to the second altitude, and, after another 20 minutes for physiological adjustment, the tests were repeated in exactly the same manner and in the same sequence. On completion of this testing the chamber was depressurised, gradually, to ground level. Particular attention was paid to any discomfort during this phase, since it is during descent that problems, e.g. inability to equalise ear pressures, particularly manifest themselves, due to the alterations of gas volume relative to pressure.

4.1.9 SUBJECT PERFORMANCE

All subjects were young and fit and, like aircrew, had no medical problems which would be manifest during such conditions. All subjects tolerated ascent, descent, and the relative hypoxia at altitude well, and no problems were experienced. At ground level the chamber was opened and all subjects, after confirmation of well being, thanked and released to their units. All results were given to the statistician present, and the medical observer had no access to these at any subsequent point. The statisticians did not discuss data progress, or results with the medical observer until the end of the project, and after full statistical assessment and collation.

The time spent at each altitude by the students, after the 20 minute adjustment period, varied according to the number of subjects in the group (3 or 4) and the time it took individuals to complete the tests. It averaged 25 to 35 minutes at each altitude, each subject having testing done, in rotation, throughout, the whole period. Thus, total time at each altitude was 45 to 55 minutes.

No medical, psychological or morale problems were encountered, with no anxiety states or claustrophobia. All subjects were relaxed, cheerful and interested in the project. (Illus. 13)

The study was completed satisfactorily, supervised by the auditors, with no problems or difficulties. All data were taken away by the statisticians, and the experimenters had no access to these until the collated results were analysed and presented.

ILLUS 13 – SUBJECTS ADAPTING TO ALTITUDE LEVEL

4.1.10 BIAS AND CONFOUNDING EXCLUSION

All tests were standardised, approved by the Ophthalmological Department of the Institute for Aviation Medicine and the overseas external assessor.

Testing was conducted by the same medical observer. The observer was blinded by not being involved in the selection of the sequence of altitudes. All test results were sealed and removed from the observer after each stage of the study. Due to the intensity of the testing and the large amount of data, it was impossible for the observer to recall results from memory. All collation and statistical analysis was performed externally. "Learning curve" influences on the part of the subjects were obviated by intensive familiarisation and practice with all instruments and components of the tests prior to commencing the test assessment.

4.1.11 DATA COLLECTION

All data, demographic and consent forms were taken by the statisticians and assessed independently. The experimenters had no access to these until the study was completed. The forms were standardised for efficiency, simplicity and accuracy. (Annexure G)

CHAPTER 5

5.1 DATA ANALYSIS

5.1.1 EXPERIMENTAL DESIGN AND PROCEDURES

This study was conducted as a repeated measures design, with each subject acting as his/her own control. Each subject participated in one session during which visual performance with the four visual tests was tested at ground level, 8000 feet and 12000 feet. During each of the three test periods subjects were allowed to stabilise at the specific altitude before tests were conducted. The ground level tests were done first as a baseline and the two higher altitudes were randomised.

Subjects were tested individually. Prior to testing each subject was briefed on the chamber's operation and they were familiarised with the visual tests.

As a control, oxygen blood level was measured at all three altitudes, using the pulse oximeter. This is a non-invasive procedure.

5.1.2 STATISTICAL ANALYSES

Student's paired t-tests (two-tailed) were used for analysis of repeated measures data, (eg changes in oxygen blood levels and pulse rates). These analyses were performed using the Statistix Software Package, Version 7.0. Hotelling's paired T-squared tests were used for analysis of repeated measure multivariate data (the anomaloscope, contrast sensitivity and phoria tests). These analyses were performed using the STATA Software package, version 6.

> **NOTE:** Just because two experimental conditions produce statistically different responses, this does not necessarily implicate that this difference is large enough to have any practical value. Any statistical difference should be evaluated for its practical value.

5.1.3 RESULTS

EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

				Anomaloscope									
				1 st		2nd		3 rd					
Date	Subject no	Level	Ishihara	Top	Bottom	Top	Bottom	Top	Bottom	TOP		BOTTOM	
06/08/2000	1	G	Y	73	11.5	17	18	35.5	17	41.83333		15.5	
06/08/2000	1	8000	Y	36	17.5	39	19	20	17	31.66667	-10.1667	17.83333	2.333333
06/08/2000	1	12000	Y	47	17	73	13	37	21	52.33333	20.66667	17	-0.83333
06/08/2000	2	G	Y	52	18	42	18	48.5	16.5	47.5		17.5	
06/08/2000	2	8000	Y	47	21	50	12.5	51	13	49.33333	1.833333	15.5	-2
06/08/2000	2	12000	Y	48.5	18.5	48	17	51	12	49.16667	-0.16667	15.83333	0.333333
06/08/2000	3	G	Y	49	18	48.5	18.5	48.5	11.5	48.66667		16	
06/08/2000	3	8000	Y	51	15.5	49.5	16.5	49.5	16	50	1.333333	16	0
06/08/2000	3	12000	Y	49.5	13	48	14	48	16	48.5	-1.5	14.33333	-1.66667
06/08/2000	4	G	Y	50.5	14	48.5	20	55	16.5	51.33333		16.83333	
06/08/2000	4	8000	Y	51.5	17	52.5	17.5	49.5	18	51.16667	-0.16667	17.5	0.666667
06/08/2000	4	12000	Y	51	18	51.5	17	51.5	14	51.33333	0.166667	16.33333	-1.16667
29/6/00	5	G	Y	47.5	16	44.5	18.5	45.5	38	45.83333		24.16667	
29/6/00	5	8000	Y	46	20.5	46.5	21	47.5	30	46.66667	0.833333	23.83333	-0.33333
29/6/00	5	12000	Y	44.5	24	45.5	38	46	20.5	45.33333	-1.33333	27.5	3.666667
29/6/00	6	G	Y	49.5	25	45	24.5	48	38	47.5		29.16667	
29/6/00	6	8000	Y	50	21	51	21	51.5	27.5	50.83333	3.333333	23.16667	-6
29/6/00	6	12000	Y	61	39	51	20.5	46.5	20.5	52.83333	2	26.66667	3.5
29/6/00	7	G	Y	45.5	19.5	47.5	20.5	47.5	18	46.83333		19.33333	
29/6/00	7	8000	Y	49	18.5	48	16	48	14.5	48.33333	1.5	16.33333	-3
29/6/00	7	12000	Y	48	18.5	46.5	20.5	48	20.5	47.5	-0.83333	19.83333	3.5
29/6/00	8	G	Y	48	24.5	46.5	33	47	21	47.16667		26.16667	
29/6/00	8	8000	Y	46	21	48	16	48	14.5	47.33333	0.166667	17.16667	-9
29/6/00	8	12000	Y	46.5	26.5	46	20.5	48	20.5	46.83333	-0.5	22.5	5.333333

02/08/2001

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Contrast Sensitivity										Phorias						Oxygen		Pulse Rate	
1 st Attempt					2 nd Attempt					1 st Attempt			2 nd Attempt						
A	B	C	D	E	A	B	C	D	E	1 st	2 nd	Diffe	1 st	2 nd	Diffe	1 st	2 nd	1 st	2 nd
6	7	7	7	5	6	7	7	6	6	6	9	3	6	8	2	98	97	59	60
7	7	7	7	6	7	7	7	7	7	6	8	2	6	9	3	95	97	63	62
7	7	7	7	7	7	7	7	7	7	6	8	2	6	8	2	85	92	65	65
5	6	5	5	3	6	6	6	5	4	9	8	1	5	8	3	97	93	85	74
6	6	6	6	5	6	6	6	6	4	5	8	3	5	8	3	95	97	74	76
6	6	6	6	6	6	6	6	6	5	5	7	2	5	7	2	87	84	69	62??
6	7	6	7	4	6	7	7	6	5	6	13	7	6	12	6	97	96	56	64
6	7	6	7	4	6	7	7	7	5	6	13	7	6	13	7	93	95	59	64
6	7	7	7	6	6	7	7	6	6	6	13	7	6	13	7	95	92	64	57
5	6	5	5	5	5	6	5	5	6	6	7	1	6	8	2	97	97	92 ??	73
6	6	6	5	5	6	6	4	5	5	6	8	2	6	7	1	97	96	74	71
5	6	5	5	4	6	6	4	5	5	6	8	2	5	6	1	91	94	77	73
6	7	6	6	4	6	7	6	6	5	3	8	5	3	8	5	94	96	76	70
7	7	7	7	7	7	7	7	7	7	3	8	5	3	8	5	90	94	65	66
7	7	7	7	5	7	7	7	7	5	3	8	5	3	8	5	82	87	65	66
6	7	6	6	2	6	7	6	6	2	5	9	4	5	8	3	97	98	55	63
6	6	6	6	2	6	6	6	6	2	4	7	3	4	9	5	96	97	52	52
6	6	6	6	2	6	6	6	6	2	4	9	5	4	9	5	88	88	53	60
6	7	7	6	6	6	7	7	7	6	7	6	1	6	7	1	95	98	70	71
6	7	7	7	7	6	7	7	7	7	7	5	2	7	5	2	96	94	56	60
6	7	7	7	7	6	7	7	7	7	6	7	1	6	7	1	85	86	78	64
6	6	6	5	4	6	7	6	5	4	5	6	1	5	5	0	95	95	58	83
6	7	7	4	4	7	7	7	4	4	5	4	1	6	4	2	98	98	57	54
6	7	6	5	4	6	7	6	3	5	5	5	0	5	5	0	89	89	59	58

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Temperature		QNH (1)	QNH (2)								Smoking			Out of area in Prev Week	Tract Infection past 2 Weeks	Medication
Room	Chamber	Waterkloof		Age	Gender	Ethnicity	Assisted Vision	Ocular Problems	Colour Vision Normal	History of Fits	Smoker	Number per Day	Last sig (min)			
19	19	1029	1029	25	M	W	N	N	N	N	N	0		N	N	N
19	19	1029	1029													
19	19	1029	1029													
19	19	1029	1029	33	M	A	N	N	Y	N	N	0		N	N	N
19	19	1029	1029													
19	19	1029	1029													
19	19	1029	1029	25	M	W	N	N	Y	N	N	0		N	N	N
19	19	1029	1029													
19	19	1029	1029													
19	19	1029	1029	31	M	C	Y	N	Y	N	N	0		N	N	Y
19	19	1029	1029													
19	19	1029	1029													
19	18	1035	1032	28	M	A	N	N	Y	N	N	0		N	N	N
19	18	1035	1032													
19	18	1035	1032													
19	18	1035	1032	24	M	W	N	N	Y	N	Y	20	30	N	N	N
19	18	1035	1032													
19	18	1035	1032													
19	18	1035	1032	27	M	A	Y	N	Y	N	N	0		N	N	N
19	18	1035	1032													
19	18	1035	1032													
19	18	1035	1032	28	M	W	N	N	Y	N	Y	20	30	N	N	N
19	18	1035	1032													
19	18	1035	1032													

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

				Anomaloscope									
				1 st		2nd		3 rd					
Date	Subject no	Level	Ishihara	Top	Bottom	Top	Bottom	Top	Bottom	TOP		BOTTOM	
07/07/2000	9	G	Y	53	13	52	19	52.5	14.5	52.5		15.5	
07/07/2000	9	8000	Y	51.5	14.5	51.5	15	53.5	11.5	52.16667	-0.33333	13.66667	-1.83333
07/07/2000	9	12000	Y	54.5	16	54	11	56	11.5	54.83333	2.666667	12.83333	-0.83333
07/07/2000	10	G	Y	50	18.5	54	16.5	53	11	52.33333		15.33333	
07/07/2000	10	8000	Y	51	20	53.5	13	49	19	51.16667	-1.16667	17.33333	2
07/07/2000	10	12000	Y	53	15.5	50	17	49.5	11.5	50.83333	-0.33333	14.66667	-2.66667
07/07/2000	11	G	Y	52	32.5	52.5	12	53	6	52.5		16.83333	
07/07/2000	11	8000	Y	50	24.5	51.5	19	51.5	24.5	51	-1.5	22.66667	5.833333
07/07/2000	11	12000	Y	51.5	22.5	51.5	23	51.5	6	51.5	0.5	17.16667	-5.5
07/07/2000	12	G	Y	53.5	7.5	51.5	18	51.5	18	52.16667		14.5	
07/07/2000	12	8000	Y	52	14.5	52	12.5	51.5	14.5	51.83333	-0.33333	13.83333	-0.66667
07/07/2000	12	12000	Y	52.5	17	52	14.5	53.5	11.5	52.66667	0.833333	14.33333	0.5
13/7/00	13	G	Y	48	15.5	47	17.5	47.5	19	47.5		17.33333	
13/7/00	13	8000	Y	46	22	47	19.5	47	19	46.66667	-0.83333	20.16667	2.833333
13/7/00	13	12000	Y	47	15	51	10.5	49	16	49	2.333333	13.83333	-6.33333
13/7/00	14	G	Y	46	17.5	42.5	18	43.5	19	44		18.16667	
13/7/00	14	8000	Y	46.5	18	45.5	18	44	19	45.33333	1.333333	18.33333	0.166667
13/7/00	14	12000	Y	48.5	15	45.5	18.5	45	22	46.33333	1	18.5	0.166667
21/7/00	15	G	Y	49	24	51	24	40.5	24	46.83333		24	
21/7/00	15	8000	Y	48.5	18.5	54	18.5	50	18.5	50.83333	4	18.5	-5.5
21/7/00	15	12000	Y	48	24	50	18.5	46.5	18.5	48.16667	-2.66667	20.33333	1.833333
13/7/00	16	G	Y	48.5	17.5	44.5	18	45	19	46		18.16667	
13/7/00	16	8000	Y	48.5	18	44.5	18	45.5	19	46.16667	0.166667	18.33333	0.166667
13/7/00	16	12000	Y	52.5	15	46.5	18.5	46.5	22	48.5	2.333333	18.5	0.166667
27/7/00	17	G	Y	47	16.5	51	20	46	20	48		18.83333	
27/7/00	17	8000	Y	51	20	47.5	20	47	20	48.5	0.5	20	1.166667
27/7/00	17	12000	Y	47.5	24.5	50	14.5	50	17	49.16667	0.666667	18.66667	-1.33333
21/7/00	18	G	Y	48	24	47	24	47	24	47.33333		24	
21/7/00	18	8000	Y	47.5	18.5	48	18.5	48	18.5	47.83333	0.5	18.5	-5.5
21/7/00	18	12000	Y	46	18.5	48	18.5	48	18.5	47.33333	-0.5	18.5	0
27/7/00	19	G	Y	46.5	16.5	45	20	47	20	46.16667		18.83333	
27/7/00	19	8000	Y	44	20	46	20	46.5	20	45.5	-0.66667	20	1.166667
27/7/00	19	12000	Y	48.5	17.5	41.5	14.5	45	18.5	45	-0.5	16.83333	-3.16667

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Contrast Sensitivity										Phorias						Oxygen		Pulse Rate	
1 st Attempt					2 nd Attempt					1 st Attempt			2 nd Attempt						
A	B	C	D	E	A	B	C	D	E	1 st	2 nd	Differ	1 st	2 nd	Differ	1 st	2 nd	1 st	2 nd
5	7	6	6	5	6	6	7	6	5	6	9	3	6	7	1	95	95	58	56
6	6	7	6	4	6	6	7	6	4	6	10	4	5	9	4	96	97	66	68
6	7	7	6	4	6	6	7	6	5	6	10	4	5	9	4	92	90	56	69
6	6	5	6	4	6	6	5	6	4	7	5	2	7	6	1	95	97	54	56
6	6	6	6	4	5	6	5	6	4	7	6	1	7	4	3	98	97	68	54
6	7	5	5	4	6	6	6	6	4	7	5	2	7	5	2	95	93	56	52
6	7	6	6	5	6	7	6	6	5	6	13	7	6	14	8	98	97	70	75
6	7	6	7	5	7	6	6	6	5	6	15	9	6	14	8	96	98	66	70
6	6	6	7	6	6	7	7	6	5	6	15	9	6	15	9	96	93	65	61
7	6	7	6	6	7	7	7	7	7	6	7	1	6	7	1	97	96	65	55
7	7	7	7	7	7	7	7	7	7	6	7	1	6	7	1	94	93	68	65
7	7	7	7	7	7	7	7	7	7	7	7	0	6	6	0	89	87	66	65
6	7	7	7	7	6	7	7	7	7	6	6	0	6	6	0	97	98	69	62
6	7	7	7	7	6	7	7	7	7	6	7	1	6	7	1	93	95	66	77
6	7	7	7	7	6	7	7	7	7	6	8	2	6	7	1	91	87	82	78
6	7	7	6	6	6	7	7	7	6	6	5	1	6	5	1	95	94	74	73
6	7	7	6	6	7	7	7	6	6	6	5	1	6	5	1	89	91	69	63
6	7	7	7	6	6	7	7	6	6	6	6	0	6	5	1	85	89	87	71
6	7	7	7	5	6	7	7	7	5	6	6	0	5	6	1	96	95	60	57
6	7	7	7	6	7	7	7	7	5	6	5	1	6	6	0	97	97	53	57
7	7	7	6	5	6	7	7	6	5	6	5	1	6	8	2	96	96	60	56
6	7	7	7	6	6	7	7	6	6	9	3	6	6	1	5	98	98	61	60
6	7	7	7	7	7	7	7	7	7	7	1	6	6	3	3	96	98	58	60
6	7	7	7	7	6	7	7	7	7	6	3	3	6	1	5	95	93	59	56
6	6	6	6	6	6	6	6	6	6	7	9	2	7	11	4	96	95	109	107
6	6	6	6	6	6	6	6	6	6	7	10	3	7	12	5	91	92	107	101
6	6	6	6	6	6	6	6	6	6	7	11	4	7	11	4	86	86	104	107
6	7	7	6	5	6	7	7	6	5	5	7	2	6	7	1	97	96	65	66
6	7	7	6	6	6	7	7	6	5	6	7	1	6	7	1	97	98	56	57
6	7	7	6	5	6	7	7	6	5	6	7	1	5	7	2	94	93	63	61
6	6	6	6	5	6	6	6	6	5	7	13	6	7	14	7	97	96	80	78
6	7	6	6	5	6	6	6	6	5	7	13	6	7	13	6	97	97	92	90
6	7	6	6	5	6	7	6	6	5	7	13	6	7	14	7	93	94	98	70

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Temperature		QNH (1)	QNH (2)								Smoking			Out of area in Prev Week	Tract Infection past 2 Weeks	Medication
Room	Chamber	Waterkloof		Age	Gender	Ethnicity	Assisted Vision	Ocular Problems	Colour Vision Normal	History of Fits	Smoker	Number per Day	Last sig (min)			
16	15	1036	1033	29	M	W	N	N	N	N	Y	25	15	N	N	N
16	15	1036	1033													
16	15	1036	1033													
16	15	1036	1033	24	M	A	N	N	Y	N	N	0		N	N	N
16	15	1036	1033													
16	15	1036	1033													
16	15	1036	1033	21	M	W	N	N	Y	N	Y	6	15	N	N	N
16	15	1036	1033													
16	15	1036	1033													
16	15	1036	1033	25	M	A	N	N	Y	N	Y	4	30	N	Y	Y
16	15	1036	1033													
16	15	1036	1033													
18	17	1027	1025	25	F	A	N	N	Y	N	N	0		N	Y	N
18	17	1027	1025													
18	17	1027	1025													
18	17	1027	1025	23	F	A	N	N	Y	N	N	0		N	N	N
18	17	1027	1025													
18	17	1027	1025													
16	15	-	1028	24	M	A	N	N	Y	N	N	0		N	N	N
16	15	-	1028													
16	15	-	1028													
18	17	1027	1025	27	F	A	N	N	Y	N	N	0		N	N	N
18	17	1027	1025													
18	17	1027	1025													
17	16	1036	1033	32	F	A	N	N	Y	Y	N	0		N	N	N
17	16	1036	1033													
17	16	1036	1033													
16	15	-	1028	36	M	A	N	N	Y	N	Y	19	30	N	N	N
16	15	-	1028													
16	15	-	1028													
17	16	1036	1033	32	M	A	N	N	Y	Y	Y	11	60	N	N	N
17	16	1036	1033													
17	16	1036	1033													

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

				Anomaloscope									
				1 st		2nd		3 rd					
Date	Subject no	Level	Ishihara	Top	Bottom	Top	Bottom	Top	Bottom	TOP		BOTTOM	
21/11/00	20	G	Y	50	13.5	54	13	51	14	51.66667		13.5	
21/11/00	20	8000	Y	54	15	52	20	53	14	53	1.333333	16.33333	2.833333
21/11/00	20	12000	Y	51	14	53.5	16	52	23	52.16667	-0.83333	17.66667	1.333333
21/11/00	21	G	Y	48.5	14.5	50.5	18	48	14	49		15.5	
21/11/00	21	8000	Y	51.5	17.5	51.5	21	50.5	12.5	51.16667	2.166667	17	1.5
21/11/00	21	12000	Y	50.5	17.5	50.5	16.5	48.5	20.5	49.83333	-1.33333	18.16667	1.166667
21/11/00	22	G	Y	47	14.5	45.5	18	44.5	14	45.66667		15.5	
21/11/00	22	8000	Y	48	23	45.5	24.5	49.5	8.5	47.66667	2	18.66667	3.166667
21/11/00	22	12000	Y	47	17.5	46.5	18	45.5	18	46.33333	-1.33333	17.83333	-0.83333
21/11/00	23	G	Y	51.5	14.5	49.5	14	52	14	51		14.16667	
21/11/00	23	8000	Y	52.5	15	52	14	52	14	52.16667	1.166667	14.33333	0.166667
21/11/00	23	12000	Y	51	16	51.5	16	50.5	15.5	51	-1.16667	15.83333	1.5
29/3/01	24	G	Y	44	27	48.5	14	48.5	14	47		18.33333	
29/3/01	24	8000	Y	46.5	17	48.5	17.5	51	12	48.66667	1.666667	15.5	-2.83333
29/3/01	24	12000	Y	47	14.5	47	16	46	20.5	46.66667	-2	17	1.5
29/3/01	25	G	Y	50.5	25	47.5	14.5	51	14	49.66667		17.83333	
29/3/01	25	8000	Y	50.5	17	50	17.5	49	16.5	49.83333	0.166667	17	-0.83333
29/3/01	25	12000	Y	50.5	18.5	48	13	48.5	16	49	-0.83333	15.83333	-1.16667
29/3/01	26	G	Y	52	14	49	14.5	48	14	49.66667		14.16667	
29/3/01	26	8000	Y	48	17	48	17.5	46	18	47.33333	-2.33333	17.5	3.333333
29/3/01	26	12000	Y	48	15.5	47	18.5	48.5	14	47.83333	0.5	16	-1.5
29/3/01	27	G	Y	45.5	24.5	46.5	14.5	48	14	46.66667		17.66667	
29/3/01	27	8000	Y	48	17.5	47.5	17.5	47	14.5	47.5	0.833333	16.5	-1.16667
29/3/01	27	12000	Y	48	19	44	12.5	47.5	16	46.5	-1	15.83333	-0.66667
04/05/2001	28	G	Y	52	14	50	12	53	13.5	51.66667		13.16667	
04/05/2001	28	8000	Y	49.5	15.5	51	16	49	15.5	49.83333	-1.83333	15.66667	2.5
04/05/2001	28	12000	Y	50	11.5	51	19.5	52	13	51	1.166667	14.66667	-1
04/05/2001	29	G	Y	51.5	15.5	48	14	51	13.5	50.16667		14.33333	
04/05/2001	29	8000	Y	47.5	13	49	12.5	51.5	14	49.33333	-0.83333	13.16667	-1.16667
04/05/2001	29	12000	Y	51.5	14.5	49.5	15	51	13.5	50.66667	1.333333	14.33333	1.166667
04/05/2001	30	G	Y	51	12	53.5	10.5	52	12.5	52.16667		11.66667	
04/05/2001	30	8000	Y	51	12.5	51.5	11.5	51.5	13	51.33333	-0.83333	12.33333	0.666667
04/05/2001	30	12000	Y	52.5	12	52.5	12.5	52.5	13.5	52.5	1.166667	12.66667	0.333333
04/05/2001	31	G	Y	52	12	50.5	14.5	54	14.5	52.16667		13.66667	
04/05/2001	31	8000	Y	54.5	14	52.5	10.5	52.5	14	53.16667	1	12.83333	-0.83333
04/05/2001	31	12000	Y	56	14	55.5	11.5	52	10	54.5	1.333333	11.83333	-1

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Contrast Sensitivity										Phorias						Oxygen		Pulse Rate	
1 st Attempt					2 nd Attempt					1 st Attempt			2 nd Attempt						
A	B	C	D	E	A	B	C	D	E	1 st	2 nd	Differ	1 st	2 nd	Differ	1 st	2 nd	1 st	2 nd
6	6	5	6	6	6	7	6	6	6	7	9	2	7	9	2	96	97	68	57
6	7	6	5	5	6	6	7	5	5	8	9	1	8	9	1	99	99	52	51
6	7	7	7	6	6	7	6	6	6	7	9	2	8	9	1	96	98	65	53
6	6	6	6	5	6	6	6	6	5	6	8	2	6	7	1	98	96	92	63
6	7	7	6	6	7	6	6	7	7	6	6	0	6	6	0	99	99	63	79
7	6	6	6	5	7	7	6	6	5	6	7	1	6	7	1	93	95	70	79
7	7	5	5	4	6	7	6	6	6	6	8	2	6	8	2	98	98	56	61
6	7	6	6	6	6	7	6	6	6	6	9	3	6	8	2	98	99	52	54
6	7	5	6	6	6	7	6	6	5	6	8	2	7	9	2	92	91	61	55
7	7	7	7	7	6	7	7	7	7	5	9	4	6	9	3	98	96	64	70
7	7	7	6	6	7	7	7	6	6	6	9	3	6	10	4	97	98	57	57
7	7	7	7	7	7	7	7	6	6	6	10	4	6	9	3	94	94	59	68
6	6	5	6	4	6	6	6	6	4	9	6	3	9	5	4	98	98	58	56
5	6	6	5	4	6	7	6	6	4	8	5	3	8	6	2	95	96	59	54
6	6	5	5	5	6	7	6	6	3	9	5	4	9	6	3	94	93	68	65
6	7	7	6	5	6	7	7	6	3	5	10	5	6	9	3	96	97	74	82
6	7	7	6	4	6	7	7	6	5	6	10	4	6	9	3	93	94	73	74
6	7	7	6	5	6	7	7	6	4	6	9	3	6	9	3	95	96	80	75
6	6	6	6	5	6	6	6	6	5	6	8	2	6	8	2	98	98	75	65
6	7	6	6	5	6	7	6	6	5	6	8	2	6	8	2	95	93	63	65
6	7	6	6	5	6	7	6	6	5	5	8	3	6	8	2	86	88	58	69
6	6	4	3	0	6	6	5	3	2	6	1	5	6	2	4	98	98	63	49
7	6	5	4	3	7	6	4	5	5	5	1	4	6	2	4	93	97	49	65
7	6	5	4	2	6	7	5	4	3	6	3	3	7	4	3	89	90	63	56
5	6	6	6	6	6	6	6	6	5	6	6	0	6	6	0	95	96	57	56
6	7	7	6	6	6	7	6	6	5	6	6	0	6	6	0	98	98	57	63
6	7	6	6	5	6	6	6	6	5	6	5	1	6	5	1	95	94	61	57
6	6	6	6	4	6	6	6	6	5	6	9	3	6	9	3	99	99	78	65
6	7	7	6	5	6	7	7	6	5	6	8	2	6	8	2	98	93	70	73
6	7	7	6	5	6	6	7	6	4	6	8	2	6	8	2	91	92	72	70
6	7	6	6	3	6	6	7	6	4	5	12	7	5	12	7	98	98	70	70
6	7	7	6	4	6	7	7	6	5	5	12	7	5	13	8	98	98	58	50
6	7	7	6	4	6	7	7	6	5	5	11	6	5	12	7	95	95	65	60
6	6	5	6	3	5	7	6	6	3	5	10	5	5	10	5	95	95	69	76
5	6	6	5	2	6	6	5	5	3	4	11	7	4	9	5	98	97	49	49
5	6	5	6	3	6	6	6	6	4	5	9	4	5	9	4	93	94	60	52

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Temperature: Room	Temperature: Chamber	QNH (1) Waterkloof	QNH (2) Waterkloof	Age	Gender	Ethnicity	Assisted Vision	Ocular Problems	Colour Vision Normal	History of Fits	Smoking: Smoker	Smoking: Number per Day	Smoking: Last sig (min)	Out of area in Prev Week	Tract Infection past 2 Weeks	Medication
21	20	1022	1021	22	M	A	N	N	Y	N	Y	10	135	N	N	N
21	20	1022	1021													
21	20	1022	1021													
21	20	1022	1021	23	F	W	N	N	Y	N	N	0		N	N	N
21	20	1022	1021													
21	20	1022	1021													
21	20	1022	1021	22	M	W	N	N	Y	N	N	0		N	N	N
21	20	1022	1021													
21	20	1022	1021													
21	20	1022	1021	22	M	W	N	N	Y	N	N	0		N	N	N
21	20	1022	1021													
21	20	1022	1021													
27	26	1028	1026	24	M	A	N	N	Y	N	Y	5	60	N	N	N
27	26	1028	1026													
27	26	1028	1026													
27	26	1028	1026	20	M	W	N	N	Y	N	N	0		N	N	Y
27	26	1028	1026													
27	26	1028	1026													
27	26	1028	1026	29	M	A	N	N	Y	N	Y	3	30	N	N	N
27	26	1028	1026													
27	26	1028	1026													
27	26	1028	1026	25	M	A	N	N	Y	N	N	0		N	N	N
27	26	1028	1026													
27	26	1028	1026													
23	22	1031	1030	25	M	A	N	N	N	N	N	0		N	N	N
23	22	1031	1030													
23	22	1031	1030													
23	22	1031	1030	20	F	W	N	N	Y	N	N	0		N	N	N
23	22	1031	1030													
23	22	1031	1030													
23	22	1031	1030	29	M	W	N	N	N	N	Y	15	45	N	Y	N
23	22	1031	1030													
23	22	1031	1030													
23	22	1031	1030	22	M	W	Y	N	Y	Y	N	0		N	N	N
23	22	1031	1030													
23	22	1031	1030													

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

				Anomaloscope									
				1 st		2nd		3 rd					
Date	Subject no	Level	Ishihara	Top	Bottom	Top	Bottom	Top	Bottom	TOP		BOTTOM	
19/4/01	32	G	Y	48	20.5	49.5	10	53.5	15	50.33333		15.16667	
19/4/01	32	8000	Y	50	15	50.5	14.5	51.5	13	50.66667	0.333333	14.16667	-1
19/4/01	32	12000	Y	52	16.5	50	16.5	49	15.5	50.33333	-0.33333	16.16667	2
19/4/01	33	G	Y	50.5	15.5	42.5	52	51.5	15	48.16667		27.5	
19/4/01	33	8000	Y	48.5	12	53.5	13.5	49	15.5	50.33333	2.166667	13.66667	-13.8333
19/4/01	33	12000	Y	50.5	12	42.5	16	47	20	46.66667	-3.66667	16	2.333333
19/4/01	34	G	Y	44	9	47.5	14	43.5	16	45		13	
19/4/01	34	8000	Y	51.5	10	49	16	49.5	14.5	50	5	13.5	0.5
19/4/01	34	12000	Y	51.5	8.5	45	10	48.5	11	48.33333	-1.66667	9.833333	-3.66667
05/10/2001	35	G	Y	46	14.5	43.5	19	53	12.5	47.5		15.33333	
05/10/2001	35	8000	Y	49.5	13.5	51	14	37	17.5	45.83333	-1.66667	15	-0.33333
05/10/2001	35	12000	Y	46.5	16	50.5	16	48.5	14.5	48.5	2.666667	15.5	0.5
05/10/2001	36	G	Y	45	16.5	46	18	51.5	14.5	47.5		16.33333	
05/10/2001	36	8000	Y	48	16.5	48.5	12	45	17	47.16667	-0.33333	15.16667	-1.16667
05/10/2001	36	12000	Y	48.5	16	46.5	18	48	14.5	47.66667	0.5	16.16667	1
05/10/2001	37	G	Y	47.5	13	49	9.5	47.5	9.5	48		10.66667	
05/10/2001	37	8000	Y	47	22.5	49	13.5	48	14	48	0	16.66667	6
05/10/2001	37	12000	Y	49	16	48.5	16	50	10.5	49.16667	1.166667	14.16667	-2.5
	38	G											
	38	8000											
	38	12000											
	39	G											
	39	8000											
	39	12000											
	40	G											
	40	8000											
	40	12000											

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Contrast Sensitivity										Phorias						Oxygen		Pulse Rate	
1 st Attempt					2 nd Attempt					1 st Attempt			2 nd Attempt						
A	B	C	D	E	A	B	C	D	E	1 st	2 nd	Differ	1 st	2 nd	Differ	1 st	2 nd	1 st	2 nd
6	7	7	6	5	6	6	7	6	5	7	7	0	6	9	3	96	97	68	67
6	7	7	7	.6	6	7	7	7	7	6	6	0	6	7	1	93	94	70	79
6	7	7	6	6	7	7	7	6	6	6	6	0	6	7	1	89	90	78	85
6	7	6	6	6	7	7	7	6	5	8	8	0	7	9	2	98	95	67	69
6	7	7	6	6	6	7	6	6	6	6	8	2	6	9	3	91	95	80	73
6	7	6	7	6	6	7	7	7	6	7	9	2	7	9	2	92	93	70	55
6	6	6	6	5	6	6	7	6	5	6	9	3	5	9	4	98	97	69	61
6	7	6	6	6	6	7	7	6	6	6	9	3	6	8	2	91	93	70	75
6	6	7	6	4	6	6	7	6	5	6	5	1	6	5	1	87	89	73	70
5	6	6	5	4	6	6	6	6	4	6	7	1	7	6	1	97	97	53	49
6	6	6	6	4	6	6	6	6	4	7	7	0	7	5	2	93	93	59	60
6	6	6	6	4	6	6	5	5	4	7	6	1	7	5	2	85	87	62	75
5	6	6	5	3	5	7	6	6	5	5	6	1	6	5	1	97	96	82	72
5	7	7	6	4	6	6	7	5	3	6	7	1	6	7	1	92	95	80	85
6	7	6	7	6	6	7	6	5	6	6	6	0	6	6	0	89	90	90	91
5	7	6	6	5	5	7	6	6	6	5	6	1	5	6	1	97	97	75	82
6	6	6	6	5	6	7	6	6	5	5	6	1	5	6	1	95	93	72	72
6	7	6	6	5	5	6	6	6	5	5	6	1	5	5	0	83	83	67	75
												0			0				
												0			0				
												0			0				
												0			0				
												0			0				
												0			0				

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EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

(Dr Campbell MacFarlane)

Temperature		QNH (1)	QNH (2)									Smoking		Out of area in Prev Week	Tract Infection past 2 Weeks	
Room	Chamber	Waterkloof		Age	Gender	Ethnicity	Assisted Vision	Ocular Problems	Colour Vision Normal	History of Fits	Smoker	Number per Day	Last sig (min)			Medication
24	23	1030	1027	31	M	A	N	N	N	N	N	0		N	N	N
24	23	1030	1027													
24	23	1030	1027													
24	23	1030	1027	23	M	A	N	N	N	N	N	0		N	N	N
24	23	1030	1027													
24	23	1030	1027													
24	23	1030	1027	26	M	A	N	N	Y	N	N	0		N	N	N
24	23	1030	1027													
24	23	1030	1027													
22	21	1030	1029	26	M	A	N	N	Y	N	N	0		N	N	N
22	21	1030	1029													
22	21	1030	1029													
22	21	1030	1029	27	M	A	N	N	Y	N	Y	?	5 DAYS	N	N	N
22	21	1030	1029													
22	21	1030	1029													
22	21	1030	1029	25	M	A	N	N	Y	N	N	0		N	N	Y
22	21	1030	1029													
22	21	1030	1029													

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5.1.3.1 DEMOGRAPHIC RESULTS

One subject could not correctly read the Ishihara plates and was excluded from subsequent analysis.

As pilots come from different ethnic groups, with different habits, a sample of 37 (36 without the subject with colour vision problems) were taken from different groups. The demographic distributions were:

Table 1: Gender of test subjects

	Frequency	Percentage
Female	6	16,7
Male	30	83,3
TOTAL	36	100

Figure 1: Graphical representation of gender distribution of participants

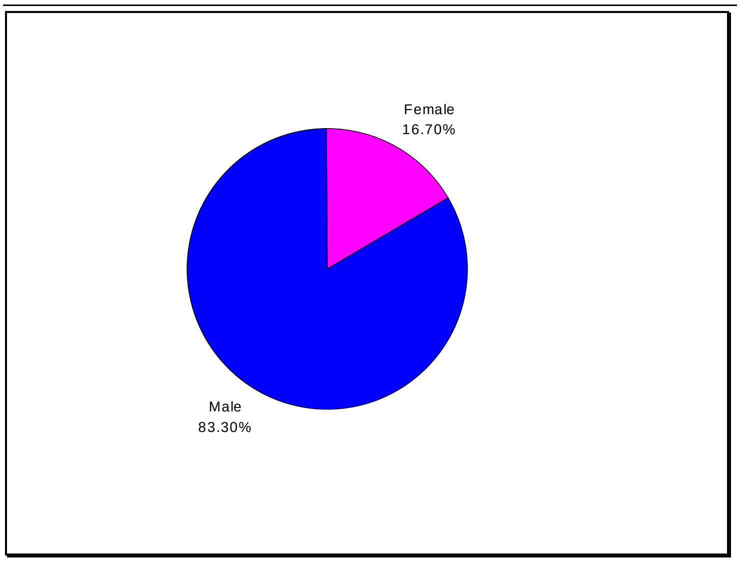


Table 2: Ethnicity of test subjects

	Frequency	Percentage
European	12	33,3
African	23	63,9
Coloured	1	2.8
TOTAL	36	100

Figure 2: Graphical representation of ethnicity distribution of participants

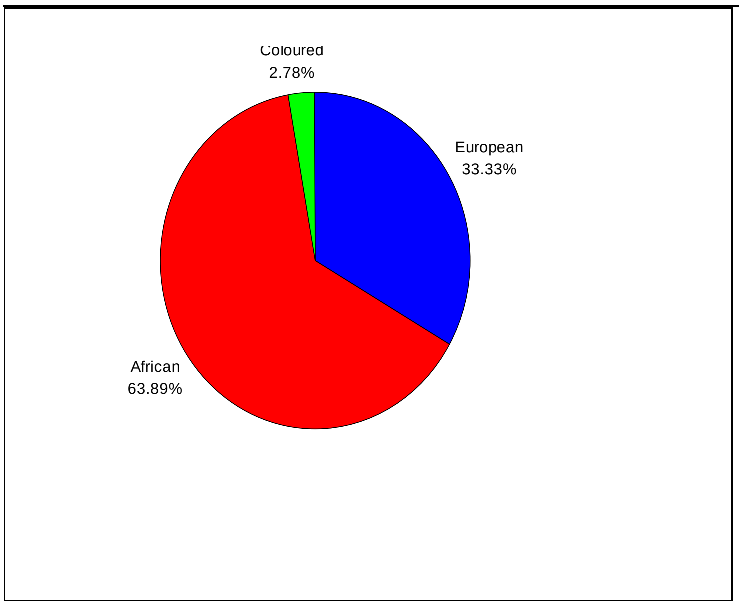
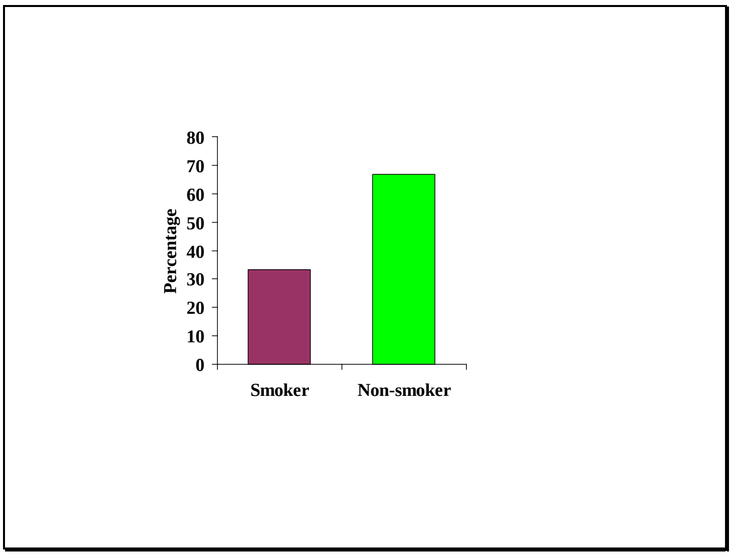


Table 3: Smoking habits of test subjects

	Frequency	Percentage
Smokers	12	33,3
Non-smokers	24	66,7
TOTAL	36	100

Figure 3: Graphical representation of smoking habits of participants



Oxygen saturation levels – smokers vs non-smokers

		Mean Level	p-value
Base level	Smokers	96,79	p = 0,5654
	Non-smokers	96,56	
8,000 feet	Smoker	96,33	p = 0,1114
	Non-smokers	95,02	
12,000 feet	Smokers	91,63	p = 0,3738
	Non-smokers	90,44	

No significant differences

5.1.3.2 PERCENT OXYGEN SATURATION

At each of the altitudes the oxygen saturation level was taken twice. The mean of these two measurements was calculated.

Mean oxygen saturation percentage levels are presented in Table 4.

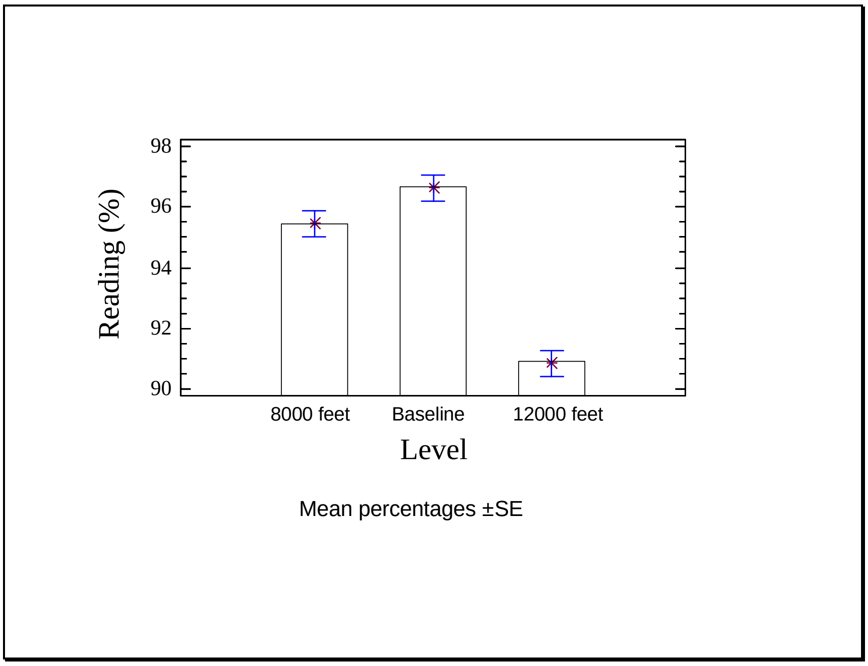
Table 4: Mean oxygen saturation levels at the different altitudes

Altitude	Mean Level	Standard Deviation	Mean Standard Error
Baseline	96,639%	1,106	0,184
8,000 feet	95,458%	2,325	0,387
12,000 feet	90,833%	3,717	0,619

Altitude	p-value
oxy B-oxy8,000 feet	p = 0,0062
oxy B-oxy12,000 feet	p = < 0,0001

The oxygen saturation levels are significantly reduced at higher altitude. The results are graphically represented in Figure 4.

Figure 4: Oxygen saturation levels at different altitudes



There is a statistically significant difference between the mean oxygen saturation levels at baseline, ie ground level and 8,000 feet as well as between levels at baseline and 12,000 feet.

5.1.3.3 PULSE RATE

At each of the altitudes the pulse rate was taken twice. The mean of these two measurements was calculated.

Mean pulse rates are presented in Table 5.

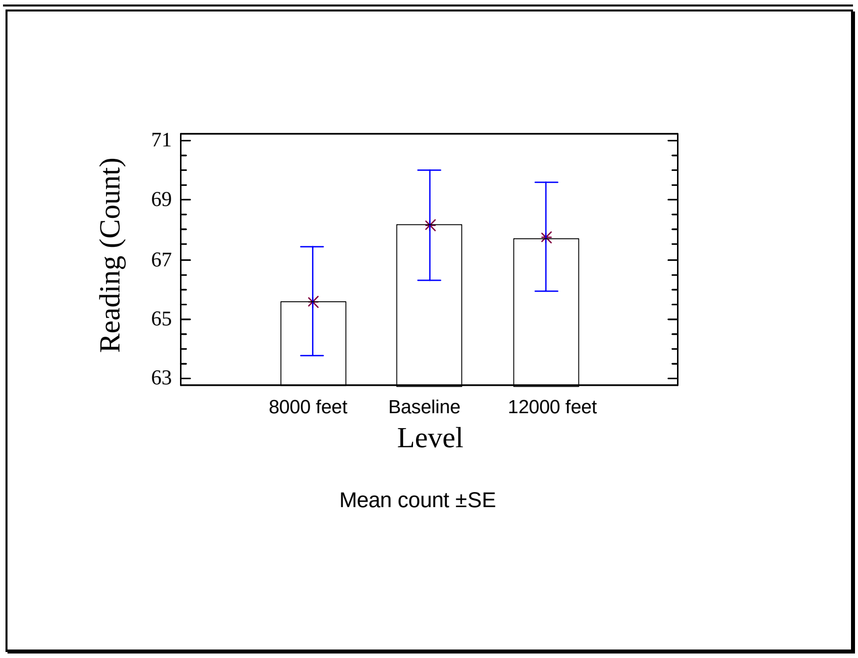
Table 5: Mean pulse rates at the different altitudes

Altitude	Mean Pulse Rate	Standard Deviation	Mean Standard Error
Baseline	68,167	10,754	1,792
8,000 feet	65,583	11,574	1,929
12,000 feet	67,764	10,969	1,828

Altitude	p-value
oxy B-oxy8,000 feet	p = 0,0701
oxy B-oxy12,000 feet	p = < 0,7636

There is no significant difference between pulse rates at baseline and 8,000 feet and also none at baseline and 12,000 feet. The results are graphically represented in Figure 5.

Figure 5: Pulse rates at different altitudes



5.1.3.4 CONTRAST SENSITIVITY

At each of the altitudes two measurements were taken for each subject on each line. The minimum of these two measurements was taken for the analysis.

The mean contrast sensitivities are presented in Table 6.

Table 6: Contrast sensitivity at the different altitudes

Altitude	Contrast Sensitivity					
	A	Standard Deviation	Mean Standard Error	B	Standard Deviation	Mean Standard Error
Baseline	5,806	0,467	0,078	6,417	0,500	0,083
8,000 feet	6,000	0,478	0,080	6,556	0,504	0,084
12,000 feet	6,028	0,446	0,074	6,556	0,504	0,084

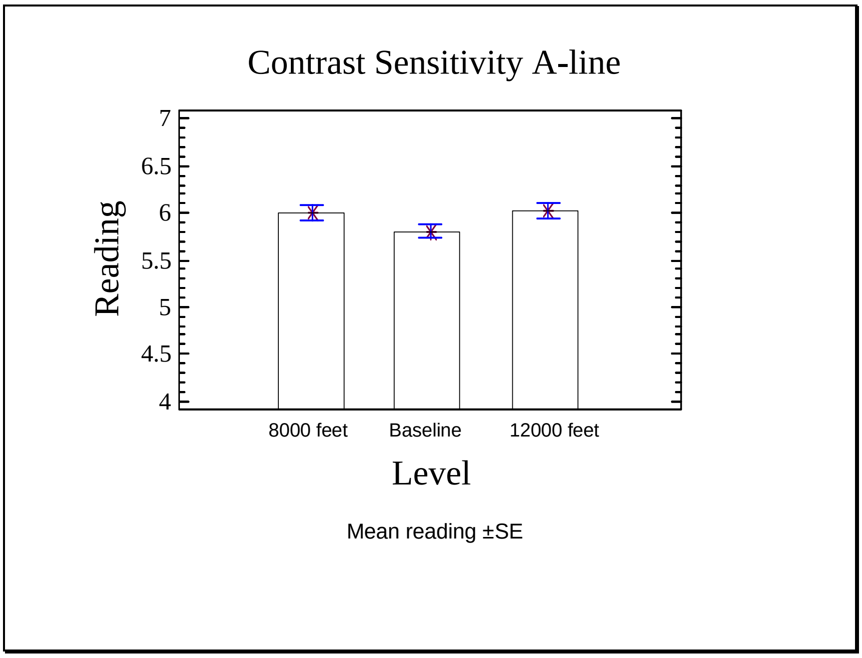
Altitude	Contrast Sensitivity					
	C	Standard Deviation	Mean Standard Error	D	Standard Deviation	Mean Standard Error
Baseline	6,028	0,774	0,129	5,833	0,697	0,116
8,000 feet	6,278	0,815	0,136	5,972	0,774	0,129
12,000 feet	6,222	0,832	0,139	5,889	0,820	0,137

Altitude	Contrast sensitivity		
	E	Standard Deviation	Mean Standard Error
Baseline	4,556	1,403	0,234
8,000 feet	4,972	1,341	0,224
12,000 feet	4,917	1,296	0,216

Altitude	Line	p-value
Baseline / 8,000 feet	A-line	0,0164 < 0,05 *
	B-line	0,0668 > 0,05
	C-line	0,0025 < 0,05 *
	D-line	0,1005 > 0,05
	E-line	0,0058 < 0,05 *
Baseline / 12,000 feet	A-line	0,0016 < 0,05 *
	B-line	0,0668 > 0,05
	C-line	0,0164 < 0,05 *
	D-line	0,3119 > 0,05
	E-line	0,0129 < 0,05 *

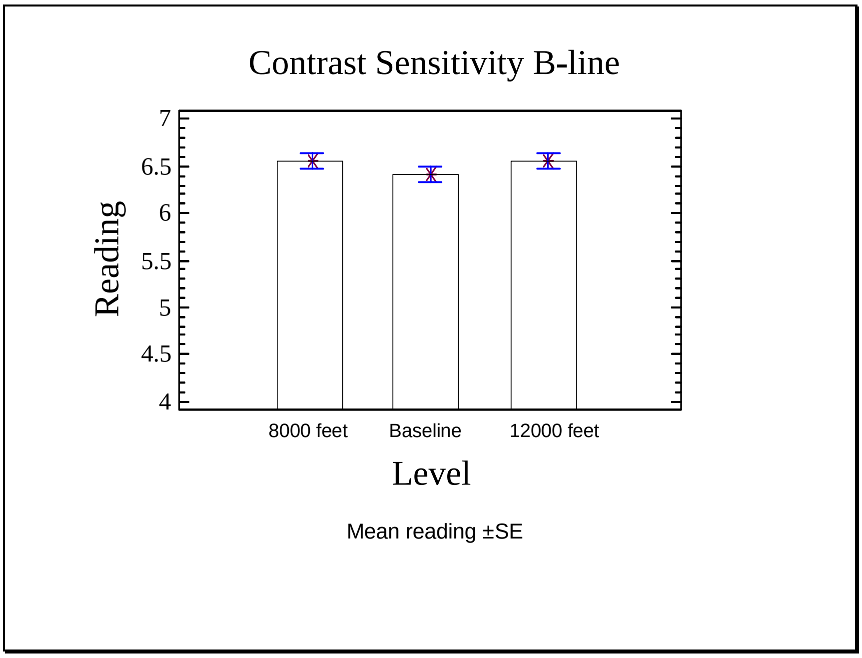
There is a significant difference between contrast sensitivity at baseline and 8,000 feet as well as at baseline and 12,000 feet for the A-line, C-line and E-line. The results are graphically represented in Figures 6-10.

Figure 6: Contrast Sensitivity as measured for the A-line at different altitudes



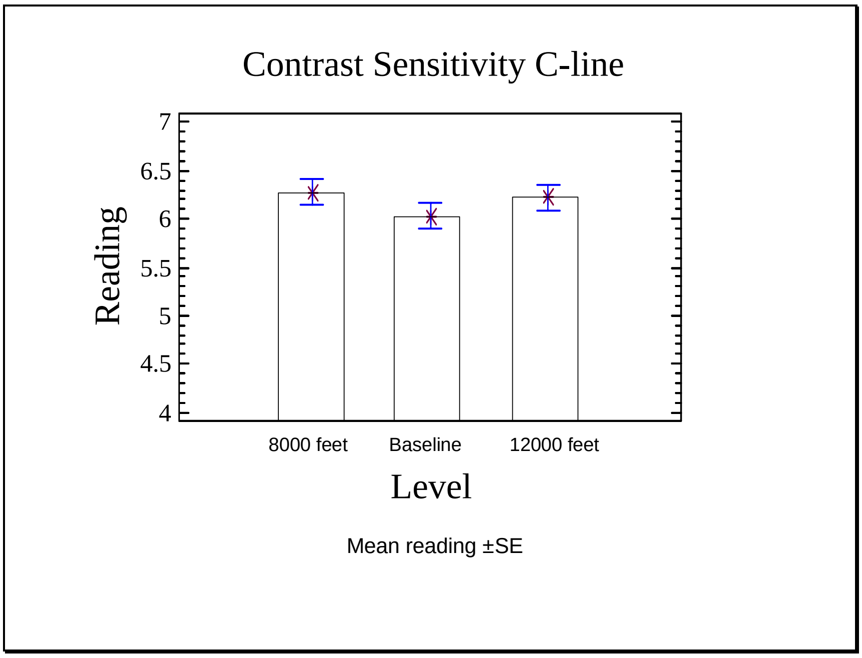
There is a statistically significant difference between contrast sensitivity for the A-line at baseline and 8,000 feet, as well as at baseline and 12,000 feet.

Figure 7: Contrast Sensitivity as measured for the B-line at different altitudes



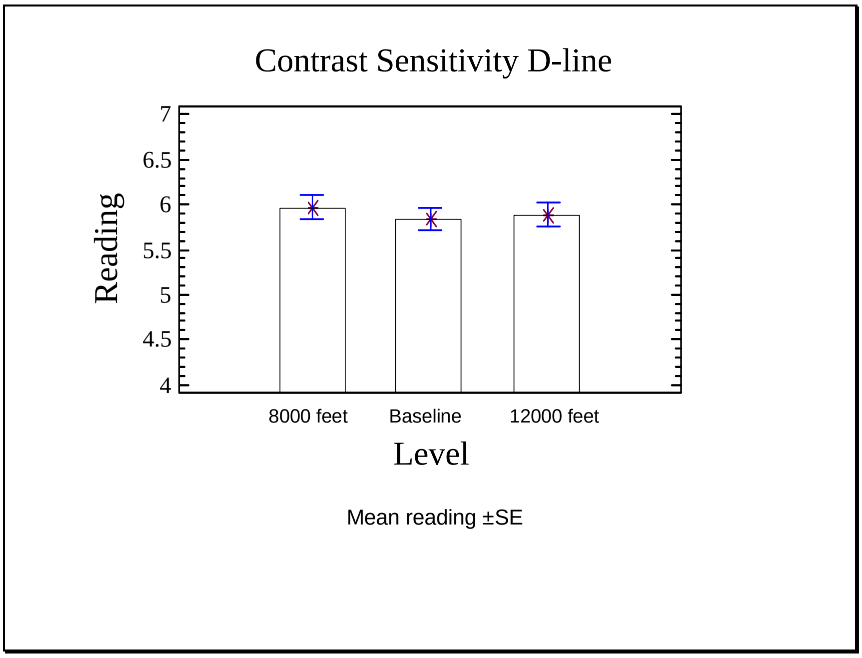
There is no statistical difference for the B-line.

Figure 8: Contrast Sensitivity as measured for the C-line at different altitudes



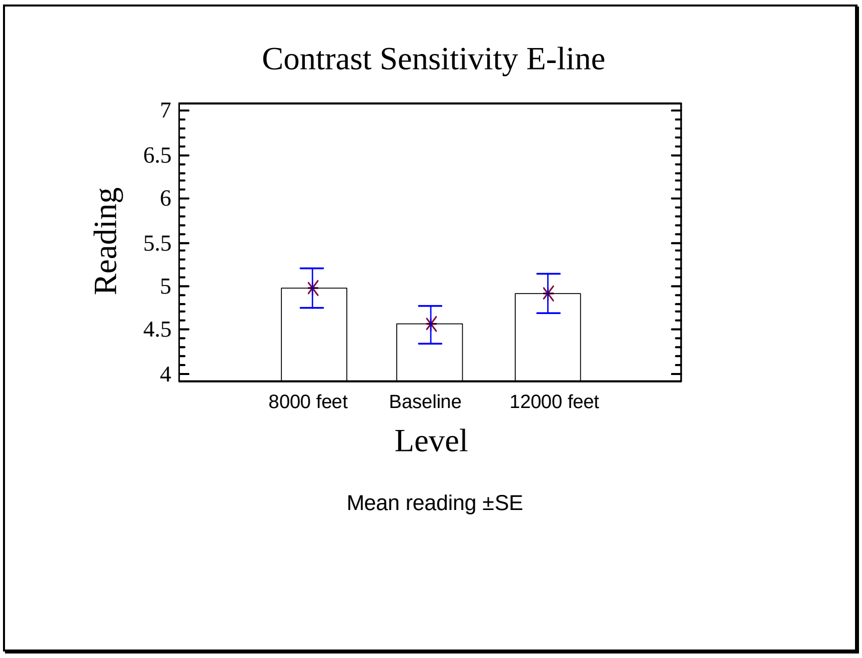
There is a statistically significant difference between contrast sensitivity for the C-line at baseline and 8,000 feet, as well as at baseline and 12,000 feet.

Figure 9: Contrast Sensitivity as measured for the D-line at different altitudes



There is no statistical difference for the D-line.

Figure 10: Contrast Sensitivity as measured for the E-line at different altitudes



There is a statistically significant difference between contrast sensitivity for the E-line at baseline and 8,000 feet, as well as at baseline and 12,000 feet.

5.1.3.5 ANOMALOSCOPE

At each of the altitudes three measurements were taken for each subject on each line. The mean value of these three measurements was taken for the analysis.

The mean readings for the anomaloscope are presented in Table 7.

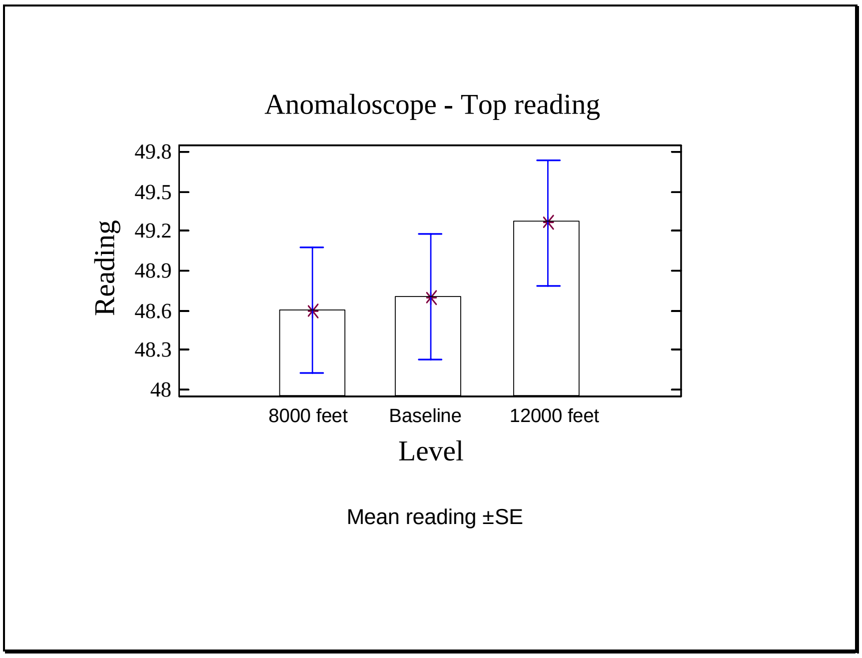
Table 7:Mean anomaloscope readings at the different altitudes

Altitude	Anomaloscope reading					
	Top	Standard Deviation	Mean Standard Error	Bottom	Standard Deviation	Mean Standard Error
Baseline	48,7	2,440	0,407	17,45	4,381	0,730
8,000 feet	48,60	3,493	0,582	17,50	3,538	0,590
12,000 feet	49,26	2,485	0,414	16,74	3,541	0,590

Altitude		p-value
Baseline / 8,000 feet	Top	0,5643 > 0,05
	Bottom	0,4776 > 0,05
Baseline / 12,000 feet	Top	0,0136 < 0,05
	Bottom	0,9244 > 0,05

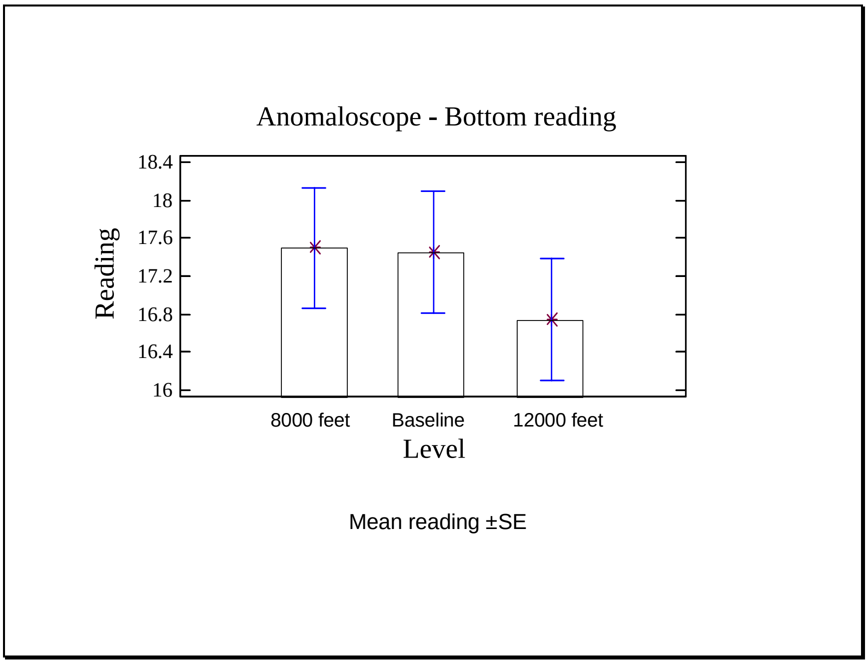
There is no significant difference between the readings at baseline and those at 8,000 feet (both top and bottom readings). There is a significant difference between the top readings at baseline and those at 12,000 feet. The results are graphically represented in Figures 11 and 12.

Figure 11: Top reading for the Anomaloscope at different altitudes



There is no significant difference between the top readings at baseline and those at 8,000 feet. There is a statistically significant difference between the top readings at baseline and those at 12,000 feet.

Figure 12: Bottom reading for the Anomaloscope at different altitudes



There is no statistical difference for the bottom readings.

5.1.3.6 PHORIAS

At each of the altitudes two measurements were taken for each subject on each line. The mean value these two measurements was taken for the analysis.

The mean readings for phorias are presented in Table 8.

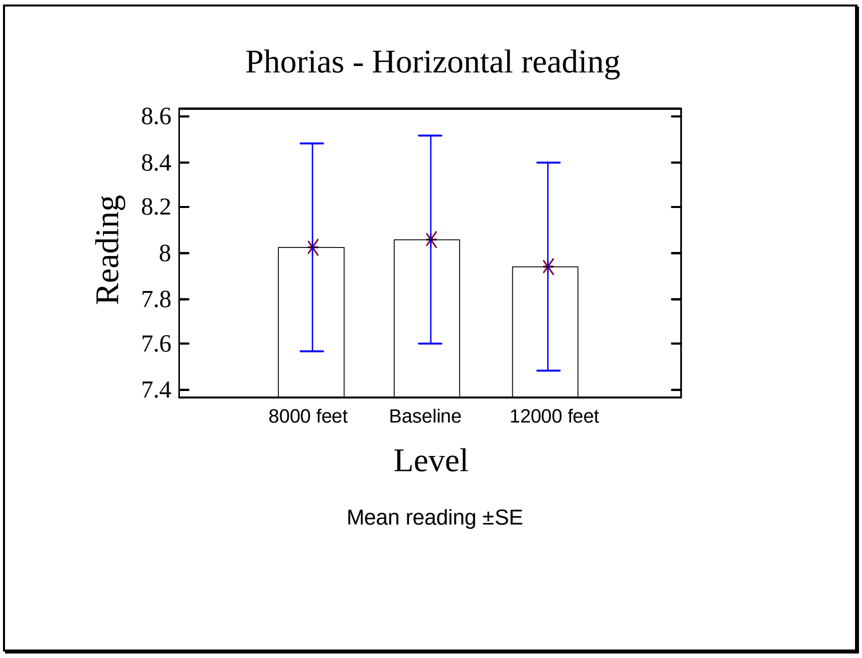
Table 8: Mean readings for phoria at the different altitudes

Altitude	Phoria Reading					
	Horizontal	Standard Deviation	Mean Standard Error	Vertical	Standard Deviation	Mean Standard Error
Baseline	8,056	2,640	0,440	6,278	1,186	0,198
8,000 feet	8,028	2,883	0,481	6,000	0,986	0,164
12,000 feet	7,944	2,683	0,447	6,083	1,052	0,175

Altitude		p-value
Baseline / 8,000 feet	Horizontal	0,5747 > 0,05
	Vertical	0,9665 > 0,05
Baseline / 12,000 feet	Horizontal	0,7186 > 0,05
	Vertical	0,8860 > 0,05

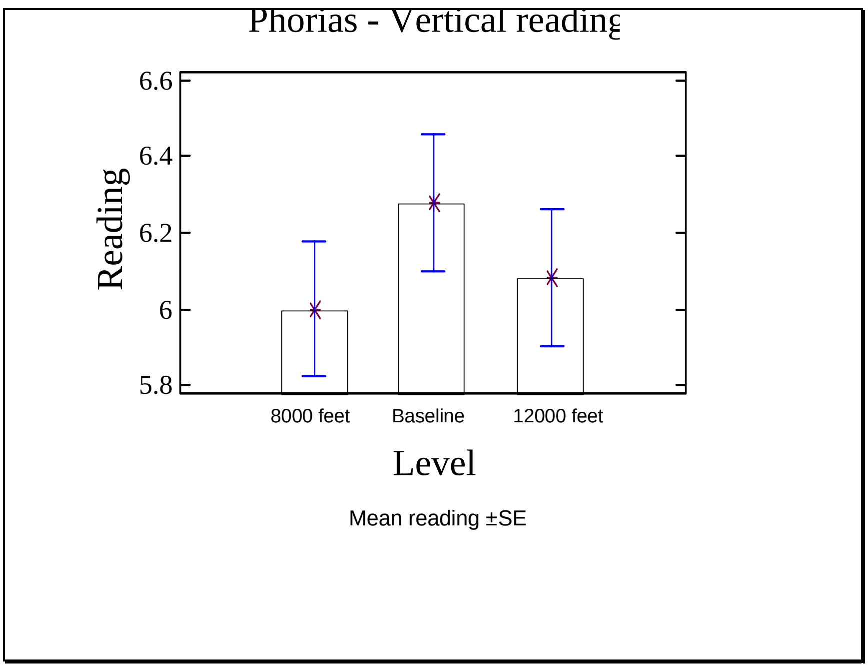
There is no significant difference between the readings at baseline and 8,000 feet and also none at baseline and 12,000 feet. The results are graphically represented in Figures 13 and 14.

Figure 13: Horizontal reading of Phorias at different altitudes



There is no statistical difference for the horizontal readings.

Figure 14: Vertical reading of Phorias at different altitudes



There is no statistical difference for the vertical readings.

CHAPTER 6

6.1 DISCUSSION OF RESULTS

The results of this study demonstrate that hypoxia was induced at altitude in the chamber, being, logically, more pronounced at 12,000 feet. This was confirmed by pulse oximetry readings, which demonstrated a drop of oxygen saturation at altitude. The mean oxygen saturation level at ground was 96,639%, at 8,000 feet 95,488% and at 12,000 feet 90,833%. The relationship between percentage oxygen saturation and oxygen partial pressure in the blood is non-linear and the drop from 96,639% to 90,833% represents a substantial reduction of partial pressure of oxygen, from over 90mm Hg to about 55mm Hg. Thus, a marked degree of hypoxia was induced. There is great individual tolerance to hypoxia, and it was interesting to note that there was little difference in the pulse rates of the subjects, indicating a relatively high systemic (but not necessarily optic) tolerance to hypoxia in this fit, young group of individuals. At no stage did any subject experience rapid breathing of the "air hunger" type.

With regard to the individual tests, the contrast sensitivity tests demonstrated no deterioration at the selected altitudes. Somewhat paradoxically, there was actually a marginal improvement of performance at altitude in three of the five test lines, the remaining two showing no difference. In the three lines demonstrating improvement, the difference was statistically significant. Although it might be construed that this is possibly within the limits of experimental variation, especially when two lines showed no difference, the fact that there was statistical significance to the differences in the three affected lines suggests that further experimental work should be directed to this area. The importance, as far as the present study and its aviation implications are concerned, is that there was no deterioration in contrast sensitivity at altitude. This is in keeping with the work, quoted above, of Yap *et al* [12] and Davis *et al* [13], who showed no deleterious effects in contrast sensitivity at 12,000 feet. This, in turn, challenges previous work by Hecht *et al* [4], which claimed deterioration present by 8,000 feet.

As far as colour vision is concerned, the Ishihara Plate screening tests for colour vision, a gross method of colour vision assessment, showed no changes at altitude. The Ishihara plates will pick up definitely established colour vision abnormalities, and none were demonstrated. With regard to the anomaloscope, an extremely sensitive colour test system which will pick up subtle changes, there were some changes in the top (red / green) readings. This was only present at 12,000 feet, and, as indicated in the data, this was of statistical significance. There was no difference in the bottom readings. This was discussed with the staff of the Eye Department of the Institute for Aviation Medicine, who indicated that the red / green differences, although statistically significant, were still within the normal range. It was determined, therefore, that these differences were not of clinical, as opposed to statistical significance, and were not reflected in the Ishihara Plate tests. Thus, flight safety was not impacted upon. The differences might, again, be within the limits of experimental error. The apparatus is very sensitive, and there were often differences between successive measurements by the same subject at the same altitude.

Nonetheless, it is possible that this could be the beginning of the effects of hypoxia manifesting itself. It would be useful to conduct further work in this area, subjecting subjects to a much longer period of hypoxia in order to detect any cumulative effect on colour vision due to the hypoxia.

With regard to assessment of phorias, the p-value of >0.05 indicated that there were no deleterious effects detected at altitude.

It was important in this experimental work to demonstrate that the illumination within the chamber was not affected by altitude. This was confirmed as being the case by the Council for Scientific and Industrial Research in their report. (Annexure D)

This experimental work forms one of the largest and most controlled series in the literature in this area of endeavour. The work was very controlled and demonstrated that, at 12,000 feet, contrast sensitivity was not reduced, indeed, unexpectedly, and not noted in any previous literature, there was marginal, but statistically significant, increased capacity at altitude. This indicates the need for further investigation. Colour vision was not grossly affected at altitude, but there were some statistically significant red / green differences. These were not considered of clinical significance. There were no phoria effects at altitude.

These tests are of functional significance to aircrew, assessing critical areas of pilot visual function and, therefore, impacting on flight safety. The results show, therefore, that there are no clinically significant adverse effects in these areas of observation at 12,000 feet, and that the current regulations requiring the administration of supplementary oxygen from 12,000 feet upwards are still valid. All the subjects were

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normally located in the Pretoria area, which, as previously mentioned, is at altitude already.

They will, therefore, have undergone the normal physiological adaptation implicit in residence at that altitude. It might be assumed, therefore, that they have already acquired a degree of resistance to hypoxia which would not be present in aircrew resident at sea level. The latter group might, theoretically, therefore, be more susceptible to hypoxic effects at 12,000 feet. Assessment of this would require that this work be repeated at sea level. No facilities for this work exist, at present, in South Africa, at sea level.

6.2 **CONCLUSIONS**

As a result of this study, it is concluded that there are no CLINICALLY significant deleterious effects, due to hypoxia, on colour vision, contrast sensitivity or phorias in subjects at a simulated altitude of 12,000 feet, all the subjects being normally resident at an altitude of 5,000 – 5,500 feet.

6.3 RECOMMENDATIONS

1. It is recommended that, based on the visual parameters selected for assessment, the present recommendation for commencement of oxygen supplementation at 12,000 feet be retained.

2. Although the subjects spent sufficient time at altitude to overfly the highest mountain areas in South Africa it is recommended that further studies be done, involving some subjects being subjected to several hours of relative hypoxia, in order to detect any cumulative effects of the longer term hypoxia.

3. In view of the fact that all the subjects were normally resident at 5,000 to 5,500 feet, and had, therefore, a minor degree of physiological adaptation to the ambient, mildly reduced, oxygen level at that altitude, it would be appropriate to repeat this work with a population group resident at sea level, in order to detect if this group had a greater susceptibility to the relative hypoxia, not having developed any physiological adaptation to relative hypoxia. There is, however, no altitude chamber located at sea level in South Africa, and moving that subject group to the chamber at altitude would distort the parameters. This work, therefore, would have to be undertaken overseas where altitude chambers are available at sea level.

4. In view of the unexpected finding of enhancement of contrast sensitivity at 12,000 feet it is suggested that further work be done to investigate this.

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ANNEXURE A

RESTRICTED

SG(2)/R/ 202/3/7

Telephone: 671-5345
Enquiries: Sgt C.M. De Wit

SAMHS Headquarters
Private Bag X102
Centurion
0046

30 July 1999

RESEARCH PROPOSAL: DR C. MACFARLANE

1. Authorisation has been given to the above-mentioned member to do a research study on "Possible colour vision, contrast sensitivity and phobias due to hypoxia at an altitude of 12000 ft"

2. The following guidelines should be adhered to:

   a. The questionnaires for his/her research, is hereby authorised for use.

   b. The researcher, study leader and typist must be in possession of the concurrent **security clearance** for the highest level of access provided to the researcher, before such access can commence.

   c. The final manuscript must first be provided to SAMHS HQ CI, then Def Int (SDCI/DDS) for authorisation, **before** it is provided to the study leader for examination purposes; or before being published. No alterations may be made after authorisation has been granted without the approval of Def Int (SDCI/DDS). A final security classification will then, if necessary, be given to the manuscript. The publication must then be handled according to the classification and SANDFO/R/2/97 dated 12 Feb 97 covering restrictions on classified documentation.

   d. A written undertaking must be provided, that personal information wrt an individual, dead or alive, that are gleaned from SAMHS files, will only be used with written consent of the member or direct family (in the case where the member is deceased). The SAMHS does not accept responsibility for any *Crimen Injuria* complaints against any researcher.

   e. Defence Intelligence (SDCI/DDS) must immediately be informed of any change of address.

   f. A fully annotated copy of the final product must be provided to the Directorate Documentation Services, no later than one month after final authorisation was provided for the product.

g. The researcher must be registered at the Directorate Documentation Services.

3. For your attention.

(MAJ C.M. PENWARDEN)
SURGEON GENERAL: LT GEN

DISTR

For Action

Dir Emergency Med Services (Attention: Dr C. Macfarelane)

Internal FAX (011) 315 2151

SG(2)/R/202/3/7

ANNEXURE B

PROVINSIALE
ADMINISTRASIE

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GAUTENG

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Enquires:	Dr R Sommers	Address:	Ethics Eittee Ward 4 Room 19 Pretoria Academic Hospital Private Bag x 169 *PRETORIA* 0001
Reference:			
Tel:	(012) 354 1560		
Fax:	(012) 354 1702	Date:	25-02-98

Nommer : 24/98

TITEL : An assessment of deterioration of colour vision, contrast sensitivity and phorias as a result of hypoxia in persons resident at altitude.

AANSOEKER : Dr C G J Le Roux; Dept Aerospace Medicine; Pretoria Academic Hospitals; PRETORIA

This Protocol and Informed Consent form has been considered by the Ethics Committee, Faculty of Medicine, Univ.of Pretoria and Pretoria Academic Hospitals on 25-02-98 and found to be acceptable.

Prof A.L. Coetzee	MA(ClinPsych);DSocSc (Leiden);MPA(Pret): Psychologist
Dr J.E.Davel (female)	MBChB:Hospital Superintendent
Prof A.P.du Toit	BA;DiplTheo(Pret) BA (Hons) (Rhodes);MA;DPhil(Pret): Philosopher
Prof C.I. Falkson (female)	MBChB;M.Med(Int);MD;Med. Oncologist
Prof G. Falkson	MBChB;M.Med(Int);MD;OSG: Medical Oncologist
Prof S.V. Grey (female)	BSc(Hons)(Stell);MSc(PU vir CHO) DSc(Pret): Deputy Dean
Dr S.W. Johnson	MBChB:Hospital Superintendent
Dr V.O.L. Karusseit	MBChB;MFGP(SA);M.Med(Chir); FCS (SA): Surgeon
Ms B.C.F. Magardie(female)	BCur:Matron/Senior Nursing Sister
Senior Sr J. Moerane(female)	BCur(EetAl)SeniorNursing Sister
Prof T.R. Mokoena	MBChB;FRCS(Glasgow);DPhil (Oxford): Surgeon
Prof H.W. Pretorius	MBChB;M.Med (Psych)MD: Psychiatrist
Dr P. Rheeder	MBChB;MMed(Int);LKI(SA);MSc (KLIN.EPI):Specialist Physician
Prof J.R. Snyman	MBChB,MPharmMed: Pharmacologist
Prof De K Sommers	BChB; HDD; MBChB; MD: Pharmacologist
Advokaat L.G.Thomas (female)	B.Iuris(University of the North); LLB(University of the Western Cape)
Prof F.W. van Oosten	BA;LLB;LLD(Pret);LLD (Unisa):Prof in Criminaland Medical Law

PROF G FALKSON ; MBChB; M.Med (Int);MD;
VOORSITTER

INFORMED CONSENT FORM

INSTITUTE FOR AVIATION MEDICINE

CONSENT TO PARTICIPATE IN RESEARCH

PROJECT

The assessment of colour vision, contrast sensitivity and phorias as a result of hypoxia in persons resident at altitude.

PURPOSE OF RESEARCH

To determine if there are subtle changes of significance in visual parameters at an altitude of 12,000 ft. The presence of these could result in a lowering of the altitude at which aircrew must take supplementary oxygen. At present, in South Africa, this is 12,000ft.

EXCLUSION

You will not be an acceptable subject for the project if:

1. You require visual correction eg. spectacles, contact lenses.
2. You have eye pathology
3. You have a cold and are unable to clear the ears
4. You have been out of the highvelt area at lower altitude in the last week.
5. You have had fits
6. You are on medications

RESEARCH PLAN

The equipment for eye testing will be installed in the altitude chamber at the institute for aviation medicine, and you will be instructed what to do. This will include looking at charts and through lenses, commenting on what you see. When you are comfortable with the equipment your vision will be tested. The chamber will then be adjusted to 8,000 and 12,000ft altitude and 30 minutes will be allowed to let the body adjust to altitude. The same eye tests will then be repeated at these simulated altitudes. During the tests your body oxygen saturation will be measured by means of a device which clips on to a finger. The altitude will then be returned to normal and the test ends.

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IMPORTANT INFORMATION

1. This is not a risky project, and is no different from sitting in an aircraft at the same altitudes.

2. There are no injections, blood tests or any other invasive procedures.

3. The only changes you are likely to notice at these altitudes are slight increase of breathing rate and pulse rate.

4. Confidentiality of results will be maintained and only those involved in the project will have access to them.

VOLUNTARY PARTICIPATION

This is an important research project which has considerable relevance to flight safety. Participation in this study is voluntary and there will be no payment for volunteers. You are free to refuse to participate in the study, without any penalty. Similarly you may withdraw from the study at any time, without penalty.

This project has been explained to me by Dr. C. MacFarlane, the project leader, and I have read this form. Any questions have been answered to my satisfaction.

I therefore willingly give consent to participate as a subject in this project, and, on signing consent, will receive a copy of this form.

______________________ ______________
SIGNATURE **DATE**

______________________ ______________
WITNESS SIGNATURE **DATE**

______________________ ______________
PHYSICIAN SIGNATURE **DATE**

ANNEXURE D

CSIR

National Metrology Laboratory

Custodian of the **national measuring standards of South Africa**

PO Box 395
Pretoria 0001 South Africa
Tel. + 27 12 841-4152
Fax. + 27 12 841-2131
e-mail. nml@csir.co.za
http://www.nml.csir.co.za

CERTIFICATE OF MEASUREMENT

Measurement of	:	RELATIVE SPECTRAL DISTRIBUTION OF ILLUMINATION FROM TUBULAR FLUORESCENT LAMPS
Manufacturer	:	General Electric
Model number	:	Lamps – Slimline F96 T12-CWEX Cool White
Serial number	:	—
Measured for	:	UNIVERSITY OF PRETORIA Faculty of Health Sciences
Measurement procedure	:	See §1 for procedure Also see NML-OR\SR-0008
Period of measurement	:	30 November 2001
Date of issue	:	9 December 2002
Certificate number	:	OR\SR-2716
Measured by	:	B Theron (012) 841-4242
Checked by	:	LAG Monard
Page	:	1 of 10

.... (approved signatory)

....

.... (for Director)

The CSIR is empowered by the Measuring Units and National Measuring Standards Act, 1973 (Act 76 of 1973), as amended, to keep and maintain all national measuring standards.

MEASUREMENT OF RELATIVE SPECTRAL DISTRIBUTION OF ILLUMINATION

1. PROCEDURE

Facilities. The measurements were conducted inside an altitude simulator, i.e. a large vacuum tank in which several people can be seated and with floor space for a table, for equipment and for people to stand. The pressure in the simulator is reduced to simulate various flight altitudes. The inside of the simulator is fitted with tubular fluorescent lamps to provide illumination. The simulator was located at the premises of the Institute for Aviation Medicine, a facility of the South African National Defence Force, situated at Lionel Slade Street, Lyttelton.

Background: The University of Pretoria has used the simulator to do studies on human test subjects (pilots) to determine the effect of altitude on their colour perception. The studies involve the use of surface colour samples, and therefore changes in colour perception are dependent:

- on changes in the spectral distribution of the illumination and
- on physiological effects of (simulated) altitude on the test subject.

Purpose of measurements. To obtain the relative spectral distribution of the illumination from the tubular fluorescent lamps as a function of simulated altitude.

Method. A white diffuse reflector was placed at a distance of approximately 0,7 m under one of the lamps, tilted at an angle of approximately 45°, receiving illumination from that lamp and also from some other lamps in the simulator. The aperture of a spectroradiometer was optically focused and aligned at an angle of approximately 45° with the reflector. Measurements were taken at simulated altitudes:

5 100 ft	Starting altitude, ground level in Pretoria
8 000 ft	Measurement 10 minutes after reaching altitude
12 000 ft	Measurement 10 minutes after reaching altitude
5 100 ft	Back at ground altitude, measurement 20 minutes after reaching altitude

The spectroradiometer measured spectral radiance and the operating software of the spectroradiometer also calculated the 1931 CIE chromaticity coordinates and the 1976 UCS chromaticity coordinates from the data. The measured spectral radiance was a relative measure of the spectral distribution of the illumination as sampled at the location of the diffuse reflector. The accuracy of the spectroradiometer was traceable to the national measuring standards of irradiance.

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2. RESULTS

The spectral radiance results are given in Table 2.1 and Figure 2.1. The corresponding chromaticity coordinates are given in Table 2.2. The uncertainty of measurement on the relative spectral radiance values are as follows

For wavelengths 380 – 420 nm: 4%
For wavelengths 420 – 1 020 nm: 3%
For wavelengths 1 020 – 1 068 nm: 5%

***Table 2.2**. Chromaticity coordinates at given (simulated) altitudes*

Chromaticity coordinates						
		5 100 ft start	**8 000 ft**	**12 000 ft**	**5 100 ft end**	**Uncertainty**
1976 UCS	u'	0,222	0,222	0,222	0,221	±0,003
	v'	0,513	0,512	0,512	0,512	±0,003
1931 2^{o} observer	x	0,390	0,389	0,389	0,388	±0,003
	y	0,401	0,398	0,397	0,400	±0,003
	z	0,209	0,213	0,214	0,213	±0,003

3. REMARKS

3.1 The reported uncertainties of measurement were calculated and expressed in accordance with the BIPM, IEC, ISO, IUPAP, OIML document entitled "A Guide to the Expression of Uncertainty in Measurement" (International Organisation for Standardisation, Geneva, Switzerland, 1993).

3.2 The reported uncertainties of measurement are based on a standard uncertainty multiplied by a coverage factor of k=2, which, unless specifically stated otherwise, provides a level of confidence of approximately 95 %.

3.3 This certificate is consistent with the CSIR-NML capabilities that are included in Appendix C of the MRA (Mutual Recognition Arrangement) drawn up by the CIPM. Under the MRA, all participating institutes recognise the validity of each other's calibration and measurement certificates for the quantities and ranges and measurement uncertainties specified in Appendix C (for details see http://www.bipm.org).

3.4 The ambient temperature was estimated to be between 20 °C and 35 °C.

3.5 The results reported in Table 2.1 cover the spectral range over which the spectroradiometer measured. However, note that the human eye is sensitive only in the spectral range 380 – 780 nm.

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***Table 2.1**. Measured spectral radiance at given (simulated) altitudes*

Wave-length (nm)	Spectral radiance ($W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$)			
	5 100 ft start	8 000 ft	12 000 ft	5 100 ft end
380	$3{,}656 \times 10^{-4}$	$3{,}455 \times 10^{-4}$	$3{,}414 \times 10^{-4}$	$4{,}452 \times 10^{-4}$
384	$4{,}504 \times 10^{-4}$	$4{,}085 \times 10^{-4}$	$4{,}031 \times 10^{-4}$	$5{,}338 \times 10^{-4}$
388	$6{,}381 \times 10^{-4}$	$6{,}118 \times 10^{-4}$	$6{,}035 \times 10^{-4}$	$7{,}201 \times 10^{-4}$
392	$8{,}890 \times 10^{-4}$	$8{,}344 \times 10^{-4}$	$8{,}357 \times 10^{-4}$	$9{,}762 \times 10^{-4}$
396	$1{,}195 \times 10^{-3}$	$1{,}156 \times 10^{-3}$	$1{,}150 \times 10^{-3}$	$1{,}314 \times 10^{-3}$
400	$2{,}090 \times 10^{-3}$	$2{,}022 \times 10^{-3}$	$2{,}017 \times 10^{-3}$	$2{,}238 \times 10^{-3}$
404	$2{,}823 \times 10^{-3}$	$2{,}745 \times 10^{-3}$	$2{,}721 \times 10^{-3}$	$2{,}979 \times 10^{-3}$
408	$2{,}110 \times 10^{-3}$	$2{,}032 \times 10^{-3}$	$2{,}004 \times 10^{-3}$	$2{,}257 \times 10^{-3}$
412	$1{,}475 \times 10^{-3}$	$1{,}413 \times 10^{-3}$	$1{,}394 \times 10^{-3}$	$1{,}645 \times 10^{-3}$
416	$1{,}572 \times 10^{-3}$	$1{,}503 \times 10^{-3}$	$1{,}491 \times 10^{-3}$	$1{,}750 \times 10^{-3}$
420	$1{,}875 \times 10^{-3}$	$1{,}821 \times 10^{-3}$	$1{,}802 \times 10^{-3}$	$2{,}053 \times 10^{-3}$
424	$2{,}436 \times 10^{-3}$	$2{,}430 \times 10^{-3}$	$2{,}411 \times 10^{-3}$	$2{,}611 \times 10^{-3}$
428	$3{,}267 \times 10^{-3}$	$3{,}342 \times 10^{-3}$	$3{,}339 \times 10^{-3}$	$3{,}453 \times 10^{-3}$
432	$7{,}289 \times 10^{-3}$	$7{,}804 \times 10^{-3}$	$7{,}866 \times 10^{-3}$	$7{,}518 \times 10^{-3}$
436	$8{,}712 \times 10^{-3}$	$9{,}321 \times 10^{-3}$	$9{,}359 \times 10^{-3}$	$8{,}908 \times 10^{-3}$
440	$4{,}813 \times 10^{-3}$	$4{,}979 \times 10^{-3}$	$4{,}956 \times 10^{-3}$	$4{,}987 \times 10^{-3}$
444	$2{,}803 \times 10^{-3}$	$2{,}761 \times 10^{-3}$	$2{,}737 \times 10^{-3}$	$3{,}015 \times 10^{-3}$
448	$2{,}809 \times 10^{-3}$	$2{,}758 \times 10^{-3}$	$2{,}731 \times 10^{-3}$	$3{,}035 \times 10^{-3}$
452	$2{,}877 \times 10^{-3}$	$2{,}827 \times 10^{-3}$	$2{,}802 \times 10^{-3}$	$3{,}115 \times 10^{-3}$
456	$2{,}977 \times 10^{-3}$	$2{,}928 \times 10^{-3}$	$2{,}907 \times 10^{-3}$	$3{,}221 \times 10^{-3}$
460	$3{,}067 \times 10^{-3}$	$3{,}026 \times 10^{-3}$	$3{,}001 \times 10^{-3}$	$3{,}319 \times 10^{-3}$
464	$3{,}148 \times 10^{-3}$	$3{,}113 \times 10^{-3}$	$3{,}082 \times 10^{-3}$	$3{,}395 \times 10^{-3}$
468	$3{,}223 \times 10^{-3}$	$3{,}187 \times 10^{-3}$	$3{,}164 \times 10^{-3}$	$3{,}476 \times 10^{-3}$
472	$3{,}267 \times 10^{-3}$	$3{,}234 \times 10^{-3}$	$3{,}208 \times 10^{-3}$	$3{,}518 \times 10^{-3}$
476	$3{,}309 \times 10^{-3}$	$3{,}282 \times 10^{-3}$	$3{,}258 \times 10^{-3}$	$3{,}560 \times 10^{-3}$
480	$3{,}335 \times 10^{-3}$	$3{,}319 \times 10^{-3}$	$3{,}293 \times 10^{-3}$	$3{,}597 \times 10^{-3}$
484	$3{,}338 \times 10^{-3}$	$3{,}321 \times 10^{-3}$	$3{,}300 \times 10^{-3}$	$3{,}589 \times 10^{-3}$
488	$3{,}361 \times 10^{-3}$	$3{,}352 \times 10^{-3}$	$3{,}325 \times 10^{-3}$	$3{,}612 \times 10^{-3}$
492	$3{,}356 \times 10^{-3}$	$3{,}339 \times 10^{-3}$	$3{,}325 \times 10^{-3}$	$3{,}614 \times 10^{-3}$
496	$3{,}315 \times 10^{-3}$	$3{,}304 \times 10^{-3}$	$3{,}281 \times 10^{-3}$	$3{,}579 \times 10^{-3}$

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Table 2.1. *Measured spectral radiance at given (simulated) altitudes*

Wave-length (nm)	Spectral radiance (W·sr^{-1}·m^{-2}·nm^{-1})			
	5 100 ft start	**8 000 ft**	**12 000 ft**	**5 100 ft end**
500	$3,297\times10^{-3}$	$3,283\times10^{-3}$	$3,260\times10^{-3}$	$3,556\times10^{-3}$
504	$3,275\times10^{-3}$	$3,264\times10^{-3}$	$3,238\times10^{-3}$	$3,535\times10^{-3}$
508	$3,283\times10^{-3}$	$3,265\times10^{-3}$	$3,235\times10^{-3}$	$3,546\times10^{-3}$
512	$3,326\times10^{-3}$	$3,298\times10^{-3}$	$3,272\times10^{-3}$	$3,596\times10^{-3}$
516	$3,399\times10^{-3}$	$3,361\times10^{-3}$	$3,334\times10^{-3}$	$3,677\times10^{-3}$
520	$3,540\times10^{-3}$	$3,495\times10^{-3}$	$3,465\times10^{-3}$	$3,827\times10^{-3}$
524	$3,749\times10^{-3}$	$3,687\times10^{-3}$	$3,657\times10^{-3}$	$4,049\times10^{-3}$
528	$4,064\times10^{-3}$	$3,985\times10^{-3}$	$3,949\times10^{-3}$	$4,374\times10^{-3}$
532	$4,444\times10^{-3}$	$4,343\times10^{-3}$	$4,303\times10^{-3}$	$4,762\times10^{-3}$
536	$5,037\times10^{-3}$	$4,923\times10^{-3}$	$4,875\times10^{-3}$	$5,361\times10^{-3}$
540	$6,963\times10^{-3}$	$6,796\times10^{-3}$	$6,751\times10^{-3}$	$7,310\times10^{-3}$
544	$9,742\times10^{-3}$	$9,484\times10^{-3}$	$9,390\times10^{-3}$	$1,009\times10^{-2}$
548	$9,798\times10^{-3}$	$9,529\times10^{-3}$	$9,440\times10^{-3}$	$1,013\times10^{-2}$
552	$8,356\times10^{-3}$	$8,181\times10^{-3}$	$8,119\times10^{-3}$	$8,703\times10^{-3}$
556	$8,353\times10^{-3}$	$8,192\times10^{-3}$	$8,130\times10^{-3}$	$8,686\times10^{-3}$
560	$8,932\times10^{-3}$	$8,777\times10^{-3}$	$8,710\times10^{-3}$	$9,255\times10^{-3}$
564	$9,482\times10^{-3}$	$9,336\times10^{-3}$	$9,262\times10^{-3}$	$9,796\times10^{-3}$
568	$9,926\times10^{-3}$	$9,792\times10^{-3}$	$9,719\times10^{-3}$	$1,023\times10^{-2}$
572	$1,061\times10^{-2}$	$1,049\times10^{-2}$	$1,042\times10^{-2}$	$1,091\times10^{-2}$
576	$1,137\times10^{-2}$	$1,125\times10^{-2}$	$1,117\times10^{-2}$	$1,166\times10^{-2}$
580	$1,123\times10^{-2}$	$1,112\times10^{-2}$	$1,104\times10^{-2}$	$1,151\times10^{-2}$
584	$1,058\times10^{-2}$	$1,049\times10^{-2}$	$1,041\times10^{-2}$	$1,086\times10^{-2}$
588	$9,960\times10^{-3}$	$9,884\times10^{-3}$	$9,818\times10^{-3}$	$1,022\times10^{-2}$
592	$9,603\times10^{-3}$	$9,532\times10^{-3}$	$9,466\times10^{-3}$	$9,843\times10^{-3}$
596	$9,188\times10^{-3}$	$9,130\times10^{-3}$	$9,068\times10^{-3}$	$9,432\times10^{-3}$
600	$8,596\times10^{-3}$	$8,542\times10^{-3}$	$8,480\times10^{-3}$	$8,849\times10^{-3}$
604	$8,053\times10^{-3}$	$8,004\times10^{-3}$	$7,942\times10^{-3}$	$8,310\times10^{-3}$
608	$7,505\times10^{-3}$	$7,460\times10^{-3}$	$7,402\times10^{-3}$	$7,766\times10^{-3}$
612	$6,867\times10^{-3}$	$6,825\times10^{-3}$	$6,774\times10^{-3}$	$7,124\times10^{-3}$
616	$6,241\times10^{-3}$	$6,208\times10^{-3}$	$6,162\times10^{-3}$	$6,499\times10^{-3}$

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Table 2.1. Measured spectral radiance at given (simulated) altitudes

Wave-length (nm)	Spectral radiance ($W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$)			
	5 100 ft start	8 000 ft	12 000 ft	5 100 ft end
620	$5,695 \times 10^{-3}$	$5,662 \times 10^{-3}$	$5,617 \times 10^{-3}$	$5,953 \times 10^{-3}$
624	$5,147 \times 10^{-3}$	$5,114 \times 10^{-3}$	$5,077 \times 10^{-3}$	$5,401 \times 10^{-3}$
628	$4,574 \times 10^{-3}$	$4,540 \times 10^{-3}$	$4,502 \times 10^{-3}$	$4,827 \times 10^{-3}$
632	$4,117 \times 10^{-3}$	$4,087 \times 10^{-3}$	$4,054 \times 10^{-3}$	$4,370 \times 10^{-3}$
636	$3,702 \times 10^{-3}$	$3,677 \times 10^{-3}$	$3,641 \times 10^{-3}$	$3,955 \times 10^{-3}$
640	$3,266 \times 10^{-3}$	$3,229 \times 10^{-3}$	$3,213 \times 10^{-3}$	$3,517 \times 10^{-3}$
644	$2,911 \times 10^{-3}$	$2,896 \times 10^{-3}$	$2,867 \times 10^{-3}$	$3,164 \times 10^{-3}$
648	$2,606 \times 10^{-3}$	$2,582 \times 10^{-3}$	$2,562 \times 10^{-3}$	$2,844 \times 10^{-3}$
652	$2,309 \times 10^{-3}$	$2,292 \times 10^{-3}$	$2,265 \times 10^{-3}$	$2,542 \times 10^{-3}$
656	$2,043 \times 10^{-3}$	$2,014 \times 10^{-3}$	$2,007 \times 10^{-3}$	$2,266 \times 10^{-3}$
660	$1,824 \times 10^{-3}$	$1,805 \times 10^{-3}$	$1,791 \times 10^{-3}$	$2,070 \times 10^{-3}$
664	$1,630 \times 10^{-3}$	$1,614 \times 10^{-3}$	$1,596 \times 10^{-3}$	$1,880 \times 10^{-3}$
668	$1,428 \times 10^{-3}$	$1,426 \times 10^{-3}$	$1,399 \times 10^{-3}$	$1,686 \times 10^{-3}$
672	$1,284 \times 10^{-3}$	$1,272 \times 10^{-3}$	$1,257 \times 10^{-3}$	$1,530 \times 10^{-3}$
676	$1,156 \times 10^{-3}$	$1,136 \times 10^{-3}$	$1,125 \times 10^{-3}$	$1,402 \times 10^{-3}$
680	$1,019 \times 10^{-3}$	$1,011 \times 10^{-3}$	$1,000 \times 10^{-3}$	$1,270 \times 10^{-3}$
684	$9,101 \times 10^{-4}$	$8,979 \times 10^{-4}$	$8,894 \times 10^{-4}$	$1,138 \times 10^{-3}$
688	$8,281 \times 10^{-4}$	$8,252 \times 10^{-4}$	$8,062 \times 10^{-4}$	$1,052 \times 10^{-3}$
692	$7,533 \times 10^{-4}$	$7,405 \times 10^{-4}$	$7,348 \times 10^{-4}$	$9,858 \times 10^{-4}$
696	$6,611 \times 10^{-4}$	$6,589 \times 10^{-4}$	$6,548 \times 10^{-4}$	$9,184 \times 10^{-4}$
700	$5,960 \times 10^{-4}$	$5,824 \times 10^{-4}$	$5,861 \times 10^{-4}$	$8,719 \times 10^{-4}$
704	$5,493 \times 10^{-4}$	$5,439 \times 10^{-4}$	$5,388 \times 10^{-4}$	$8,520 \times 10^{-4}$
708	$5,027 \times 10^{-4}$	$4,958 \times 10^{-4}$	$4,884 \times 10^{-4}$	$8,369 \times 10^{-4}$
712	$4,494 \times 10^{-4}$	$4,516 \times 10^{-4}$	$4,434 \times 10^{-4}$	$7,922 \times 10^{-4}$
716	$4,144 \times 10^{-4}$	$4,085 \times 10^{-4}$	$4,023 \times 10^{-4}$	$7,280 \times 10^{-4}$
720	$3,867 \times 10^{-4}$	$3,814 \times 10^{-4}$	$3,735 \times 10^{-4}$	$6,996 \times 10^{-4}$
724	$3,619 \times 10^{-4}$	$3,524 \times 10^{-4}$	$3,508 \times 10^{-4}$	$6,856 \times 10^{-4}$
728	$3,406 \times 10^{-4}$	$3,324 \times 10^{-4}$	$3,323 \times 10^{-4}$	$7,192 \times 10^{-4}$
732	$3,280 \times 10^{-4}$	$3,259 \times 10^{-4}$	$3,307 \times 10^{-4}$	$7,666 \times 10^{-4}$
736	$3,225 \times 10^{-4}$	$3,198 \times 10^{-4}$	$3,189 \times 10^{-4}$	$8,145 \times 10^{-4}$

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***Table 2.1**. Measured spectral radiance at given (simulated) altitudes*

Wave-length (nm)	Spectral radiance (W·sr^{-1}·m^{-2}·nm^{-1})			
	5 100 ft start	8 000 ft	12 000 ft	5 100 ft end
740	3,065x10^{-4}	3,004x10^{-4}	3,015x10^{-4}	8,439x10^{-4}
744	3,036x10^{-4}	3,022x10^{-4}	2,985x10^{-4}	8,752x10^{-4}
748	2,955x10^{-4}	2,951x10^{-4}	2,946x10^{-4}	8,789x10^{-4}
752	2,675x10^{-4}	2,618x10^{-4}	2,643x10^{-4}	8,310x10^{-4}
756	2,342x10^{-4}	2,495x10^{-4}	2,398x10^{-4}	6,750x10^{-4}
760	2,381x10^{-4}	2,467x10^{-4}	2,606x10^{-4}	5,865x10^{-4}
764	2,241x10^{-4}	2,367x10^{-4}	2,410x10^{-4}	6,624x10^{-4}
768	2,129x10^{-4}	2,149x10^{-4}	2,167x10^{-4}	7,528x10^{-4}
772	2,009x10^{-4}	2,065x10^{-4}	2,031x10^{-4}	7,868x10^{-4}
776	1,820x10^{-4}	1,805x10^{-4}	1,762x10^{-4}	7,731x10^{-4}
780	1,710x10^{-4}	1,646x10^{-4}	1,690x10^{-4}	7,635x10^{-4}
784	1,677x10^{-4}	1,587x10^{-4}	1,618x10^{-4}	7,338x10^{-4}
788	1,659x10^{-4}	1,640x10^{-4}	1,560x10^{-4}	7,096x10^{-4}
792	1,624x10^{-4}	1,717x10^{-4}	1,645x10^{-4}	6,940x10^{-4}
796	1,643x10^{-4}	1,738x10^{-4}	1,807x10^{-4}	6,928x10^{-4}
800	1,604x10^{-4}	1,743x10^{-4}	1,751x10^{-4}	6,867x10^{-4}
804	1,644x10^{-4}	1,767x10^{-4}	1,850x10^{-4}	6,798x10^{-4}
808	1,833x10^{-4}	2,231x10^{-4}	2,304x10^{-4}	6,787x10^{-4}
812	1,838x10^{-4}	2,236x10^{-4}	2,379x10^{-4}	6,159x10^{-4}
816	1,436x10^{-4}	1,562x10^{-4}	1,640x10^{-4}	5,419x10^{-4}
820	1,317x10^{-4}	1,327x10^{-4}	1,372x10^{-4}	5,224x10^{-4}
824	1,277x10^{-4}	1,291x10^{-4}	1,337x10^{-4}	5,394x10^{-4}
828	1,247x10^{-4}	1,294x10^{-4}	1,182x10^{-4}	5,525x10^{-4}
832	1,117x10^{-4}	1,157x10^{-4}	1,146x10^{-4}	5,680x10^{-4}
836	1,240x10^{-4}	1,342x10^{-4}	1,307x10^{-4}	6,079x10^{-4}
840	1,328x10^{-4}	1,468x10^{-4}	1,606x10^{-4}	6,447x10^{-4}
844	1,217x10^{-4}	1,350x10^{-4}	1,413x10^{-4}	6,467x10^{-4}
848	1,007x10^{-4}	1,024x10^{-4}	1,061x10^{-4}	6,294x10^{-4}
852	9,603x10^{-5}	9,415x10^{-5}	9,691x10^{-5}	6,150x10^{-4}
856	8,684x10^{-5}	8,395x10^{-5}	9,173x10^{-5}	6,087x10^{-4}

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***Table 2.1**. Measured spectral radiance at given (simulated) altitudes*

Wave-length (nm)	Spectral radiance ($W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$)			
	5 100 ft start	8 000 ft	12 000 ft	5 100 ft end
860	$8{,}013 \times 10^{-5}$	$8{,}349 \times 10^{-5}$	$8{,}450 \times 10^{-5}$	$6{,}091 \times 10^{-4}$
864	$7{,}966 \times 10^{-5}$	$8{,}286 \times 10^{-5}$	$8{,}844 \times 10^{-5}$	$5{,}976 \times 10^{-4}$
868	$8{,}039 \times 10^{-5}$	$7{,}617 \times 10^{-5}$	$7{,}560 \times 10^{-5}$	$6{,}150 \times 10^{-4}$
872	$7{,}461 \times 10^{-5}$	$7{,}824 \times 10^{-5}$	$7{,}376 \times 10^{-5}$	$6{,}025 \times 10^{-4}$
876	$7{,}687 \times 10^{-5}$	$6{,}864 \times 10^{-5}$	$7{,}048 \times 10^{-5}$	$5{,}937 \times 10^{-4}$
880	$7{,}157 \times 10^{-5}$	$6{,}434 \times 10^{-5}$	$6{,}776 \times 10^{-5}$	$5{,}860 \times 10^{-4}$
884	$6{,}767 \times 10^{-5}$	$5{,}316 \times 10^{-5}$	$7{,}087 \times 10^{-5}$	$5{,}762 \times 10^{-4}$
888	$6{,}512 \times 10^{-5}$	$6{,}390 \times 10^{-5}$	$6{,}295 \times 10^{-5}$	$5{,}446 \times 10^{-4}$
892	$6{,}290 \times 10^{-5}$	$6{,}044 \times 10^{-5}$	$6{,}381 \times 10^{-5}$	$4{,}794 \times 10^{-4}$
896	$6{,}530 \times 10^{-5}$	$7{,}157 \times 10^{-5}$	$5{,}818 \times 10^{-5}$	$4{,}007 \times 10^{-4}$
900	$5{,}264 \times 10^{-5}$	$5{,}345 \times 10^{-5}$	$5{,}266 \times 10^{-5}$	$3{,}655 \times 10^{-4}$
904	$6{,}340 \times 10^{-5}$	$7{,}281 \times 10^{-5}$	$6{,}309 \times 10^{-5}$	$3{,}682 \times 10^{-4}$
908	$6{,}710 \times 10^{-5}$	$8{,}129 \times 10^{-5}$	$8{,}514 \times 10^{-5}$	$3{,}534 \times 10^{-4}$
912	$7{,}251 \times 10^{-5}$	$9{,}129 \times 10^{-5}$	$8{,}141 \times 10^{-5}$	$3{,}430 \times 10^{-4}$
916	$6{,}012 \times 10^{-5}$	$8{,}293 \times 10^{-5}$	$6{,}671 \times 10^{-5}$	$3{,}347 \times 10^{-4}$
920	$5{,}969 \times 10^{-5}$	$5{,}837 \times 10^{-5}$	$7{,}015 \times 10^{-5}$	$3{,}577 \times 10^{-4}$
924	$4{,}757 \times 10^{-5}$	$6{,}512 \times 10^{-5}$	$5{,}021 \times 10^{-5}$	$3{,}004 \times 10^{-4}$
928	$5{,}232 \times 10^{-5}$	$4{,}495 \times 10^{-5}$	$4{,}253 \times 10^{-5}$	$2{,}088 \times 10^{-4}$
932	$3{,}953 \times 10^{-5}$	$3{,}645 \times 10^{-5}$	$1{,}979 \times 10^{-5}$	$1{,}422 \times 10^{-4}$
936	$4{,}633 \times 10^{-5}$	$5{,}378 \times 10^{-5}$	$3{,}804 \times 10^{-5}$	$1{,}188 \times 10^{-4}$
940	$3{,}255 \times 10^{-5}$	$3{,}318 \times 10^{-5}$	$2{,}964 \times 10^{-5}$	$1{,}311 \times 10^{-4}$
944	$4{,}405 \times 10^{-5}$	$2{,}921 \times 10^{-5}$	$3{,}977 \times 10^{-5}$	$1{,}059 \times 10^{-4}$
948	$3{,}653 \times 10^{-5}$	$2{,}473 \times 10^{-5}$	$3{,}259 \times 10^{-5}$	$1{,}304 \times 10^{-4}$
952	$4{,}512 \times 10^{-5}$	$4{,}245 \times 10^{-5}$	$3{,}152 \times 10^{-5}$	$1{,}323 \times 10^{-4}$
956	$2{,}681 \times 10^{-5}$	$3{,}105 \times 10^{-5}$	$4{,}229 \times 10^{-5}$	$1{,}567 \times 10^{-4}$
960	$5{,}234 \times 10^{-5}$	$6{,}609 \times 10^{-5}$	$3{,}726 \times 10^{-5}$	$2{,}006 \times 10^{-4}$
964	$3{,}502 \times 10^{-5}$	$4{,}239 \times 10^{-5}$	$5{,}212 \times 10^{-5}$	$2{,}487 \times 10^{-4}$
968	$4{,}504 \times 10^{-5}$	$6{,}239 \times 10^{-5}$	$4{,}169 \times 10^{-5}$	$2{,}799 \times 10^{-4}$
972	$3{,}574 \times 10^{-5}$	$5{,}805 \times 10^{-5}$	$4{,}397 \times 10^{-5}$	$2{,}958 \times 10^{-4}$
976	$4{,}037 \times 10^{-5}$	$4{,}524 \times 10^{-5}$	$4{,}380 \times 10^{-5}$	$2{,}908 \times 10^{-4}$

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MEASUREMENT OF RELATIVE SPECTRAL DISTRIBUTION OF ILLUMINATION

Table 2.1. Measured spectral radiance at given (simulated) altitudes

Wave-length (nm)	Spectral radiance ($W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$)			
	5 100 ft start	**8 000 ft**	**12 000 ft**	**5 100 ft end**
980	$3,577 \times 10^{-5}$	$6,267 \times 10^{-5}$	$6,977 \times 10^{-5}$	$3,290 \times 10^{-4}$
984	$4,894 \times 10^{-5}$	$2,097 \times 10^{-5}$	$4,158 \times 10^{-5}$	$3,805 \times 10^{-4}$
988	$4,738 \times 10^{-5}$	$1,112 \times 10^{-5}$	$4,453 \times 10^{-5}$	$3,885 \times 10^{-4}$
992	$5,156 \times 10^{-5}$	$3,449 \times 10^{-5}$	$2,930 \times 10^{-5}$	$4,748 \times 10^{-4}$
996	$4,734 \times 10^{-5}$	$5,641 \times 10^{-5}$	$8,752 \times 10^{-5}$	$4,346 \times 10^{-4}$
1 000	$7,888 \times 10^{-5}$	$8,689 \times 10^{-5}$	$7,178 \times 10^{-5}$	$5,065 \times 10^{-4}$
1 004	$9,775 \times 10^{-5}$	$7,401 \times 10^{-5}$	$1,211 \times 10^{-4}$	$4,963 \times 10^{-4}$
1 008	$3,946 \times 10^{-4}$	$3,453 \times 10^{-4}$	$3,832 \times 10^{-4}$	$7,659 \times 10^{-4}$
1 012	$6,987 \times 10^{-4}$	$6,975 \times 10^{-4}$	$6,924 \times 10^{-4}$	$1,129 \times 10^{-3}$
1 016	$6,229 \times 10^{-4}$	$6,761 \times 10^{-4}$	$6,439 \times 10^{-4}$	$1,046 \times 10^{-3}$
1 020	$3,153 \times 10^{-4}$	$2,467 \times 10^{-4}$	$2,956 \times 10^{-4}$	$7,180 \times 10^{-4}$
1 024	$1,559 \times 10^{-4}$	$2,112 \times 10^{-4}$	$2,045 \times 10^{-4}$	$5,487 \times 10^{-4}$
1 028	$9,196 \times 10^{-5}$	$2,008 \times 10^{-5}$	$1,107 \times 10^{-4}$	$5,943 \times 10^{-4}$
1 032	$1,230 \times 10^{-4}$	$8,271 \times 10^{-5}$	$7,256 \times 10^{-5}$	$4,924 \times 10^{-4}$
1 036	$8,218 \times 10^{-5}$	$1,456 \times 10^{-4}$	$1,317 \times 10^{-4}$	$4,720 \times 10^{-4}$
1 040	$1,512 \times 10^{-4}$	$2,028 \times 10^{-4}$	$1,059 \times 10^{-4}$	$4,939 \times 10^{-4}$
1 044	$8,334 \times 10^{-5}$	$6,758 \times 10^{-5}$	$1,093 \times 10^{-4}$	$4,126 \times 10^{-4}$
1 048	$1,259 \times 10^{-4}$	$1,002 \times 10^{-5}$	$1,578 \times 10^{-4}$	$6,085 \times 10^{-4}$
1 052	$1,548 \times 10^{-4}$	$6,488 \times 10^{-5}$	$9,514 \times 10^{-5}$	$3,093 \times 10^{-4}$
1 056	$1,779 \times 10^{-4}$	$1,063 \times 10^{-4}$	$1,286 \times 10^{-4}$	$4,818 \times 10^{-4}$
1 060	$1,110 \times 10^{-4}$	$1,864 \times 10^{-4}$	$1,037 \times 10^{-4}$	$5,875 \times 10^{-4}$
1 064	$1,138 \times 10^{-4}$	$1,098 \times 10^{-4}$	$6,306 \times 10^{-5}$	$5,816 \times 10^{-4}$
1 068	$1,458 \times 10^{-4}$	$1,996 \times 10^{-4}$	$1,358 \times 10^{-4}$	$5,650 \times 10^{-4}$

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MEASUREMENT OF RELATIVE SPECTRAL DISTRIBUTION OF ILLUMINATION

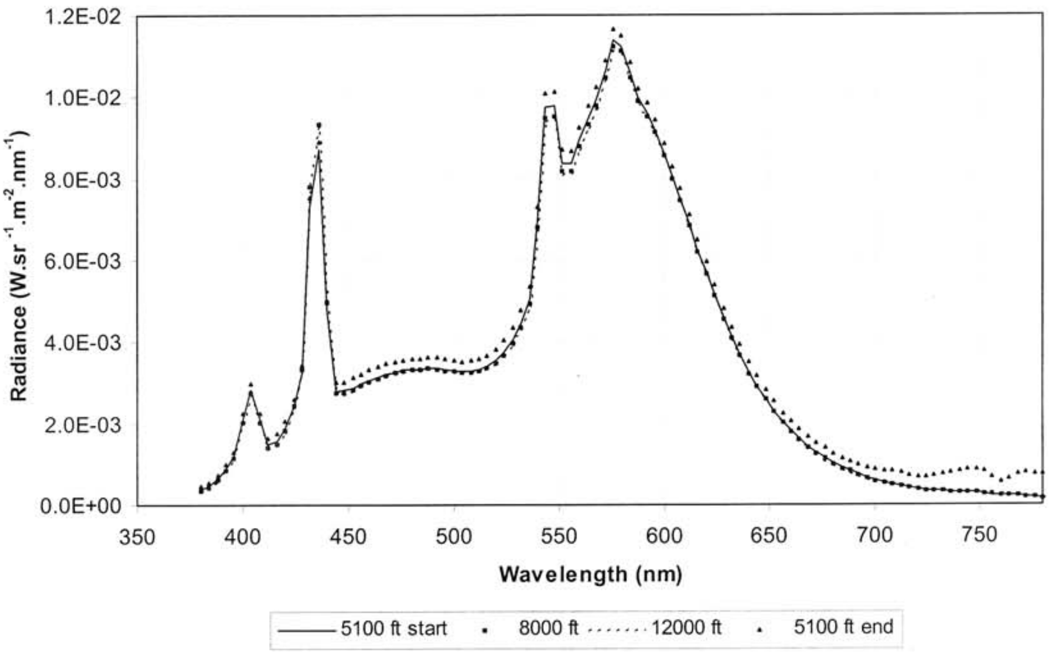

***Figure 2.1**. Measured spectral radiance at given (simulated) altitudes*

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ANNEXURE E

RESEARCH PROJECT: EFFECTS OF ALTITUDE ON CERTAIN VISUAL PARAMETERS

Researcher: Dr Campbell MacFarlane.

SUBJECT IDENTIFICATION AND PROFILE

DATE: ____

TIME: ____

SUBJECT NO: ______________________________________

AGE: ____

GENDER: ____

ETHNICITY: _______________________________________

ASSISTED VISION: - YES / NO ___________________________

PAST HISTORY OF OCULAR PROBLEMS: - YES / NO ________________

COLOUR VISION NORMAL: - YES / NO ______________________

PAST HISTORY OF FITS: - YES/ NO _______________________

SMOKER: - YES / NO ________________________________

IF YES, NUMBER PER DAY ________; Time Since Last Cigarette: ________ Minutes

OUT OF AREA IN PREVIOUS WEEK: - YES / NO ________________

RESPIRATORY TRACT INFECTION IN PREVIOUS 2 WEEKS: - YES / NO _______

MEDICATION: - YES / NO ____________________________

IF YES WHAT: _____________________________________

____

____

____

____

____

ANNEXURE F

RESEARCH PROJECT: EFFECTS OF ALTITUDE ON CERTAIN
VISUAL PARAMETERS

Researcher: Dr Campbell MacFarlane

TEST DATA SHEET FOR USE INSIDE CHAMBER

SUBJECT NUMBER:_____ DATE:____________ TIME:______________

LEVEL: (Mark the appropriate one)

Ground	1st Altitude	2nd Altitude

ISHIHARA PLATES:

ANOMALOSCOPE:

1st Attempt		2nd Attempt		3rd Attempt	
Top		Top		Top	
Bottom		Bottom		Bottom	

CONTRAST SENSITIVITY:

	A	B	C	D	E
1st Attempt					
2nd Attempt					

PHORIAS:

1st Attempt	1		2	

2nd Attempt	1		2	

OXYGEN:

1st Reading		2nd Reading	

PULSE RATE:

1st Reading		2nd Reading	

ANNEXURE G

TEST DATA SHEET FOR USE BY CHAMBER OPERATOR

NOTE: ACCELERATION / DECELERATION: 2000 ft/min

SUBJECT NUMBERS:_______________ DATE:______________

	Starting Time	Time arriving at altitude	Time starting to measure	Ending time	Duration (Minutes)	Temperature in Room (°C)	Temperature in Chamber (°C)	Luminosity (Lux)	QNH (Waterkloof Airforce Base)
Ground Level									
1st Altitude __________ft									
2nd Altitude __________ft									

REMARKS:
____
____
____
____

SIGNATURES:

______________________________ ALTITUDE CHAMBER OPERATOR

______________________________ INDEPENDENT OBSERVER

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NUMBER OF PAGES

NUMBER OF WORDS

NUMBER OF REFERENCES

NUMBER OF TABLES

NUMBER OF FIGURES

AN ASSESSMENT OF DETERIORATION OF COLOR VISION, CONTRAST SENSITIVITY AND DEVELOPMENT OF PHORIAS AS A RESULT OF HYPOXIA IN FLIGHT IN PERSONS RESIDENT AT ALTITUDE IN SOUTH AFRICA

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C LE ROUX M Sc
A BLIGNAUT

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Number of words:

Running title

Visual effects of Hypoxia in aviators.

Dr C MacFarlane – Head of Emergency Medical Services Training, Gauteng Provincial Government and Department Surgery, University of the Witwatersrand, Johannesburg, South Africa.

ABSTRACT

BACKGROUND:

The altitude at which oxygen supplementation should commence to be administered to aircrew in South Africa, flying in unpressurised aircraft, is 12,000 feet. Above that altitude it is considered that significant effects of reduced tissue oxygen content (hypoxia) become manifest. It has been shown that vision is particularly sensitive to hypoxia, and is commonly the first system affected.

HYPOTHESIS:

There was concern that there might be subtle visual effects due to relative hypoxia at 12,000 feet, which might not be obvious to aircrew, but which could affect flight safety. If this were so, the level for commencement of oxygen supplementation might have to be lowered.

To assess this situation three important parameters of vision, namely, color vision, contrast sensitivity, and the development of phorias (potential squint), were selected for study.

METHODS:

37 healthy volunteers, in small groups, had these parameters assessed at ground level in an altitude chamber at the Institute for Aviation Medicine, Lyttleton, South Africa. They were then taken to simulated altitudes of 8,000 feet and 12,000 feet. Sufficient time was allowed at each altitude for physiological adaptation, and the visual parameters reassessed. Oxygen saturation of tissues was also measured to confirm relative hypoxia at altitude.

RESULTS:

Statistical analysis of the visual parameters concluded that there were no clinically significant deleterious effects, due to relative hypoxia, on the visual parameters studied, at a simulated altitude of 12,000 feet.

CONCLUSION:

There was no indication, based on this study, to lower the existing threshold for oxygen supplementation from 12,000 feet.

It is recommended that further work be done to detect any cumulative effects of prolonged flight at 12,000 feet and also to repeat the work with aircrew based at sea level. Such personnel would not have the small degree of physiological adaptation existing in those resident at the altitude of Pretoria, and might, theoretically, be more susceptible.

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Index terms – Hypoxia, color vision, contrast sensitivity, phorias.

INTRODUCTION AND BACKGROUND

A requirement for adequate brain sensory and motor function is an adequate oxygen supply, delivered to the tissues via the respiratory and circulatory systems. A reduction in tissue concentrations of oxygen (hypoxia) causes impairment of body systems and functions. This becomes more marked with greater reduction of oxygen, and some tissues and organs are more sensitive to oxygen reduction than others (see literature review below).

In view of this, oxygen supplementation is necessary in aircrew at certain altitudes, unless the crew members are functioning in the adequately oxygenated microclimate of a pressurised aircraft.

International rules and conventions are such that aircrew are required to commence oxygen supplementation, in unpressurised aircraft, at altitudes above 10,000 to 12,000 feet. Various countries have different commencing altitude thresholds within this band. In South Africa 12,000 feet is used. Investigation as to why this has been chosen reveals little evidence as to why this particular altitude has been selected, but it has been passed from generation to generation. As the literature review below will indicate, the levels chosen are based on experimental work conducted mainly in the 1920s and 1930s. The evidence for the appropriateness of this is rather vague, and some of the experimental methods are somewhat dubious. It is interesting to note that U.S. Army aircrew, because of combat requirement in non-pressurised helicopters, are allowed to ascend to 14,000 feet without oxygen, in case of tactical necessity, in combat [1]. This altitude may not be maintained longer than thirty minutes, implicitly recognising the effects of hypoxia at that altitude.

It will be seen in the literature review that aspects of vision are amongst the first of the body functions to be affected by low levels of circulating oxygen (hypoxia). In the light of this, interest was expressed in determining whether the present South African recommendation of oxygen supplementation from 12,000 feet was appropriate.

Since vision is affected early in a hypoxic situation, it was considered that this would be a sensitive area for detecting early signs of hypoxic effects. It is also a very important, indeed crucial, aspect of pilot function. Consideration was given as to whether, at 12,000 feet, there might be subtle effects, due to relative hypoxia, on pilot vision, which might not be obvious to aircrew, but which were adversely affecting flight safety. It was therefore decided to assess aspects of vision in the altitude chamber at the Institute for Aviation Medicine at Lyttleton,

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near Pretoria. This is a facility owned and operated by the South African Military Health Service of the South African National Defence Force and for the benefit of the Civil Aviation Industry in Southern Africa in general.

Aircrew permanently resident in the Johannesburg / Pretoria area have, like all inhabitants of these areas, already adjusted to living at some degree of altitude (5,000 to 5,500 feet), but it was not known if this element of adaptation would have any effect on the development of hypoxic effects in aviation. The visual parameters, defined below, which were selected for investigation, were color vision, contrast sensitivity and development of phorias. It was felt important to investigate this area of flight physiology in order to determine whether the current South African regulations requiring oxygen supplementation from 12,000 feet were appropriate, or should be altered to a lower altitude.

REVIEW OF LITERATURE

RELEVANT PAPERS

Literature review has revealed surprisingly little with regard to the topics under study. Some of the original literature is quite old, but reveals acute clinical, scientific and observational capability.

The classical original paper is that of Wilmer and Berens [2], published in 1918. The authors describe various visual effects at varying altitudes from 5, 000 to over 20,000 feet. This work was conducted by the U.S. military in a low pressure chamber, a form of which existed even in those days. The hypoxia of altitude could therefore be simulated. Disturbances of vision as a result of hypoxia were found. These were mainly between 15,000 and 20,000 feet. They were noted as affecting stereoscopic vision, pilot reaction time, field of binocular vision and eye muscle balance (early evidence of phoria). Also affected were field of vision, retinal detection and sensitivity, eye accommodation, convergence, intra-ocular tension, color vision. Many of these visual parameters were, clearly, adversely affected by hypoxia, the greater the degree of hypoxia, the greater the degree of abnormality. Significantly, all the deliterious effects were rapidly corrected by the administration of oxygen.

The next stimulus to scientific investigation in this area occurred during World War Two. In a classic paper published by R.A. McFarland in 1941[3] he indicated that much of the experimental work on vision and altitude had not been particularly well conducted. By performing more exact experiments he was, nevertheless, able to confirm much of Wilmer and Berens' work. He further refined the effects of hypoxia on visual functions. This included deleterious effects on visual sensitivity, color vision, light sense and dark adaptation, contrast discrimination, visual acuity, visual fields, accommodation and convergence and ocular movement co-ordination. He also indicated that the contrast sensitivity work done hitherto was inadequate.

In 1946 Hecht *et al* [4] published a paper concerning anoxia and brightness discrimination. This demonstrated that deterioration in contrast discrimination begins at low altitudes and is definite at 8,000 feet.

In 1971 McFarland [5] published another classic paper in aviation medicine. In summarizing the state of the art he presented a wealth of scientific information, including the fact that studies had confirmed that oxygen is required at altitudes above 10-12,000 feet for prolonged flights. He also indicated that the effects of altitude are accentuated by alcohol and that the carbon monoxide effects from smoking can lower the ceiling at which altitude effects begin.

Also in 1971, Ernest and Krill [6] drew attention to the psycho-physiological aspects of the effect of hypoxia on visual function. They confirmed deleterious effects on retinal function as a result of hypoxia, and also reported the interesting observation that hyperventilation, commonly as a result of anxiety or stress, may cause an elevation in the subject's hemoglobin oxygen saturation, along with hypocapnia and alkalosis, and that this can compromise visual performance.

Kobrick [7] had, in 1970, demonstrated the effects of hypoxia on colour sensitivity zones at various altitudes, the lowest altitude at which effects were encountered being 13,000 feet. Smith *et al* [8], in view of contradictory results regarding the effects of hypoxia on colour vision, reassessed this in 1975, utilising the FM 100 HUE test. This is a sensitive test of colour discrimination. They confirmed the deliterious effects of hypoxia on HUE test performance, especially under conditions of reduced illumination.

Kobrick *et al* [9] (1984) confirmed deliterious effects of hypoxia on night vision and Vingrys and Garner [10] (1987) demonstrated loss of colour vision affecting both red-green and blue-yellow discrimination at 12,000 feet. Further evidence of the adverse effects of hypoxia on green-red colour vision was produced by Richalet *et al* [11] in 1988, using a portable anomoloscope, an extremely sensitive colour vision assessment instrument.

By contrast, in 1995 Yap *et al* [12] demonstrated insignificant changes in spatial and temporal contrast sensitivity, central visual field thresholds and dazzle recovery time, with respect to simulated altitudes of 7,000 and 12,000 feet in an altitude chamber. They also indicated the importance, in these types of experiments, of maintaining an experimental subject for at least 15 minutes at any test altitude, to allow for equilibration of ambient and blood gas levels, before commencing visual testing.

Also in 1995, Davis *et al* [13] published a paper concerning visual performance of military pilots using tactical night vision aids in military aircraft, particularly army helicopters, operating at altitudes which resulted in degrees of hypoxia. They pointed out that the work of M^c^Farland, Hecht and others (see above) had demonstrated degradation of visual performance

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in conditions of hypoxia, especially under low illumination circumstances, and that contrast sensitivity may decrease by as much as 50% under low illumination. They found that, at 12,000 feet, in a chamber, there was some diminution in visual acuity, but no diminution in contrast sensitivity.

In reviewing the literature it is evident that hypoxia has been shown to affect colour vision and, in some work, contrast sensitivity. There is, however, some argument as to the altitude at which these effects develop. There is further uncertainty as to whether contrast sensitivity is affected by moderate hypoxia or not. It is interesting to note that there is remarkably little about the effects of hypoxia with regard to phorias. (the potential to develop squints under certain circumstances) The early work by Wilmer and Berens (1918), as mentioned above, does mention the development of ocular muscle imbalance as a result of hypoxia, and this could be interpreted as referring to phorias. Little has been published since, on this matter.

Remarkably, in some of the experimental work described, very small numbers of subjects were used, the smallest numbers being two, the average six to eight, and the maximum 26. In addition, some of the experimental hypoxia was achieved by means of breathing hypoxic levels of oxygen from a mask. This is not greatly accurate, being subject to leakage, possible abnormal breathing patterns and other factors. In addition, the altered atmospheric pressure levels, as experienced at altitude, or in an altitude chamber, are not operative.

OBJECTIVE

The objective of this project was to determine if there is significant deterioration of colour vision, contrast sensitivity and phorias in aircrew, due to the effects of hypoxia, when flying in unpressurised aircraft at an altitude of 12,000 feet.

STUDY DESIGN

The chosen visual parameters, e.g. colour vision, contrast sensitivity and phorias are of particular importance in the aviation environment, and changes in these could have subtle effects on performance, not necessarily noted by the aircrew, unlike more gross impairments of vision, which are more likely to declare themselves to the aircrew, and receive corrective action, e.g. descent to lower altitude or oxygen supplementation.

Colour vision is important in discerning signals and aircraft identification symbols. It is also important in interpreting computerised navigational displays, map symbols, flares and lights. Contrast sensitivity is important in spotting other aircraft against various backgrounds and in varying degrees of illumination. It is also important in discerning ground objects against various backgrounds. The transition of a phoria (latent squint) into a squint, with functional effects, could affect visual capacity, including focusing. A phoria may be described as an extra-ocular eye muscle imbalance and co-ordination impairment, measured in vertical and horizontal planes when the ability to focus is suppressed. As discussed in the literature review[2], there is some evidence that hypoxia affects all these parameters, but the evidence is conflicting, and the altitudes predisposing to deliterious effects not clear.

It was therefore decided to utilise around 40 subjects, 37 eventually being selected. This was a number significantly greater than previously reported in the literature, and was considered by the statisticians to be sufficient for validity.

The subjects were South African Military Health Service Medical Special Forces soldiers or South African Air Force members, all of whom had high standards of medical fitness, equivalent to aircrew.

The visual parameters for assessment were to be measured at ground level, 8,000 feet and 12,000 feet in an altitude chamber, to see if any changes occurred. A test level at 8,000 feet was suggested by the statisticians as a standardisation and control element.

This was a double blind crossover trial with randomisation of exposure order, with blinding of the observer and subjects. The subjects were their own controls.

ETHICAL CONSIDERATIONS

The maximum altitude experienced by the subjects in the chamber was 12,000 feet, as is current practice in South African aviation. All subjects were healthy volunteers, and they were informed in detail about the experiment. An appropriate consent form was developed, discussed and completed for each subject. In this form, the project was explained, exclusions were indicated, the assessment methods were explained, any likely physiological effects discussed.

The project was approved by the ethics committee of the University of Pretoria, by Headquarters, South African Military Health Service and Headquarters, South African Air Force.

MEASURING INSTRUMENTS

(a) OXYGEN SATURATION **PULSE OXIMETER.**

Nonin Medical Hand Held Pulse Oximeter Model 8500,
Nonin Medical, Plymouth MN, USA

(b) COLOUR VISION – 1. **ISHIHARA PLATES.**

Tests for Colour Blindness,
S. Ishihara,
Kanehara Shuppan Co. Ltd,
Tokyo, Japan

2. **ANOMALOSCOPE.**

Neitz Anomaloscope OT – II
Neitz Company,
Japan

(c) CONTRAST SENSITIVITY – VISION CONTRAST TEST SYSTEM.

Vision Contrast Test Systems.
Dayton, Ohio, USA

(d) PHORIA – STEREO OPTICAL VISION TESTER. (Orthorator)

Stereo Optical Vision Tester.
Stereo Optical Co. Inc.,
Chicago, USA

METHODS AND MATERIALS

SUBJECTS

Participating in the study were 37 healthy military volunteers, all serving with the South African National Defence Force. Most were in the South African Military Health Service, but four were in the South African Air Force. There were 31 males and 6 females. Of the group, 12 were European, 24 were African and one was coloured.

EXCLUSION CRITERIA

Exclusion criteria for the study were:-

1. Visual correction (spectacles, contact lenses, surgical correction)
2. Presence of eye pathology
3. Presence of upper respiratory tract infection, particularly if unable to clear ears. This could make the chamber experience, with alteration of air pressure and volume, uncomfortable or painful
4. Out of geographical test area, at a different altitude, in the preceding 10 days. Subjects had adapted physiologically to the relatively high altitude of the local area, and, for standardisation, it was considered that this should not be disturbed
5. History of fits. It is known that a tendency to fits can be exacerbated by hypoxia
6. On medications

It was, therefore, attempted to standardise as much as possible. All had been assessed by their units as having normal colour vision.

All subjects completed a subject identification and profile form and this was discussed with each subject. Whether the subject smoked or not was captured, for interest. All subjects were assessed for capacity to clear ears, with otological inspection, while exhaling against resistence, used as necessary.

VISION TESTING METHODS AND MEASUREMENTS

A table was placed at the end of the altitude chamber furthest from the door. On it were placed the Ishihara Plates book, the anomoloscope and the orthorator. The contrast sensitivity chart was placed against the wall of the chamber furthest from the door, the subject reading it standing with his or her heels up against the lip of the entrance door. The distance from the reading point to the chart was 2,40 metres.

Supplementary illumination for the Ishihara plates, was provided, as is common practice, by positioning an overlying lamp. The luminescence in the chamber was provided by the inbuilt fluorescent light system. This was measured by the Photometry and Radiometry Department Council for Scientific and Industrial Research, and was considered adequate at all altitudes.

The luminosity, distances and optical considerations were assessed by an external authority, Dr A Uvijls, from the Ophthalmology Department of the University of Ghent, in Belgium. All were deemed satisfactory.

NON VISUAL MEASUREMENTS

To determine the functional degree of hypoxia during visual testing, the pulse oximeter was applied to the index digit of each subject at the different altitudes, thereby recording the percentage oxygen saturation of the blood at the different altitudes. The same instrument also measured the pulse rate.

The chamber operator recorded altitude, barometric pressure and temperature inside the chamber, ensuring standardisation.

EXPERIMENT CONDUCT AND PROCEDURES

This study was based on repeated measurements, with each subject acting as his/her control.

Considerable time was taken beforehand in briefing the subjects, ensuring exclusion criteria were implemented, and in familiarising the subjects with the vision testing equipment. This was in order to eliminate "learning curve" effects in using the equipment. To this end, all subjects were instructed on the equipment, in the chamber with the door open, until they were competent in the use of that equipment.

All equipment was placed in a standard fashion in the chamber, and was not moved throughout the study. The medical observer remained in the chamber throughout. It was considered that the medical observer should not breathe oxygen during the phase of relative hypoxia in case leakage from the mask altered the oxygen concentration in the chamber.

Subjects were tested individually by sequential rotation through all the tests. Thus, testing of any individual was spread out over the whole test period, rather than one subject having all his/her tests at the beginning of the test period and another at the end. By this means greater standardisation could be achieved.

Groups of subjects were usually in fours, occasionally threes, due to availability or if exclusion criteria were invoked.

The sequence of events for each subject was as follows:-

1. The subject was shown the Ishihara plates, and required to identify all the images.
2. The subject's colour vision was further tested by utilising the anomaloscope.
3. Candidates then moved to the orthorator for phoria testing.
4. The candidate then stood with his/her heels against the lip of the door and read off the contrast sensitivity chart. This had a series of five lines of circles, numbered A,B,C,D,E from top to bottom. Each circle was numbered 1 to 9 from left to right. The system comprises a series of circles, each one containing contrasting dark and light stripes of varying boldness. They were tilted either to the left, right, up or were blank. The circle contrasts were most prominent on the left progressively becoming more difficult to determine on traversing to the right. Subjects were required to read each line, starting from the left. On each line the furthest circle to the right that the

subject could progress to in identification was recorded. This gave a measurement of visual contrast capability.

5. The subject then had the pulse oximeter attached to the right index finger, when seated, and the percentage oxygen saturation and pulse rate were measured.

Each subject was tested in this way, in the same sequence. The sequence was then repeated, with each subject being re-tested in the same order. The Ishihara Plate test, being a gross assessment test, was not repeated. The anomaloscope test is very subjective, and a small movement of the knob can make a relatively large change in the figures. This test was, therefore, sequentially repeated a third time to give a greater spread of measurements for averaging.

When the base line assessments were completed at ground level the completed forms were passed out of the chamber to the statisticians, who were acting also as external observers and for quality assurance, as well as timekeeping.

After the ground level tests were completed, the chamber was sealed, and was pressurised to altitude. Pressurization was to a simulated altitude of 8,000 feet and 12,000 feet. Which altitude was achieved first was selected randomly by the chamber operator, so that the medical observer in the chamber did not know which had been selected. On achieving the first altitude, a period of 20 minutes was allowed before re-testing visual parameters. This was to allow the body physiology to adapt to the new altitude.

After the 20 minutes, vision tests were repeated in exactly the same way, and in the same sequence. On completion of tests the chamber was pressurised to the second altitude, and, after another 20 minutes for physiological adjustment, the tests were repeated in exactly the same manner and in the same sequence. On completion of this testing the chamber was depressurised, gradually, to ground level.

The time spent at each altitude by the students, after the 20 minute adjustment period, varied according to the number of subjects in the group (3 or 4) and the time it took individuals to complete the tests. It averaged 25 to 35 minutes at each altitude, each subject having testing done, in rotation, throughout, the whole period. Thus, total time at each altitude was 45 to 55 minutes.

DATA ANALYSIS

EXPERIMENTAL DESIGN AND PROCEDURES

This study was conducted as a repeated measures design, with each subject acting as his/her own control. Each subject participated in one session during which visual performance with the four visual tests was tested at ground level, 8000 feet and 12000 feet. During each of the three test periods subjects were allowed to stabilise at the specific altitude before tests were conducted. The ground level tests were done first as a baseline and the two higher altitudes were randomised.

Subjects were tested individually. Prior to testing each subject was briefed on the chamber's operation and they were familiarised with the visual tests.

As a control, oxygen blood level was measured at all three altitudes.

STATISTICAL ANALYSES

Student's paired t-tests (two-tailed) were used for analysis of repeated measures data, (eg changes in oxygen blood levels and pulse rates). These analyses were performed using the Statistix Software Package, Version 7.0. Hotelling's paired T-squared tests were used for analysis of repeated measure multivariate data (the anomaloscope, contrast sensitivity and phoria tests). These analyses were performed using the STATA Software package, version 6.

RESULTS

Oxygen saturation levels – smokers vs non-smokers

		Mean level	p-valve
Base level	Smoker	96,79	p = 0,5654
	Non-smoker	96,56	
8,000 feet	Smoker	96,33	p = 0,1114
	Non-smokers	95,02	
12,000 feet	Smokers	91,63	p = 0,3738
	Non-smokers	90,44	

No significant differences

PERCENT OXYGEN SATURATION

Table 1: Mean oxygen saturation levels at the different altitudes

Altitude	Mean level	Standard deviation	Mean standard error
Baseline	96,639%	1,106	0,184
8000 feet	95,458%	2,325	0,387
12000 feet	90,833%	3,717	0,619

Altitude	p-valve
oxy-B = oxy – 8,000 feet	p = 0,0062
oxy-B = oxy – 12,000 feet	p = < 0,0001

There is a statistically significant difference between the mean oxygen saturation levels at baseline, ie ground level and 8000 feet as well as between levels at baseline and 12000 feet.

PULSE RATE

Table 2: Mean pulse rates at the different altitudes

Altitude	Mean Pulse Rate	Standard deviation	Mean standard error
Baseline	68,167	10,754	1,792
8000 feet	65,583	11,574	1,929
12000 feet	67,764	10,969	1,828

Altitude	p-valve
oxy-B = oxy – 8,000 feet	p = 0,0701
oxy-B = oxy – 12,000 feet	p = < 0,7636

There is no significant difference between pulse rates at baseline and 8,000 feet and also none at baseline and 12,000 feet.

CONTRAST SENSITIVITY

Table 3: Contrast sensitivity at the different altitudes

Altitude	Contrast sensitivity					
	A	Standard deviation	Mean standard error	B	Standard deviation	Mean standard error
Baseline	5,806	0,467	0,078	6,417	0,500	0,083
8000 feet	6,000	0,478	0,080	6,556	0,504	0,084
12000 feet	6,028	0,446	0,074	6,556	0,504	0,084

Altitude	Contrast sensitivity					
	C	Standard deviation	Mean standard error	D	Standard deviation	Mean standard error
Baseline	6,028	0,774	0,129	5,833	0,697	0,116
8000 feet	6,278	0,815	0,136	5,972	0,774	0,129
12000 feet	6,222	0,832	0,139	5,889	0,820	0,137

Altitude	Contrast sensitivity		
	E	Standard deviation	Mean standard error
Baseline	4,556	1,403	0,234
8000 feet	4,972	1,341	0,224
12000 feet	4,917	1,296	0,216

Altitude	Line	p-valve
Baseline / 8,000 feet	A-line	0,0164 < 0,05 *
	B-line	0,0668 > 0,05
	C-line	0,0025 < 0,05 *
	D-line	0,1005 > 0,05
	E-line	0,0058 < 0,05 *
Baseline / 12,000 feet	A-line	0,0016 < 0,05 *
	B-line	0,0668 > 0,05
	C-line	0,0164 < 0,05 *
	D-line	0,3119 > 0,05
	E-line	0,0129 < 0,05 *

There is a significant difference between contrast sensitivity at baseline and 8,000 feet as well as at baseline and 12,000 feet for the A-line, C-line and E-line.

<u>ANOMALOSCOPE</u>

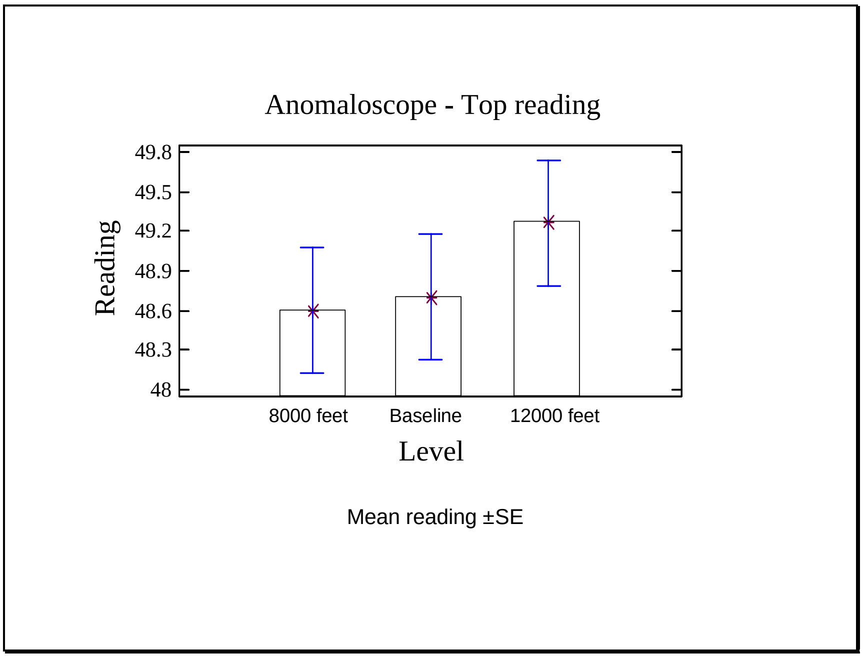
Table 4:Mean anomaloscope readings at the different altitudes

Altitude	Anomaloscope reading					
	Top	Standard deviation	Mean standard error	Bottom	Standard deviation	Mean standard error
Baseline	48,7	2,440	0,407	17,45	4,381	0,730
8000 feet	48,60	3,493	0,582	17,50	3,538	0,590
12000 feet	49,26	2,485	0,414	16,74	3,541	0,590

Altitude		p-valve
Baseline / 8,000 feet	Top	0,5643 > 0,05
	Bottom	0,4776 > 0,05
Baseline / 12,000 feet	Top	0,0136 < 0,05 *
	Bottom	0,9244 > 0,05

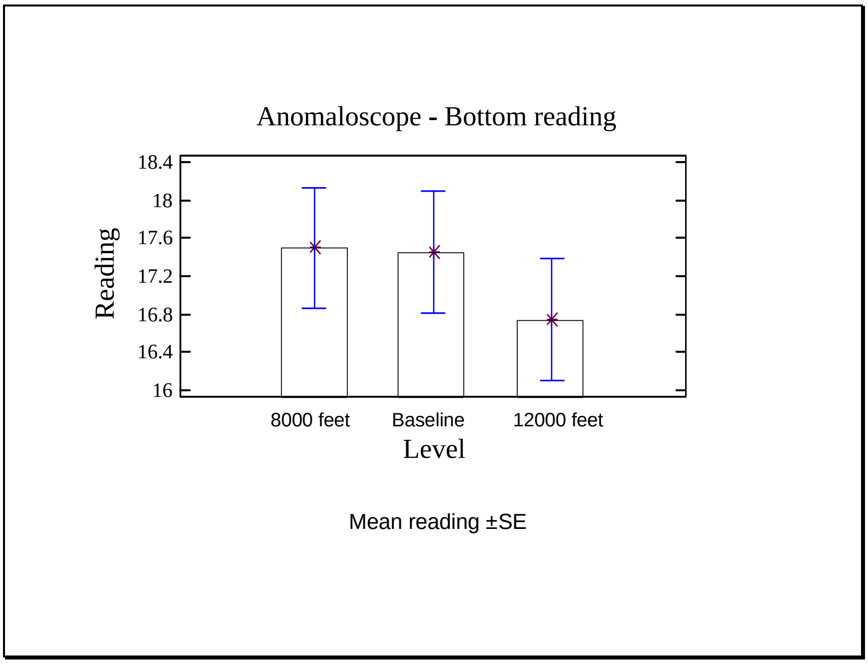
There is no significant difference between the readings at baseline and those at 8,000 feet (both top and bottom readings). There is a significant difference between the top readings at baseline and those at 12,000 feet.

Figure 1: Top reading for the Anomaloscope at different altitudes



There is no significant difference between the top readings at baseline and those at 8,000 feet. There is a statistically significant difference between the top readings at baseline and those at 12,000 feet.

Figure 2: Bottom reading for the Anomaloscope at different altitudes



There is no statistical difference for the bottom readings.

PHORIAS

Table 5: Mean readings for phoria at the different altitudes

Altitude	Phoria Reading					
	Horizontal	Standard deviation	Mean standard error	Vertical	Standard deviation	Mean standard error
Baseline	8,056	2,640	0,440	6,278	1,186	0,198
8000 feet	8,028	2,883	0,481	6,000	0,986	0,164
12000 feet	7,944	2,683	0,447	6,083	1,052	0,175

Altitude		p-valve
Baseline / 8,000 feet	Horizontal	0,5747 > 0,05
	Vertical	0,9665 > 0,05
Baseline / 12,000 feet	Horizontal	0,7186 > 0,05
	Vertical	0,8860 > 0,05

There is no significant difference between the readings at baseline and 8,000 feet and also none at baseline and 12,000 feet.

DISCUSSION OF RESULTS:

The results of this study demonstrate that hypoxia was induced at altitude in the chamber, being, logically, more pronounced at 12,000 feet. This was confirmed by pulse oximetry readings, which demonstrated a drop of oxygen saturation at altitude. The mean oxygen saturation level at ground was 96,639%, at 8,000 feet 95,488% and at 12,000 feet 90,833%. Thus, a significant degree of hypoxia was induced. It was interesting to note that there was little difference in the pulse rate, indicating a relatively high systemic (but not necessarily optic) tolerance to hypoxia in this fit, young group of individuals. At no stage did any subjects experience rapid breathing of the "air hunger" type.

With regard to the individual tests, the contrast sensitivity tests demonstrated no deterioration at the selected altitudes. Somewhat paradoxically, there was actually a marginal improvement of performance at altitude in three of the five test lines, the remaining two showing no difference. In the three lines demonstrating improvement, the difference was statistically significant. Although it might be construed that this is possibly within the limits of experimental variation, especially when two lines showed no difference, the fact that there was statistical significance to the differences in the three affected lines suggests that further experimental work should be directed to this area. The importance, as far as the present study and its aviation implications are concerned, is that there was no deterioration in contrast sensitivity at altitude. This is in keeping with the work, quoted above, of Yap *et al* [12] and Davis *et al* [13], who showed no deliterious effects in contrast sensitivity at 12,000 feet. This, in turn, challenges previous work by Hecht *et al* [4], which claimed deterioration present by 8,000 feet.

As far as colour vision is concerned, the Ishihara plate screening tests for colour vision, a gross method of colour vision assessment, showed no changes at altitude. With regard to the anomaloscope, an extremely sensitive colour test system which will pick up subtle changes, there were some changes in the top (red / green) readings. This was only present at 12,000 feet, and was of statistical significance. There was no difference in the bottom readings. This was discussed with the staff of the Eye Department of the Institute for Aviation Medicine, who indicated that the differences, although statistically significant, were still within the normal range. It was determined, therefore, that these differences were not of clinical, as opposed to statistical significance. Thus, flight safety was not impacted upon. The differences might, again, be within the limits of experimental error. The apparatus is very sensitive, and there were often differences between successive measurements at the same altitude.

Nonetheless, it is possible that this could be the beginning of the effects of hypoxia manifesting itself. It would be useful to conduct further work in this area, subjecting subjects to a much longer period of hypoxia in order to detect any cumulative effect on colour vision due to the hypoxia.

With regard to assessment of phorias, the p-valve of >0.05 indicated that there were no deliterious effects detected at altitude.

It was important in this experimental work to demonstrate that the illumination within the chamber was not affected by altitude. This was confirmed as being the case by the Council for Scientific and Industrial Research.

This work demonstrated that, at 12,000 feet, contrast sensitivity was not reduced, indeed, unexpectedly, and not noted in any previous literature, there was marginal, but statistically significant, increased capacity at altitude. This indicates the need for further investigation. Colour vision was not grossly affected at altitude, but there were some statistically significant red / green differences. These were not considered of clinical significance. There were no phoria effects at altitude.

These three tests are of functional significance to aircrew, assessing critical areas of pilot visual function and, therefore, impacting on flight safety. The results show, therefore, that there are no clinically significant adverse effects in these areas of observation at 12,000 feet, and that the current regulations requiring the administration of supplementary oxygen form 12,000 feet upwards are still valid. All the subjects ere normally located in the Pretoria area, which, as previously mentioned, is at altitude already.

They will, therefore, have undergone the normal physiological adaptations implicit in residence at that altitude. It might be assumed, therefore, that they have already acquired a degree of resistance to hypoxia which would not be present in aircrew at sea level. The latter group might, theoretically, therefore, be more susceptible to hypoxic effects at 12,000 feet. Assessment of this would require that this work be repeated at sea level. No facilities for this work exist, at present, in South Africa at sea level.

CONCLUSIONS:

As a result of this study, it is concluded that there are no CLINICALLY significant deliterious effects, due to hypoxia, on colour vision, contrast sensitivity or phorias in subjects at a simulated altitude of 12,000 feet, all the subjects being normally resident at an altitude of 5,000 – 5,500 feet.

RECOMMENDATIONS:

1. It is recommended that, based on the visual parameters selected for assessment, the present recommendation for commencement of oxygen supplementation at 12,000 feet be retained.

2. Although the subjects spent sufficient time at altitude to overfly the highest mountain areas in South Africa it is recommended that further studies be done, involving some subjects being subjected to several hours of relative hypoxia, in order to detect any cumulative effects of the longer term hypoxia.

3. In view of the fact that all the subjects were normally resident at 5,000 to 5,500 feet, and had, therefore, a minor degree of physiological adaptation to the ambient, mildly reduced, oxygen level at that altitude, it would be appropriate to repeat this work with a population group resident at sea level, in order to detect if this group had a greater susceptibility to the relative hypoxia, not having developed any physiological adaptation to relative hypoxia. There is, however, no altitude chamber located at sea level in South Africa, and moving that subject group to the chamber at altitude would distort the parameters. This work, therefore, would have to be undertaken overseas where altitude chambers are available at sea level.

4. In view of the unexpected finding of enhancement of contrast sensitivity at 12,000 feet it is suggested that further work be done to investigate this.

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