Changes to Colour Vision on Exposure to High Altitude

AJ Davies[1], DS Morris[2], NS Kalson[3], AD Wright[4], CHE Imray[5], CR Hogg[6] on behalf of The Birmingham Medical Research Expeditionary Society

[1]Specialist Trainee in Ophthalmology, Department of Ophthalmology, The Royal Oldham Hospital, Greater Manchester; [2]Consultant Ophthalmic Surgeon, Department of Ophthalmology, The University Hospital of Wales, Cardiff; [3]PhD student, The University of Manchester, Manchester; [4]Retired Consultant Endocrinologist, University Hospital, Birmingham; [5]Professor of Vascular Surgery, Warwick Medical School & University Hospitals Coventry and Warwickshire NHS Trust, Coventry; [6]Electrophysiologist, Moorfields Eye Hospital, London, UK

Abstract

Objectives: Several studies have shown deterioration in colour vision at altitudes above 3,000m. These studies have been conducted in photopic (bright daylight) conditions, whereas many military operations take place in mesopic (dim light) conditions. Data suggests that the tritan colour vision axis (blue cones, TA) are more susceptible to hypoxic insult than protan axis (red cones, PA). The objective of this study was to examine colour vision at high altitude, in mesopic conditions, and using a novel method of assessment to discriminate between the tritan and protan axis.

Methods: We examined 42 eyes (21 subjects, mean age 44, range 22-71), at sea level and within 12-36 hours of exposure to 3300m. This was done in a darkened room, with refractive error correction. Colour vision was studied using ChromaTestTM, a software programme that analyzes colour contrast threshold (CCT) of both TA and PA. We planned to repeat CCT measurement at 4,392m, but technology failure prevented this. Non-parametric paired data was examined using the Wilcoxon signed rank test.

Results: There was found to be no change to either the PA (p=0.409) or the TA (p=0.871) upon ascent. Within the PA 16 eyes had a lower CCT at high altitude, whilst 26 were higher. In the TA 20 eyes had a lower CCT and 22 were higher. At sea level, mean CCT for PA was 4.21 (SD 2.29) TA was 7.06 (SD 1.77). At 3,300m mean CCT for PA was 4.36 (SD 2.86) and TA was 6.93 (SD 2.39).

Conclusions: This experiment revealed no changes to colour vision with exposure to 3,300m. This may be below the threshold altitude for cone dysfunction, alternatively colour vision deterioration may be less significant in mesopic conditions.

Introduction

As part of the medical screening process for employment by the British Armed Forces, candidates must pass colour vision assessment as performed by the Ishihara test, suggesting that accurate colour vision is important for military duty. The army use three colour perception (CP) standards: CP2, CP3 and CP4. To pass CP2, the most stringent standard, the candidate must make no errors on the first 14 plates of the Ishihara test (25 plate version). These should be shown in bright daylight or equivalent artificial lighting, and should be presented in random order to prevent memorisation of plate sequence. Failure to achieve CP2 will restrict the candidate from certain roles within the army. Colour vision is affected by the hypoxic conditions of high altitude.

Colour Vision

Colour vision is the capacity to distinguish objects based on the different wavelengths of light reflected by them, which strike the cone photoreceptors of the retina before being interpreted by the visual cortex. There are three types of cone, each with peak sensitivity to a different wavelength of light (Figure 1). The medium and long cones are genetically coded for on the X chromosome, hence their relationship with X-linked colour blindness. Short wavelength cones are morphologically and biochemically distinct, encoded for on chromosome 7, and are more sparsely distributed, accounting for approximately 10% of the cone population [1].

Cone type	Peak wavelength	Colour	Colour axis
S (Short)	420nm	Blue	Tritan
M (Medium)	534nm	Green	Deutan
L (Long)	564nm	Red	Protan

Figure 1. The three types of cones present in the retina

Colour vision at high altitude

A study of 28 eyes at altitude [2] showed that, at 4000m, no-one had deterioration in their deutan axis, 4% had minimal reduction in their protan axis, and 72% had minimally reduced tritan axis. Further on, at 5400m, all eyes had normal protan and deutan axis, while three quarters had minimally reduced, and one quarter moderately reduced, tritan axis. An earlier study had demonstrated significant deterioration in the blue-yellow (tritan) range as low as 3000m [3]. Both of these studies were performed in photopic (bright daylight) conditions.

Colour Vision and Disease

Colour vision deteriorates early in many retinal and optic nerve diseases, including diabetic retinopathy, glaucoma and optic neuritis. More specifically, the blue (tritan) axis is affected

Corresponding Author: Correspondence: Andrew J. Davies, Department of Ophthalmology, The Royal Oldham Hospital, Rochdale Road, Oldham, OL1 2JH.
E-mail: andrew.davies-7@postgrad.manchester.ac.uk
Tel: +44(0)7841585065

particularly early. Whilst the reasons are not clear, this could be because the blue cones are more fragile, because they are fewer in number, or because the receptive field is much larger than that of the green and red cones whose peak sensitivities are much closer together (Figure 2) [1]. When patients with colour vision defects due to diabetic retinopathy breathe high flow oxygen, their colour vision discriminatory ability improves significantly, suggesting a contributory role of hypoxia in this colour vision defect [4]. Many different tools can be used to assess colour vision, and several have already been used at high altitude [2,3].

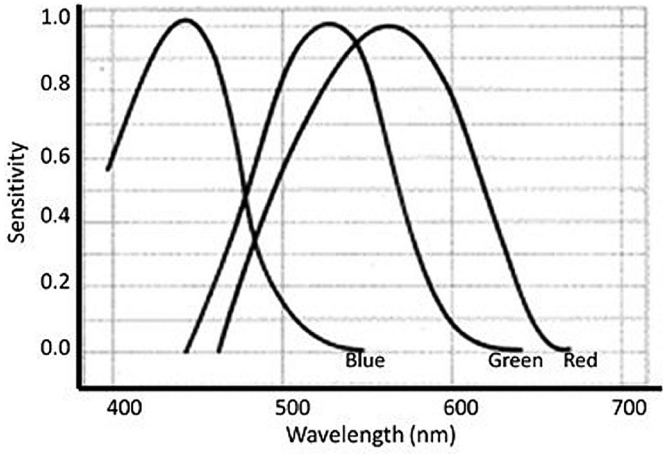

Figure 2. The peak sensitivities of Blue (S), Green (M) and Red (L) cones

Methods

Twenty one adult members of a high altitude research team conducting various research projects on the Altiplano in Chile had their colour vision assessed as they ascended towards a maximum altitude of 4392m. All were non-smokers, normotensive, on no medication, physically fit, and with no recent exposure to high altitude. All subjects had no ocular pathology, had to be able to read N10 font at one metre, and wore appropriate refractive correction. Fundoscopy was performed on all subjects after exposure to 4392m - no retinal haemorrhages were present at the time of colour vision assessment. Written informed consent was obtained from all subjects and the study was approved by South Birmingham Research Ethics Committee.

Equipment

Colour vision was analysed using ChromaTest™ software (C H Electronics, Bromley, UK). It is an automated, digital colour contrast threshold (CCT) threshold programme that has already been validated in use for screening diabetic retinopathy and glaucoma. The software was run on the Sony VAIO VGN-FE41S laptop, with images displayed on a separate visual display unit. The programme displays a coloured letter (optotype - Figure 3), that is flashed on the VDU with a subject sitting at 1m distance wearing appropriate refractive correction. The optotype is displayed at a CCT determined by a pre-formatted algorithm, which applies a modified binary search routine, and brackets an individual eye's CCT. Data was analysed using SPSS software (SPSS Inc., Chicago, IL, USA).

Protocol

All subjects performed a trial run at sea level (Arica, Northern Chile), to reduce learning bias, after which, subjects performed colour vision testing twice in each eye at sea level. The group then ascended to Putre, Northern Chile (3300m) where colour vision was again tested twice in each eye within a period of 12 - 24 hours of arrival at this altitude. The ascent from sea level to 3300m was via motor vehicle and took six hours. The CCT was tested in both eyes, with the right eye being tested first and the left eye second, conducted in a darkened room and under a blackout cloth, with the test subject in these conditions for 5 minutes prior to starting the test. The VDU was calibrated before each session to ensure consistency. The group then ascended to Parinacota (4392m) where it was planned to repeat CCT measurement. Unfortunately, at this point, the laptop computer that was running the ChromaTest™ software failed to work, and the study was abandoned.

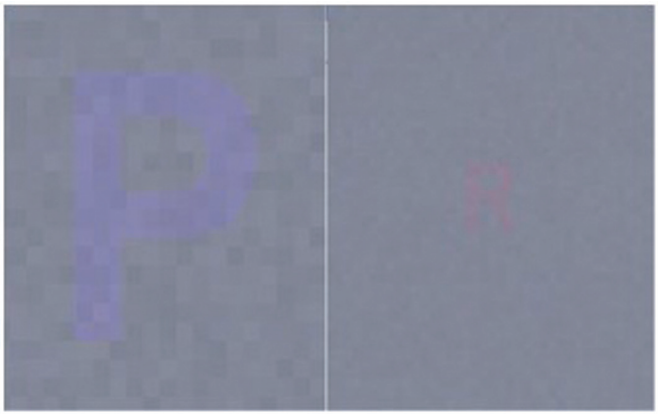

Figure 3. An example of the ChromaTest™ Optotype

Results

42 eyes (21 subjects) were included in the study (mean age 44, range 22-71, 16 male, 5 female). Non-parametric paired data was examined using the Wilcoxon signed rank test. There was found to be no change to either the protan axis (p=4.09) or the tritan axis (p=0.871) after ascent.

Protan Axis

Within the protan axis 16 eyes had a lower CCT at high altitude, whilst 26 were higher. The mean CCT at sea level was 4.21 (SD 2.29), and at 3,500m was 4.36 (SD 2.86).

Tritan Axis

In the tritan axis 20 eyes had a lower CCT and 22 were higher. The mean CCT at sea level was 7.06 (SD 1.77), and at 3,500m was 6.93 (SD 2.39).

Discussion

This experiment revealed no changes to colour vision with exposure to high altitude. This may be because the hypoxia experienced at 3300m is below the threshold that affects retinal cone dysfunction. Karakucuk et al [3] found cone dysfunction in the tritan axis at 3000m, however, their study was performed under photopic conditions (bright daylight), whereas many military operations would be under mesopic conditions (dim lighting) or scotopic conditions (no light), where cone function alters. To be militarily relevant this study was conducted in mesopic conditions, where the only light source was from the monitor being used to display the optotype.

An alternative explanation is that subjects had already acclimatised, and any retinal cone dysfunction that may have existed had resolved. The testing modality has been proven to be a sensitive modality, but we do not have direct comparisons between

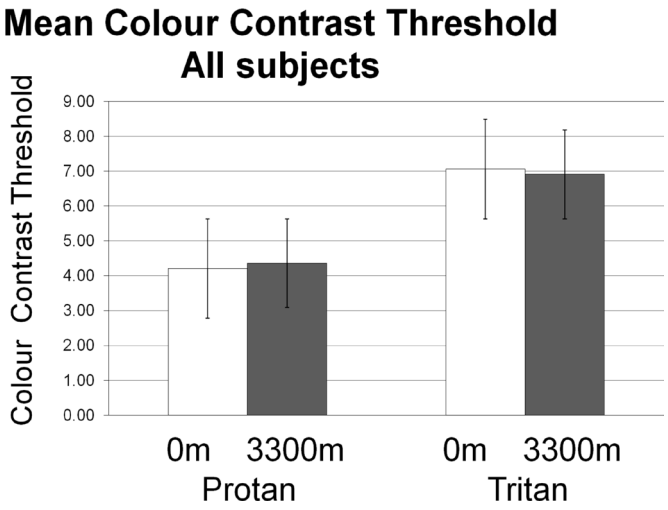

Figure 4. Graph showing mean colour contrast threshold for 42 eyes, divided for protan and tritan colour axis. Standard Error bars shown.

other methods. Of particular interest the ChromaTest™ has been tested on patients with retinal pathology for which hypoxia is believed to be the causative factor (diabetic retinopathy).

Perhaps the most important lesson relates to the difficulties of conducting research at altitude and the failure of technology to work under extreme conditions. The authors hypothesised that this failure was due to reduced barometric pressure and the effect this has on the Hard Disc Drive (HDD). Most manufacturers state that their hardware is not suitable for use over 3000m. This is because the HDD has a spinning disc inside it, with a spindle read/write head system that is 4nm above the disc. Changes in air pressure can lead to alterations in this miniscule gap resulting in failure of the HDD to operate. In future high altitude research it would be worth considering investment in a Solid State Drive (SSD) hard disc drive. These do not have a spinning disc and are regarded as suitable for use with low barometric pressure.

Conducting high altitude physiology research in the field is fraught with difficulties, as demonstrated by this study. This must be taken into account when designing a study protocol. The often hostile conditions impact on the technology that can be used, due to issues such as power supply, cold, barometric pressure, transport and space.

Although this study failed to find any changes to colour vision at high altitude, this is still an area worthy of further exploration, particularly from a military perspective where colour vision can play a crucial role in operations. Future studies could assess colour vision at a progressive altitude profile, including acclimatisation studies, to explore the hypoxia threshold at which colour vision does deteriorate and for how long it remains impaired. It would also be interesting, from both a military and physiological perspective, to assess these changes in different lighting conditions as this study suggests this could play a role.

References

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