Title: Impairment of color vision in aircraft maintenance workers

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Abstract

Purpose: The purpose of the study was to examine possible persisting effects to color vision in a group from the Royal Australian Air Force who had exposure to formulations containing neurotoxins during F-111 fuel tank maintenance, relative to two contemporaneous comparison groups.

Methods: Color vision was tested in 512 exposed personnel , 458 technical-trade comparisons and 330 non-technical comparisons using the Ishihara test plates and the Lanthony D-15 Desaturated Color disc arrangement test. Participants were excluded if they failed the Ishihara test as this indicates congenital color blindness. From the Lanthony results the type of color deficient vision (CDV) was diagnosed, and additionally, the Bowman's color confusion index (CCI) was calculated. Regression models were used to examine whether there was an association between color vision deficiencies and F-111 fuel tank maintenance, adjusting for possible confounders.

Results: The CCI ranged from 1 to 2.8 (median 1.2, quartiles 1.1, 1.4) in the 2600 eyes tested. Forty five percent of all participants had blue-yellow CDV in at least one eye. Deficiencies of this nature are caused by environmental exposures. Logistic regression demonstrated statistically significant differences in CCI category in the exposed group versus technical group (odds ratio 1.7: 95% CI 1.3-2.0) and a blue-yellow confusion in the exposed group versus technical group (odds ratio 1.4: 95% CI 1.1-1.7). No differences were observed between the exposed group versus the non-technical group.

Conclusion: The results indicate reduced color discrimination among the exposed subjects compared to one of two controlgroups. The findings may be due to previous exposure to solvents among the air force personnel.

Word count: 259

Key words: neurotoxicity; color vision; military service; aircraft; aircraft maintenance; risk factors; depressive disorders; diabetes; maintenance.

Introduction

Changes to the perception of color due to occupational exposures were first described as early as 1885 in workers exposed to elemental mercury. Gobba (2003), in his 2003 review of the effects of chemical exposures on the sensory organs, suggested that whilst the decline of perception in vision with increasing age is well known and accepted as unavoidable, there is increasing data to support the notion that at least part of the loss in the perception of color is related to occupational and/or environmental exposure to industrial chemicals.

Occupational-related color deficient vision (CDV), like other acquired CDVs, usually results in impairment of the blue-yellow color discrimination or, less frequently, in a combination of blue-yellow and red-green loss, while congenital CDV more frequently results in red-green discrimination (Verriest 1963; Mergler and Blain 1987a; Hart 1987). In addition, acquired CDV may be age dependent, involve the eyes unequally or be monocular, and can have variable, progressive or regressive outcomes, depending on various factors, including various types of exposure (Verriest 1963; Mergler and Blain 1987a; Gobba 2000; Gobba and Cavalleri 2000; Goffeng et al. 2008).

Studies in occupational populations have reported that visual evoked potentials VEPs, color vision and visual contrast sensitivity are affected by exposure to n-hexane, toluene, ethyl-benzene and solvent mixtures (Gobba 2000). Raitta et. al. (1978) found color vision deficiencies in the blue-yellow spectrum in 80% of a group of n-hexane workers. The study by Urban and Lukas (1990) of VEPs in rotogravure printers exposed to toluene, found 24% of the participants had abnormal color vision, with the frequency of abnormal VEPs correlating positively with the duration of exposure to toluene and also with the degree of alcohol consumption. Zavalic et. al. (1998) examined color vision in 45 male workers occupationally exposed to toluene and found that the effect could be reversible; when withdrawn from exposure for at least 64 hours color vision returned to pre-exposure scores. In 2000, Cavalleri et. al. (2000) reported that, when investigating dose-response relationships in workers exposed to toluene within the occupational limit proposed by the American Conference of Governmental Industrial Hygienists, color vision deficiencies appear to worsen as exposure continues.

As previously indicated, acquired color vision loss generally manifests in the blue-yellow spectrum. Mergler and Blain (1987b) reported for all individuals presenting with acquired color vision loss, blue-yellow confusion was usually present. However for some of the dyschromatopic workers, blue-yellow loss was accompanied by red-green or scotopic loss (complex CDV). These results are further

confirmed in the case-series reported in 2000 by Dick et.al. (2000): a number of neurological deficits were found in five former dockyard painters with a history of exposure to high concentrations of solvents at work. One of the most striking features of this series was acquired confusion in the blue-yellow spectrum.

A number of studies have been reported where workers were exposed to mixtures of solvents. The main problem in the comparison of these studies is that the term ‘solvent mixtures’ is very vague. A large number of solvents are generally included in mixtures, with different toxicokinetics and effects, and metabolic and toxic interactions are likely (Gobba and Cavalleri 2003). Despite these limitations, most of the studies are in agreement in showing impairment in color vision in solvent exposed workers.

One occupational group which was exposed to solvents, and thus at potentially increased risk of color vision loss, consists of F-111 fuel tank maintenance workers. The F-111 aircraft does not have dedicated fuel bladders, with fuel instead occupying the empty spaces between other metal structures. Over time, the sealant between internal structures degraded, resulting in fuel leaks, and it was necessary to set up periodic sealant repair programs which required dissolving and removing the original sealant (desealing) and then replacing it with new sealant (resealing).

In Australia, the Royal Australia Air Force (RAAF) performed four formal F-111 fuel tank Deseal/Reseal (DSRS) programs over more than two decades (1975-1999), each involving different processes and a range of approximately 60 hazardous substances, including jet fuel, a variety organic solvents, epoxy resins and various paint formulations. Between 2001 and 2004, we conducted a comprehensive, large-scale epidemiological investigation on behalf of the Australian Department of Defence of all personnel involved in the formal DSRS activities in Australia since the programs began (D'Este et al. 2003; D'Este et al. 2004). Sensory and neuropsychological outcomes were a particular focus of the study, due mainly to evidence of their association with organic solvent exposures and the large number of anecdotal complaints about these outcomes in the DSRS workers (Donaldson 2000; Ross April 2000).

Previously examined as part of this study have been outcomes of cancer(D'Este et al. 2008), mental health(Schofield et al. 2006), neuropsychological health(Attia et al. 2006), sexual function(Brown et al. 2009), hearing(Guest et al. 2010b), vestibular function(Guest et al. 2010c) and peripheral

neuropathy(Guest et al. 2010a). The aim of this paper is to investigate color vision in workers involved in F-111 fuel tank maintenance relative to appropriate comparison groups.

Methods

The Study of Health Outcomes in Aircraft Maintenance Personnel (SHOAMP) was a retrospective cohort study investigating the possible association between DSRS activities and adverse health status. The methods have been reported previously in detail (Attia et al. 2006; Schofield et al. 2006; Guest et al. 2010b) and are briefly summarized here. The study involved a mailed postal questionnaire to all participants and a series of clinic assessments with consenting participants.

Ethical approval to conduct the study was granted from the following institutional ethics committees: the Human Research Ethics Committee of the University of Newcastle, the Australian Defence Human Research Ethics Committee and the Department of Veterans' Affairs Human Research Ethics Committee.

1.1 Study Population

Two comparison groups were obtained using stratified random sampling from the computerized Air Force Personnel Executive Management System (AFPEMS), with stratification by gender, five-year age group, posting category (five year period of posting) and rank category: contemporaneous comparisons were selected from the same base (Amberley RAAF Base) who worked in non-aircraft maintenance jobs, ("same base, different job") and; from a different RAAF Base (in Richmond, NSW) who did work in aircraft maintenance, but not on F-111 aircraft, ("different base, similar job").

Measures

A number of health assessments were performed by a physician, nurse and clinical psychologist over a total of three to four hours at one of eight centres of Health Services Australia (HSA), a national provider of health assessments. Screening for congenital red-green color blindness was conducted using the Ishihara testing booklet of cards according to the standard instructions for the test (Health and Safety Executive 2005). To test for acquired color vision deficiencies the Lanthony desaturated 15-hue color chip arrangement test (L-D15-d) was used. The test required the participant to arrange the colored caps into a natural color order starting with a fixed reference cap. The test allows for the evaluation of hue, saturation, or lightness discrimination using pigment colors in a clinical

environment (Geller and Hudnell 1997). The participants were tested monocularly in both eyes, wearing their glasses where necessary. To ensure valid results, the test was conducted under a Richmond True Daylight Illuminator Lamp which gives off 6280 degree K light which corresponds to a spectral distribution of light roughly described as 'northern daylight'(Birch et al. 1979; Melamud et al. 2004).

Color Vision Outcomes

The results of the L-D15-D were scored in two ways. Firstly, a Color Confusion Index (CCI) was calculated for each participant according to the method described by Bowman (1982). This is calculated as the ratio of the sum of the differences in distance in color space between adjacent caps as positioned by the participant, relative to the sum of the differences between caps correctly positioned. For a perfect score where the caps are placed in the correct numerical order this ratio is 1. The more mistakes known as "crossings", made by the participant, the greater the distance between consecutively placed caps and the higher the CCI.

Secondly, a clinical diagnosis of the type of loss was determined by a research optometrist by plotting response on a standard score sheet. This allowed the determination of the type of loss by assessing the axis of color confusion (see Figure 1 for examples of types of color vision deficiencies). The direction of the confusion axis determines the type of color vision deficiency. Based on the major confusion axis, a diagnosis of normal, red-green (protan), blue-yellow (tritan), mixed or non-specific deficiency can be made. The classification of mixed CDV is a more severe form of blue-yellow deficit. The CDV diagnostic categories were subsequently combined to produce a dichotomous grouping for the statistical analysis of: blue-yellow or mixed color vision deficit versus all others.
INSERT Figure 1 HERE

Other Risk Factors

During the clinical examination, the existence of anxiety and depression was assessed using the Composite International Diagnosis Interview (CIDI) by a clinical psychologist. The methods have been reported previously in detail (Attia et al. 2006; World Health Organisation 1997). Visual acuity was measured by a nurse using a Snellen eye chart. The chart was read while standing at a distance of 6 meters. Acuity is represented as a fraction, with the distance at which the participant is standing

being the numerator, and the normal maximum legible viewing distance as the denominator. In addition all participants were screened using the Rey-15 item test (Rey 1964) to examine the potential for inadequate effort during psychological testing. Participants with a score of eight or less, which is an indication of potentially unreliable results, were excluded from analyses (Goldberg and Miller 1986; Hiscock et al. 1994).

The postal questionnaire was mailed to all possible study participants and included self-reported information on general health and well-being, as well as a variety of potential confounders including alcohol intake, smoking history, doctor diagnosis of diabetes, current medications, and a civilian job history calendar. Alcohol intake was coded to four categories: teetotaler and safe drinker, moderate drinker, hazardous chronic drinker and hazardous binge drinker according to The Australian Alcohol Guidelines (National Health & Medical Research Council 2001). Smoking behavior was grouped into one of three categories: never smoked, ex-smokers and current smoker. Participants provided a list of medications regularly used which were subsequently coded by a research pharmacist to the World Health Organization's Anatomical Therapeutic Chemical Classification (ATC). Of particular interest to this study was the use of anti-depressants. The civilian job history calendar was used to determine civilian exposure to organic solvents and lead prior to or subsequent to their Air Force enlistment. This data was obtained by initially classifying jobs to the Australian Standard Classification of Occupation(McLennan 1997; Australian Bureau of Statistics 1997) and translated into the Finnish occupation codes used in the Finnish Job Exposure Matrix (FINJEM) (Kauppinen 1998). Participants were classified as having an exposure if they had reported a civilian job for which the FINJEM probability of exposure was greater than 20%.

No estimate of chemical exposures was made as occupational hygiene surveys over the last three decades for the Amberley and Richmond RAAF bases were not readily available.

Statistical Analyses

The two outcomes of interest for this study were: 1) CCI score and 2) CDV diagnosis. Socio-demographic characteristics, potential confounders, CCI category and CDV diagnosis were compared across the exposure groups using Pearson's chi-square test, Kruskal-Wallis or Analysis of Variance. Logistic regression models were used to examine the association between F-111 DSRS exposure and color vision in both eyes, adjusting for potential confounders. Since this approach uses two observations per participant (one for each eye), robust, clustered, standard errors were obtained

which adjust for possible correlation between observations of the same participant (Williams 2000). All variables of interest were initially included in the regression model, and backwards stepwise methods used to exclude variables which were not significant at the 0.1 level based on the Wald Test. Odds ratios with 95% confidence intervals (CI) are reported. The statistical analysis package STATA v11.0 was used for analysis (StataCorp. 2009).

Results

The response to recruitment and final participation figures have previously been reported, thus we provide a summary (Attia et al. 2006; Schofield et al. 2006). A total of 872 exposed individuals, 1251 Amberley comparisons, and 1264 Richmond comparisons were eligible for inclusion in the General Health and Medical Study, of whom 1538 (45%) had a health examination. As only twenty-one participants were females and rates of CDVs differ by gender, females were excluded from this analysis. Of the 1532 participants who took the Ishihara test, ninety-one (6%) failed. Participants were included in the analysis if they passed the Rey and the Ishihara Color Plate Test and had complete data for variables remaining in the parsimonious model, leaving 1,300 in the analysis dataset.

A small number of participants in each group did not complete all questions in the postal questionnaire; therefore totals in each analysis vary accordingly. Table 1 presents the distribution of characteristics across the three exposure groups.

INSERT TABLE 1

The CCI scores ranged from 1 to 2.6 (median 1.1, quartiles 1, 1.3). The distribution was highly skewed to the right and there were a large number with a perfect score of 1. Thus, transformation did not improve normality. To remedy this issue the CCI was categorized into two groups: normal or slight CDV and moderate to severe CDV. The normal/slight classification was assigned if the participant had a CCI score less than the 75^{th} percentile of the non-perfect CCI scores (CCI < 1.4). Table 2 shows the number and proportion of participants in each CCI category. In the left eye there is a small non-significant statistical difference between exposure groups in the CCI category, however, in the right eye there is a statistically significant difference between the exposure groups (p = 0.03). The Amberley non-technical comparison population has a higher proportion of participants

with moderate to severe CDV based on CCI. Logistic regression modeling was used as the outcome was binary.

Table 2 also shows the number and percentage of individuals with clinical diagnosis of normal color vision, blue-yellow red-green, non-specific, and mixed deficiencies for the exposure groups. Overall almost one third of participants in the study had blue-yellow CDV, however there were not statistically significant differences between the groups.

INSERT TABLE 2 HERE

The results of logistic regression models are shown in Table 3 (for normal/slight versus moderate to severe abnormality) and Table 4 (for normal versus blue-yellow or mixed discrimination). In both analyses, the odd ratios of exposure were significantly different from 1 at the 5% level. The exposed group who participated in the DSRS programs had 1.7 times the odds of having a moderate/severe deficiency in color vision based on CCI score relative to the Richmond comparison groups (95% CI of 1.3 - 2.0). Alcohol consumption, smoking status, anxiety, depression, rank, posting categories and civilian exposures were not statistically significantly associated with CDV, however, age, diabetes and HSA examination centre remained in the parsimonious model.

The exposed group also had statistically significantly higher odds of having a clinical diagnosis of blue-yellow confusion than the Richmond comparison group: odds ratio 1.4, with a 95% CI of 1.1, 1.7. Alcohol consumption, smoking status, anxiety, depression, posting categories, and civilian exposures were not statistically significantly associated with CDV. However age, rank diabetes and HSA EXAMINATION centre remained in the parsimonious model.

INSERT TABLES 3 & 4 HERE

Discussion

The main finding is that there is a difference in the ability to distinguish colors between the exposed and Richmond technical comparison groups. Color vision was assessed in 2 ways: using a binary classification of the Color Confusion Index, as well as a binary clinical diagnosis of CDV type. Using the L-D15-d test there was a statistically significant difference in both outcomes between the exposed group of DSRS workers and a comparison group of aircraft maintenance personnel posted to

Richmond who undertake similar tasks on aircraft other than F-111 DSRS. Age, diagnosed diabetes and HSA examination centre remained significant in both analyses and rank in clinical diagnosis model. Enlisted personnel have 50 - 60% greater odds of a CDV. This is not an unexpected result as it is reasonable to expect that the enlisted personnel had greater occupational exposures than their supervisors.

Numerous studies have identified various demographic and personal characteristics such as age (Lanthony 1986; Bowman 1980; Paramei et al. 2004), alcohol consumption (Mergler et al. 1988; Paramei et al. 2004) and smoking (Paramei et al. 2004), and conditions such as diabetes (Duke et al. 2007), depression(Melamud et al. 2004), and poor visual acuity (Paramei et al. 2004) which can affect the results of testing of color vision (Gobba 2000; Melamud et al. 2004; Bowman 1980). We found a strong association between CDV and age. It has been suggested that after about 40 years of age, sensitivity to colors with short wavelengths is reduced by the yellowing of the nucleus of the crystalline lens (Werner et al. 1990; Paramei et al. 2004). In an arrangement test such as the L-D15-d the influence of age results in poorer discrimination in the blue-yellow range (Paramei et al. 2004). Interestingly, the 2004 meta analysis of the relationship between solvent exposure and CDV by Paramei et al. (2004) reported that some studies exclude heavy drinkers and heavy smokers. In conducting the meta-analysis the authors found no systematic difference in effect sizes between those studies which excluded heavy smokers and those which did not. It was more difficult to determine the effect size in relation to alcohol consumption and CDV as most studies had excluded heavy drinkers, however it was noted that the definition of heavy drinker differed in the studies reviewed. We did not find an association between CDV and either smoking or alcohol consumption. Paramei et al. (2004) did note the findings of Schaper et al. (2004) which used biomarkers for alcohol consumption and smoking and found no association between the biomarkers and CCI.

One of the most striking findings was the slightly higher proportion of blue-yellow CDV in the Amberley comparison group compared to the exposed and Richmond comparisons. This group initially had a high proportion of participants who failed the Ishihara color plate test indicating possible congenital color blindness. This may reflect the differing screening criteria used by the Royal Australian Air Force in the recruitment of technical and non-technical personnel. Those congenitally color blind are not enlisted in technical trades. It is impossible to know to what impact this screening procedure had on the distribution of blue-yellow CDV among the exposed and comparison groups, since enlistment color vision tests results were not available. It is thus impossible

to attribute any differences in CDV between the technical and non-technical groups to exposure to DSRS.

Almost one third of all participants (both exposed and comparison) had an abnormal Color Confusion Index or a blue-yellow color deficit. This proportion seems very high compared to other studies such as those of Gong et. al. (2003) and Ihrig et. al. (2003).

The four formal DSRS programs were conducted between 1975 and 1999, so that time since exposure for participants was between 5 and 29 years. Some participants were still working in the Air Force; however the majority had been discharged and no longer exposed to potential neurotoxins within the military environment. We did control for civilian exposures to neurotoxins in civilian occupations since prior to enlistment and post discharge, however this was not statistically significantly related to either outcome. The implication of this is that the effects we see on color vision are likely to be chronic effects. A controversial issue in the color vision literature is the issue of long-term cumulative effect (Paramei et al. 2004). Whilst some studies (Cavalleri et al. 2000; Castillo et al. 2001) have shown an improvement in color vision when solvent exposure has decreased over a period of years, it has also been noted that exposure can have long term effects on other visual functions, for example, cumulative exposure has been shown to lead to chronic damage to the neuro-optic pathway (Castillo et al. 2001).

Many previous studies have analyzed the continuous scores of the Color Confusion Index, rather than categorizing the values. It is our experience that this variable had a highly skewed distribution; while this is not a problem for univariate analyses since non-parametric methods can be used, it was problematic for multiple linear regression analyses. Residuals were not normally distributed, thus violating one of the assumptions required for linear regression. Hence the data were converted to a binary variable.

Following their 2004 meta-analysis of the relationship between organic solvent exposure and impairment of color vision, Paramei et al. (2004) found heterogeneity in the results of the studies reviewed. Of concern was the use of CCI as the global measure of color vision loss, as it may lack sensitivity to any effect of solvent exposure on color discrimination. One reason for the heterogeneity in the relationship between solvent exposure and CCI may be the violation of the normality assumption when using parametric statistical tests. While some studies report using parametric tests which we conclude is inappropriate, many have taken the same approach we used of

categorizing the outcome and subsequently losing information. Whilst the CCI is an extremely useful clinical measure to quantify the level of CDV in clinical practice, for epidemiological studies further research is required to establish a measure which is more amenable to statistical analysis whilst retaining information relating to confusion axis and severity. Paramei et al. (2004) conclude it is likely that differential indices (Vingrys and King-Smith 1988) are more suitable for occupational studies, such as the confusion axis which is more sensitive than CCI in highlighting early CDV in solvent exposed workers (Gobba and Cavalleri 2000) and the confusion angle, enabling differentiation between blue-yellow and red-green types of impairment.

Study Strengths and Weaknesses

This large cohort study has described the rate of CDV in this Australian military population. It is the first Australian study of a military population to be published which has examined color vision. A strength of this study is the sample size of 1300, being one of the largest studies investigating the relationship between solvent exposure and CDV. In addition, our approach to the statistical analysis of using the data collected from both eyes, rather than the more usual approaches of averaging or using the worst observation has increased the number of observations. The findings relating to age, alcohol consumption and smoking add to the current body of knowledge in this field. A weakness in the study is that it was carried out retrospectively without exposure data for the various solvents used in the DSRS programs and without access to the pre-employment/recruitment visual screening results.

CONCLUSION

In summary, this study examined the effects of DSRS chemical exposures and aircraft maintenance on color vision. The study reveals a greater degree of CDV among the F-111 DSRS workers; and is consistent with previous studies relating CDV to organic solvents. We also confirm the influence of age but not of smoking or alcohol consumption.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Appendix A

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Appendix C

This journal article has been reviewed by the Department of Veterans' Affairs and the Department of Defence prior to publication and the views expressed are not necessarily those of the Australian Government.

Tables

Table 1: Characteristics of SHOAMP participants by exposure group

	Exposed		Amberley		Richmond				
	N = 512		N = 330		N = 458		ANOVA		
	Mean	S.D.	Mean	S.D.	Mean	S.D.	F	DF	P
Age (years)	43.9	9.0	43.6	7.7	44.8	7.8	2.6	2	0.11
							Pearson Chi2		
	N	%	N	%	N	%	Chi2	DF	P
Posting Category									
1975-1979	177	35	107	34	170	38			
1980-1984	116	23	85	26	114	25			
1985-1989	110	21	74	22	107	23			
1990-1994	70	14	38	12	41	9			
1995-1999	39	8	26	8	26	6	9.0	8	0.3
Rank Category									
Civilian, Enlisted & Unknown	344	67	217	66	284	62			
Officer	168	33	113	34	174	38	3.0	2	0.2
Drinker Type									
Safe Drinker	189	37	138	42	192	42			
Moderate	124	24	49	15	96	21			
Hazardous Binge Drinker	152	30	109	33	135	30			
Hazardous Drinker Chronic	47	9	32	10	33	7	13.1	6	0.04
Smoking History									
Never smoker	219	43	127	38	215	47			
Ex smoker	190	37	129	39	176	38			
Smoker	102	20	74	22	67	15	10.3	4	0.03
Diagnosed diabetic	17	334	11	3.3	14	3.0	0.1	2	0.9
Uses antidepressant meds.	46	9	23	7	26	6	4.0	2	0.1
CIDI depression	148	29	70	21	78	17	20	2	<0.01
CIDI anxiety	127	25	55	17	52	11	30	2	<0.01
Civilian exp. to neurotoxins	59	12	30	9	76	17	11	2	<0.01
Civilian exp. to solvents	204	41	59	18	145	32	46	2	<0.01
HSA examination centre									
Brisbane and Townsville	216	42	125	38	125	27			
Adelaide, and Darwin	19	4	23	7	35	8			
Melbourne and Hobart	19	4	33	10	33	8			
Ipswich	141	28	41	12	34	7			
Newcastle	15	3	11	3	36	8			
Parramatta	79	15	71	22	151	33			
Perth	13	3	17	5	19	4			
Canberra	10	2	9	3	25	5	159	14	<0.01

Table 2: Descriptive statistics of vision test results

	Exposed		Amberley		Richmond				
	N = 512		N = 330		N = 458		Kruskal-Wallis		
	median	IQR	median	IQR	median	IQR	Chi2	DF	P
Color Confusion Index									
Left eye	1.1	0.3	1.1	0.3	1.1	0.3	2.4	2	0.3
Right eye	1.1	0.3	1.2	0.3	1.1	0.3	9.4	2	<0.01
							Pearson Chi2		
	N	%	N	%	N	%	Chi2	DF	P
Color Confusion Index – Left eye									
Normal/slight (CCI<1.4)	424	83	281	85	389	85			
Moderate/severe	88	18	49	15	69	15	1.1	2	0.6
Color Confusion Index – Right eye									
Normal/slight (CCI<1.4)	420	82	258	78	391	85			
Moderate/severe	92	18	72	22	67	15	6.8	2	0.03
Clinical Deficiency in Color Vision – Left eye									
No deficiency	302	59	177	54	278	61			
Red-Green	7	1.4	4	1.2	3	0.7			
Non-specific	17	3	14	4	16	4			
Mixed	20	4	8	2	12	3			
Blue-Yellow	164	32	122	38	147	32	7.1	8	0.5
Clinical Deficiency in Color Vision – Right eye									
No deficiency	295	58	173	54	280	61			
Red-Green	11	2	3	0.9	4	0.9			
Non-specific	23	5	13	4	23	5			
Mixed	22	4	13	4	16	4			
Blue-Yellow	159	31	124	38	133	29	11.6	8	0.2
Visual Acuity – Left eye									
6/6 (20/20)	404	82	250	81	352	80			
6/9 (20/30)	58	12	41	13	67	15			
6/12 (20/40)	19	4	12	4	12	3			
6/18–6/60(20/60–20/200)	12	2	6	2	8	2	3.7	6	0.7
Visual Acuity – Right eye									
6/6 (20/20)	406	83	253	82	342	78			
6/9 (20/30)	57	12	40	13	68	15			
6/12 (20/40)	14	3	11	4	14	3			
6/18–6/60(20/60–20/200)	11	2	4	1	15	3	7.1	6	0.3

Table 3: Logistic regression model of binary Color Confusion Index Category (CCI>1.4) using both eyes

		N=2,600		
Variable	Variable detail	Odds Ratio	95% CI	P
Exposure group	Exposed (reference)			
	Amberley	1.0	0.7, 1.4	0.99
	Richmond	0.6	0.5, 0.8	<0.01
Age	Years/10	1.7	1.5, 2.0	<0.01
Diagnosed diabetic	Yes	2.0	1.1, 3.6	0.02
HSA examination centre	Brisbane, Townsville, Ipswich, Perth, Melbourne, Hobart, (reference)			
	Adelaide, Darwin, Newcastle, Parramatta, Canberra	2.3	1.8, 3.0	<0.01

Table 4: Logistic regression model on dichotomised clinical diagnosis of any blue-yellow deficiency using both eyes

		N=2,570		
Variable	Variable detail	Odds Ratio	95% CI	P
Exposure group	Exposed (reference)			
	Amberley	1.2	1.0, 1.6	0.11
	Richmond	0.7	0.6, 0.9	0.02
Age	Years/10	1.7	1.5, 2.0	<0.01
Rank	Officer (reference)			
	Enlisted	1.3	1.1, 1.7	<0.01
Diagnosed diabetic	Yes	1.6	1.0, 2.7	0.06
HSA examination centre	Brisbane, Townsville, Ipswich, Perth, Melbourne, Hobart, (reference)			
	Adelaide, Darwin, Newcastle, Parramatta, Canberra	1.8	1.5, 2.2	<0.01

Figures

Figure 1: Types of color vision deficiency

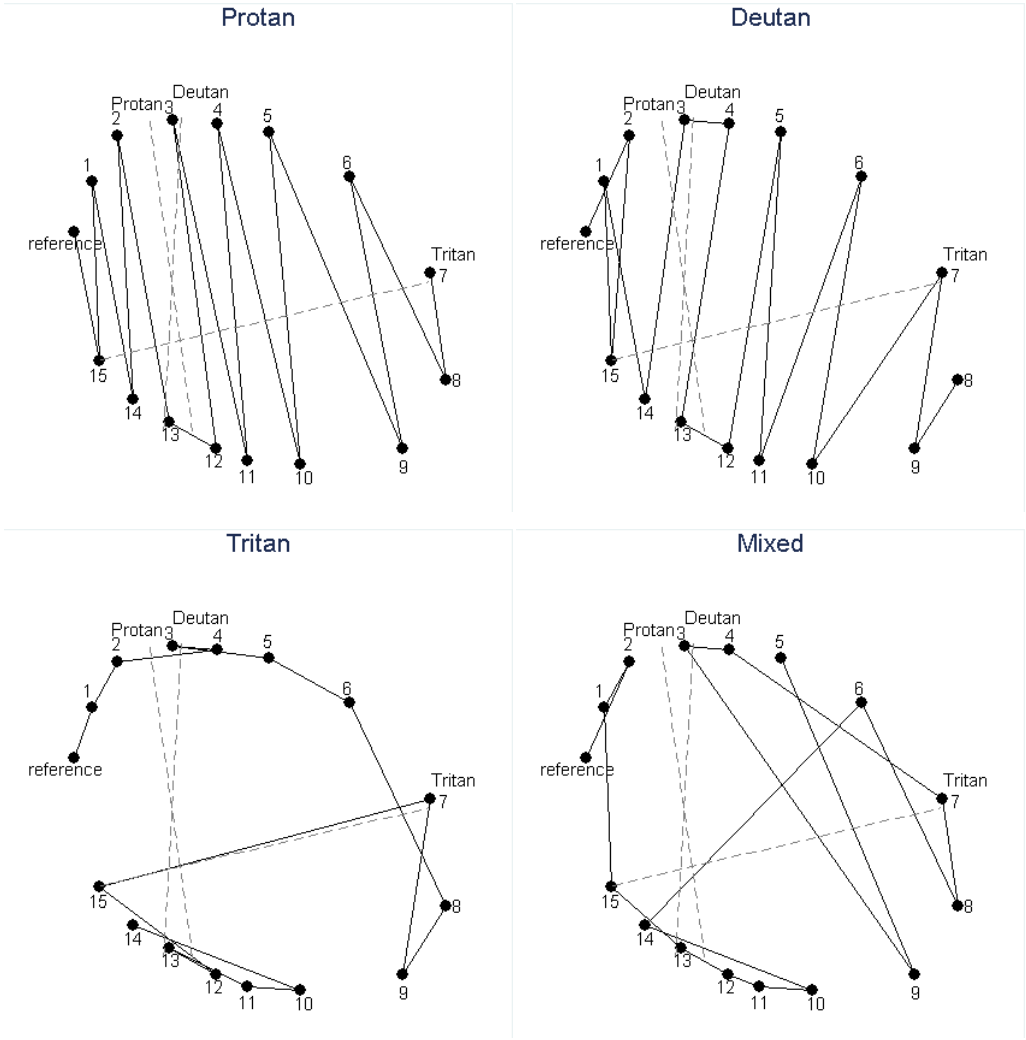

Figure 1: Types of deficiency in color vision (IN COLOR)