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Colour vision screening

A critical appraisal of the literature

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EXECUTIVE SUMMARY

Objectives

A literature review and critical appraisal was performed to provide an evidence-based review evaluating colour vision screening through the use of recognised screening criteria.

Data sources

The search was restricted to English and European languages. There was no restriction by the date of publication of the retrieved studies or the study design used.

Study selection

Studies were selected and articles were appraised if they examined data relating to the natural history, treatment, or prevalence of colour vision deficiencies or if they examined disabilities resulting from impaired colour vision, the validity of colour vision screening tests or colour vision screening programmes.

Criteria for exclusion from appraisal were:

- participation rate <50%
- sample size <25
- significant difference in the baseline characteristics of cases and controls
- lack of demographic details about the study participants
- updated results published
- papers for debate or editorials
- abstract only

A single reviewer applied these criteria.

Sixty-one of 431 identified articles were eligible for selection after applying these exclusion criteria.

Data extraction

Critical appraisal forms standardised by study design were used to extract and appraise the literature. These forms were designed for use at Puget Sound, Seattle, USA (Group Health Cooperative of Puget Sound, 1996) and adopted by the New Zealand Guidelines Group.

A single reviewer conducted the appraisal of studies.

The level of evidence was evaluated using the U.S. Preventive Services Task Force protocol (U.S. Preventive Services Task Force, 1989), **(See p. 6).**

Data synthesis

There were 20 studies identified that measured the prevalence of colour vision deficiencies. Pooled data (weighted by sample size) suggested the prevalence of impaired colour vision in males was 7.3%. Two studies measured the prevalence in New Zealand males. Pooling this data and adjusting the ethnic mix to 1996 census data suggested a prevalence of 6%.

Six studies were identified that compared the rate of motor vehicle crashes in the impaired colour vision group with the normal colour vision group. In one of these six there was a significantly higher rate of accidents in the impaired colour vision group.

Five studies were identified that compared the performance between those with impaired and normal colour vision for occupational performance. Those with impaired colour vision had inferior performance in air traffic control and sea search and rescue operations.

Three studies evaluated educational performance and all three found no significant difference in performance between those with impaired or normal colour vision.

There were 17 studies identified that evaluated the validity of various colour vision screening tests. Ishihara's pseudoisochromatic test was not demonstrated to be inferior to any other screening test. It had 96% sensitivity and 98.5% specificity, on average, after excluding studies that included preschool children. All screening tests evaluated appeared to have inferior performance in preschool children although this was not tested in a direct comparison.

There were three studies identified that evaluated aspects of colour vision screening programmes. These studies were insufficiently rigorous in design to allow an estimation of the effectiveness of the programmes surveyed.

Conclusions

The studies identified for critical appraisal had limitations that should be considered when interpreting the following conclusions:

❑   There were no adequate treatment options for the correction of impaired colour vision on current evidence.

❑   Of the approximately 7% of the male population with congenitally impaired colour vision approximately 40% of that population appears to be unaware of the defect prior to leaving secondary school.

❑   It was not possible to identify the impact colour vision screening has on reducing educational and occupational difficulties or motor vehicle crash rates.

❑   There was insufficient evidence to either agree or disagree with the hypothesis that those with impaired colour vision have more road traffic crashes.

❑   Further research was required to assess the role impaired colour vision has on educational attainment.

❑   Those involved in air traffic control and sea search and rescue operations should have normal colour vision. Research on other occupations, which normally restrict those with impaired colour vision, was not identified in this report but it should not be assumed that such restrictions are unnecessary.

❑   There was insufficient evidence for the use of colour vision screening as a method of first detection of an adverse health outcome other than impaired colour vision.

❑   There was currently insufficient evidence to recommend a change in the colour vision screening test currently in use within New Zealand (Ishihara's pseudoisochromatic test) on the basis of its validity. Cost-effectiveness information is needed to compare the costs of the various screening tests against sensitivity and specificity criteria.

❑   There was insufficient evidence to recommend a change in the age at which colour vision screening should occur in New Zealand.

❑   It was not possible to evaluate the effectiveness of a colour vision screening programme on the basis of current research. This was identified as an area requiring further research, incorporating a randomised controlled trial as the most appropriate research design for this purpose.

❑   The cost-effectiveness of colour vision screening could not be estimated due to the lack of research in this area. This is an area requiring further research attention.

Mesh Headings

Color vision defects, color perception, vision screening, mass screening, color perception tests, prevalence, career choice.

LIST OF ABBREVIATIONS

AO-HRR	—	American Optical Hardy Rand Rittler pseudoisochromatic test
APT-5	—	Anomaloscope Plate Test
CUCVT	—	City University Colour Vision Test
ESI	—	Electrical Supply Industry test
F-M 100-hue	—	Farnsworth Munsell 100-hue test
HbA$_{1c}$	—	Glycosylated haemoglobin
PACT	—	Pease Allen Colour Test
RAF	—	Royal Air Force
SPP-A	—	Standard pseudoisochromatic Plates – Acquired deficiencies
SPP-C	—	Standard pseudoisochromatic Plates – Congenital deficiencies
χ^2	—	Chi squared test

GLOSSARY

Anomaloscope ∼ An instrument used in testing abnormalities of colour vision by having the subject match mixed spectral lines.

Anomalous trichromat ∼ Defective colour vision in which the patient has all three cone pigments, one of which is deficient or anomalous, but not absent.

Before and after study ∼ A situation in which the investigator compares outcomes before and after the introduction of a new intervention.

Bias ∼ Deviation of results or inferences from the truth, or processes leading to such deviation.

Case control study ∼ The observational epidemiologic study of persons with the disease (or other outcome variable) of interest and a suitable control group of persons without the disease. The relationship of an attribute to the disease is examined by the diseased and the non-diseased with regard to how frequently the attribute is present.

Cohort study ∼ The analytic method of epidemiologic study in which subsets of a defined population can be identified who are, have been, or in the future may be exposed or not exposed, or exposed in different degrees, to a factor or factors hypothesised to influence the probability of occurrence of a given disease or outcome.

Cone ∼ A visual cell that serves light and colour vision and visual acuity.

Cross-sectional study ∼ A study that examines the relationship between diseases (or other health related characteristics) and other variables of interest as they exist in a defined population at one particular time.

Descriptive study ∼ A study concerned with and designed only to describe the existing distribution of variables, without regard to causal or other hypotheses.

Deutan ∼ Pertaining to decreased sensitivity of green sensitive cones.

Dichromat ∼ A person with a defect in colour vision in which one of the three cone pigments is missing.

Generalisability ∼ Applicability of the results to other populations.

Meta-analysis ∼ Any systematic method that uses statistical analysis to integrate the data from a number of independent studies.

Misclassification ∼ The erroneous classification of an individual, a value, or an attribute into a category other than that to which it should be assigned.

Multiple regression ∼ Any analysis of data that takes into account a number of variables simultaneously.

Negative predictive value ～ The probability a person does not have the disease when the screening test is negative.

Positive predictive value ～ The probability a person actually has the disease when the screening test is positive.

Prevalence ～ The number of events in a given population at a designated time.

Protan ～ Pertaining to decreased sensitivity of red sensitive cones.

Randomised controlled trial ～ An epidemiologic experiment in which subjects in a population are randomly allocated into groups to receive or not receive an experimental preventive or therapeutic procedure, manoeuvre, or intervention. Randomised controlled trials are generally regarded as the most scientifically rigorous method of hypothesis testing available in epidemiology.

Selection bias ～ Error due to systematic differences in characteristics between those who are selected for study and those who are not.

Sensitivity ～ The proportion of truly diseased persons in the screened population who are identified as diseased by the screening test.

Sensitivity analysis ～ A method to determine the robustness of an assessment by examining the extent to which results are affected by changes in methods, values of variables, or assumptions.

Specificity ～ The proportion of truly non-diseased persons who are so identified by the screening test.

Tritan ～ Pertaining to decreased sensitive of blue sensitive cones.

Variance ～ A measure of the variation shown by a set of observations, defined by the sum of the squares of deviation from the mean, divided by the number of degrees of freedom in the set of observations.

TABLE OF CONTENTS

INTRODUCTION   1

METHODOLOGY   5

PREVALENCE   7

DISABILITY   19

SCREENING TESTS   29

LIST OF TABLES

1

Introduction

WHAT IS THE OBJECTIVE OF THIS REPORT?

The objective of this report was to inform the Health Funding Authority (HFA) on the current evidence evaluating colour vision screening through the application of validated screening criteria.

WHAT CRITERIA ARE NORMALLY REQUIRED FOR THE DEVELOPMENT OF A SCREENING PROGRAMME?

Criteria for assessing the validity of screening programmes have been described by a number of authors (Cuckle and Wald, 1984, Gray, 1997). However, Wilson and Jungner's (Wilson and Jungner, 1968) criteria remain the benchmark for evaluation. These have been summarised by Snowdon and Stewart-Brown (Snowdon and Stewart-Brown, 1997) and were used in this report.

These criteria were:

- The condition should be common and disabling.
- The natural history of the condition should be known.
- There is a recognisable latent or presymptomatic phase of the condition.
- There should be a reliable, valid and repeatable screening test.
- The screening test should be acceptable, safe and easy to perform.
- The screening test should have a high positive predictive value.
- The screening test should be sensitive and specific.
- The cost of the screening programme should be commensurate with the benefits of early detection.
- There should be effective and available treatment.
- The service provision should be adequate to treat the children identified by the screening programme.
- There should be an agreed policy on who will be treated.

It is argued that a screening programme's failure to fulfil any one of these criteria calls into question its validity.

WHAT QUESTIONS SHOULD BE ASKED TO EVALUATE THE ADVISABILITY OF PURCHASING FOR COLOUR VISION SCREENING?

Bearing in mind the objective of this report and the screening criteria listed, the following research questions were formulated for this report:

- What is the prevalence of impaired colour vision? There was a specific requirement to determine ethnic differences in prevalence.
- What is the natural history of impaired colour vision?
- What are the consequences of impaired colour vision? These consequences were to include health and other fields. Therefore consequences of impaired colour vision were considered in occupation, education and health spheres.
- Is there any treatment for impaired colour vision?
- Is there a suitable screening test for impaired colour vision?
- Is colour vision screening cost-effective?
- Are these screening criteria suitable for the evaluation of colour vision screening? Other potential benefits from colour vision screening exist suggesting screening criteria developed for the health arena alone might not be valid. Other potential health benefits from screening might exist if colour vision screening detects disease earlier than any diagnosis by other methods. Normally screening programmes are specific for one disease.

Colour vision screening is currently performed in 11-year-old boys within New Zealand but the scope of this report was to include an evaluation of screening in other age groups.

WHAT IS KNOWN ABOUT THE NATURAL HISTORY OF COLOUR VISION DEFICIENCIES?

In answer to the question regarding natural history, it is recognised that most colour vision defects are constant throughout life in type and severity (Lyle, 1990). Therefore, there is an understanding of the natural history of impaired colour vision.

COLOUR VISION SCREENING

WHAT OPTIONS EXIST FOR THE TREATMENT OF COLOUR VISION DEFICIENCIES?

One study was identified that investigated the options for treatment of impaired colour vision. This study investigated long wavelength pass filters (Hovis, 1997). Participants with red-green colour vision deficiencies were recruited by advertisement in this descriptive study (Grade III evidence). There were 29 participants with a median age of 30. The effectiveness of the filters was assessed through response on colour vision tests. There was a significant improvement in the tests requiring judgements between large colour differences and pseudoisochromatic plate tests which used red and green for the figure and background colours but performance was reduced in the blue-yellow spectrum. Overall effectiveness was rated as "not very effective" in 44% and only 17% were interested in purchasing the lenses after a one-week trial.

This uncontrolled trial is a poor method of evaluating therapeutic options so the results of this study should be treated with caution. There was not a clear method of identifying the group of people who thought they would benefit from purchase of the filters.

It was concluded that:

There were no adequate treatment options for the correction of impaired colour vision on current evidence.

WHAT IS THE PHYSIOLOGY OF COLOUR VISION?

Cones mediate colour vision. One cone pigment is primarily responsible for sensing blue light, one for green and one for red. Protanopia describes the lack of any red sensitive pigment in the retina, deuteranopia lacks green sensitive pigment and tritanopia blue sensitive pigment. The latter is rare with a prevalence between one and five per 10,000 Caucasian live births (Buyse, 1990).

Colour vision begins with this three colour, three receptor system. Single cells deal with two sets of cones with overlapping spectral sensitivities. It is this structure that permits nerve cells to code different colours in an unambiguous manner (Michael, 1973). Genes for long and middle wavelength sensitive visual pigments (red-green spectrum) are encoded on the X chromosome (Neitz and Neitz, 1995).

HOW IS IMPAIRED COLOUR VISION CLASSIFIED?

Congenital colour deficiency can be classified as shown in **Table 1 (p. 3)**, (Birch, 1993).

The protan and deutan deficiencies are inherited through an X linked recessive mechanism whereas the tritan deficiencies are autosomal dominant. Rod monochromatism is autosomal recessive and atypical monochromatic is X linked recessive.

Table 1.   Classification of congenital colour deficiency.

Number of variables in wavelength matching	Number of cone photopigments	Type	Denomination	Hue discrimination
1	None	Monochromat (Achromat)	Typical or rod monochromat	Absent
1	One	Monochromat (Achromat)	Atypical, incomplete, or cone monochromat	Absent
2	Two	Dichromat	Protanope Deuteranope Tritanope	Severely impaired
3	Three (one abnormal)	Anomalous trichromat	Protanomalous Deuteranomalous Tritanomalous	Continuous range of severity from severe to mild
3	Three	Normal trichromat	Normal trichromat	Optimum

WHAT POPULATIONS HAVE ALTERED COLOUR VISION?

Colour vision is altered in diabetics (Ismail and Whitaker, 1998; North et al., 1997; Kurtenbach et al., 1993; Banford et al., 1994). In a group of patients aged between eight and 17 years (mean age = 13 years) with insulin dependent diabetes mellitus there were significantly more errors on the Farnsworth D15 panel and the Lanthony desaturated D15 test compared with a control population (mean age = 12 years) of healthy children (Banford et al., 1994). Significantly more errors were made in the Farnsworth-Munsell 100-hue test (F-M 100-hue test) among those with more severe retinopathy but colour vision abnormality was not sufficiently discriminating to separate diabetics with and without retinopathy (Ismail and Whitaker, 1998).

Dominant optic atrophy is associated with early disturbance of colour vision (Brown et al., 1997). In comparing affected and unaffected participants with the F-M 100-hue test, significantly more errors were made by affected participants in all age groups ($p<0.03$). Kjer type of dominant optic atrophy has been described before the age of eight years (Kjer, 1959) and has a prevalence of approximately 1 in 50 000 (Lyle, 1990).

Colour vision is significantly impaired in the majority of optic neuritis patients (Schneck and Haegerstrom-Portnoy, 1997). However, optic neuritis is uncommon in childhood (Rollinson, 1977).

Anti-epileptic medication has been implicated in alteration of colour vision (Steinhoff et al., 1997b; Steinhoff et al., 1997a).

Methodology

LITERATURE SEARCH

The literature search was divided into the following sections:

- prevalence of colour vision disorders, natural history, disability
- treatment
- screening programmes

Because of the difficulty in locating adequate information on the prevalence of colour vision disorders in European populations the search was taken back as far as possible on Medline and continued with a hand search of Index Medicus under the headings "color blindness" and "color perception". The years 1924-1934 and 1955-1960 were selected for the hand search owing to an apparent interest in the prevalence of colour vision defects during these years which had been identified in references from articles obtained during the course of the project.

Other sections of the literature search were restricted to the last 10 years.

Searches were carried out during late June and early July 1998.

The search strategies used for Medline/Healthstar and Embase are given in **Appendix 1**. The Healthstar search was limited to non-Medline references.

The other databases were searched using the thesaurus heading *color vision* where available, or if there was no controlled vocabulary, the keywords *colour vision*/*color vision*.

A particular effort was made to obtain articles that appeared relevant whether or not they were available in New Zealand. However, articles in languages other than English, French, and German were excluded.

SOURCES SEARCHED

The sources searched included:

- Medline/Index Medicus
- Healthstar
- Current Contents (combined files)
- Cinahl
- Cochrane Library
- Best Evidence CD-ROM
- Embase

- ERIC (Educational Resources Information Centre) database
- Psychlit
- Sociofile
- Social Science Index
- Science Citation Index
- Social Science Citation Index
- Database of Abstracts of Reviews of Effectiveness (DARE)
- NHS Economic Evaluation Database
- TRIP (Turning Research into Practice) database - Gwent Health Authority
- publications and current projects of the International Network of Agencies for Health Technology Assessment (INAHTA)
- New Zealand Health Information Service statistics
- reference lists of documents obtained during the course of the project

INCLUSION AND EXCLUSION CRITERIA

Studies were considered for this report if they used one of the following designs:

- meta-analysis
- randomised controlled trial (RCT)
- cohort study
- case-control study
- before and after study
- descriptive study

Details of these study designs are found in **Appendix 2**. Economic analyses were also considered.

Exclusion criteria

The following criteria were used to exclude studies from appraisal:

- participation rate <50%
- sample size <25
- significant difference in the baseline characteristics of cases and controls
- lack of demographic details about the study participants
- updated results published
- papers for debate or editorials
- abstract only

The studies that were excluded are identified in **Appendix 3**.

APPRAISAL METHODOLOGY

Articles were formally appraised using the schedule developed by the Group Health Cooperative of Puget Sound (Group Health Cooperative of Puget

Sound, 1996) and adapted by the New Zealand Guidelines Group of the National Health Committee (New Zealand Guidelines Group, 1997).

Summaries of appraisal results have usually been presented in tabular form and conclusions have been drawn that were dependent on the study design and findings and the specific problems associated with the individual studies.

The sensitivity and specificity were the favoured methods of presenting results in the evaluation of the validity of screening tests for impaired colour vision. Formulae for these parameters are presented in **Appendix 4**.

The grade of evidence (which evaluates quality) was assigned using the U.S. Preventive Services Task Force protocol (U.S. Preventive Services Task Force, 1989). Thus, levels of evidence were:

I   Evidence obtained from at least one properly designed randomised-controlled trial.

II-1   Evidence obtained from well-designed controlled trials without randomisation.

II-2   Evidence obtained from well-designed cohort or case-control analytic studies, preferably from more than one centre or research group.

II-3   Evidence obtained from multiple time series with or without intervention.

III   Opinions of respected authorities, based on clinical experience, descriptive studies, or reports of expert committees.

Epi-info version 6.04 (Dean et al., 1995) was used to determine χ^2 values and level of significance when the author of this report evaluated categorical data.

CONSULTANT REVIEW

Dr Mark Elder peer reviewed a draft of this report and his comments are included in **Appendix 5.**

LIMITATIONS OF THE REPORT

Although, in general, randomised-controlled trials are usually best able to reduce the effects of bias and confounding, the most important determinant of the validity of the study is the rigour applied to its design and analysis and not necessarily the type of study design used. In addition, certain study designs are more appropriate for particular issues.

For example, randomised-controlled trials are best for comparisons between different therapeutic options, cohort studies are best for assessing prognosis and cross-sectional studies are best for describing the prevalence of a condition at one point in time.

Although this report has greatly benefited from advice provided by consultants, it has not been exposed to wide peer review. In addition, the report has been limited to the published academic literature and has not appraised unpublished work.

The report was conducted over a limited period of time (July – October, 1998).

Prevalence

INTRODUCTION

In this report the term prevalence refers to the point prevalence and can be defined as "the number of events in a given population at a designated time."

Screening programmes are increasingly valuable as the prevalence of the condition under study increases. There are two main reasons for this:

1. There can be a greater reduction in the impact of a condition if that condition has a high prevalence (other things being equal).

2. The screening tests have a higher positive predictive value in conditions of high prevalence. This results in less utilisation of unnecessary resources (through unnecessary confirmatory testing) resulting in a better cost-benefit profile.

A third issue to be considered concerns the proportion of the potential screening population that are unaware they are colour vision impaired. The higher this proportion is, the more favourable a screening programme would be.

WHAT IS THE PREVALENCE OF IMPAIRED COLOUR VISION?

Twenty studies were identified that examined the prevalence of colour vision impairment. These studies are summarised in **Table 2 (p. 12)**. The χ^2 tests included in this table were calculated by the author of this report.

Modarres et al., 1996

The prevalence of congenital colour vision impairment was assessed in 12 to 14-year-olds (mean age not stated) in Iran. There were 1136 males and 922 females in the survey. Ishihara pseudoisochromatic plates were used for testing. The study was cross-sectional (Grade III evidence) in design.

Colour vision impairment was identified in 8.18% of males and 0.43% of females.

Limitations of the study included:

- The participation rate was not stated.
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.

- The study participants were not randomly selected and selection was based on class rather than individual students.
- The generalisability should be treated with caution since the study was set in Iran.

Al-Amood et al., 1981

The prevalence of impaired colour vision in Iraqi Arabs was assessed in 1221 males and 845 females presenting for premedical admission screening (age range and mean age not stated). The Ishihara pseudoisochromatic plates were used for testing. The study was cross-sectional (Grade III evidence) in design.

Impaired colour vision was present in 8.19% of males and 3.2% of females.

Limitations of the study included:

- The participation rate was not stated.
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- It was unclear whether the level of colour vision impairment in this population of premedical admissions would be similar to the general Iraqi population.
- The generalisability of these results should be treated with caution.

Kim et al., 1989

The prevalence of congenital colour impairment was assessed in Koreans attending school. There were 4678 males and 4760 females in the study aged 14-15 years. The Hardy-Rand-Rittler pseudoiso-chromatic plates (AO-HRR) were used for testing. The study was cross-sectional (Grade III evidence) in design.

Colour impairment was detected in 5.9% of men and 0.44% of women.

Limitations included:

- It was unclear whether the participants were randomly selected.
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- The participation rate was not stated.
- Generalisability should be treated with caution.

Macfarlane et al., 1987

The prevalence of ocular disorders was described in 1007 Queensland children aged between six and 11 years (mean age not stated). Colour perception was tested with the Ishihara pseudoisochromatic plates. The study was cross-sectional (Grade III evidence) in design.

Abnormalities of colour perception were detected in 3.7% of those tested.

Limitations of the study included:

- Male and female results were not differentiated.
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- Participants were not randomly selected.
- The participation rate was 87%.

Feig and Ropers, 1978

A cross-sectional study (Grade III evidence) of 5565 German schoolboys aged 10 to 19 years (mean age not stated) used Ishihara pseudoisochromatic plates to identify colour vision impairment. Two or more mistakes were taken as evidence of defective colour vision.

There was a discernible defect in 7.8% of the sample.

Limitations of the study included:

- The participation rate was not stated.
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- There was an unclear selection process.
- There was a possible misclassification bias due to the stringent requirements used to pass the Ishihara testing.
- The generalisability is uncertain.

Choi et al., 1995

A study of eye disease was conducted in Los Angeles in six and seven year old children. Colour vision impairment was assessed with the Ishihara pseudoisochromatic test and colour deficiency was defined as missing six or more plates. The results presented were restricted to 1,134 boys. The study was cross-sectional (Grade III evidence) in design.

Red/green colour deficiency was observed in 2.6% of participants with a further 0.5% making between one and five errors on the plates.

Limitations of the study included:

- The participation rate for colour testing was not stated although 99% of the eligible population participated in the other eye tests (this population included all the female population in the study group).
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- The study was limited to all eligible pupils in one school district in Los Angeles, providing a possible selection bias.

- The overall study population included 58% Hispanics and 17% Asians which may have been responsible for the comparatively low rate of disorder in this population.
- The generalisability to the New Zealand population is limited.

Buckalew et al., 1989

The prevalence of colour vision impairment was assessed in 112 volunteers in the United States. The participants ranged in age between 20 and 69 years (mean age = 40 years). An unnamed pseudoisochromatic test was used in the evaluation. The study was cross-sectional (Grade III evidence) in design.

Of the 112 persons tested, 8% of men and 3% of women were colour deficient.

Limitations of the study included:

- Using volunteers potentially biases the sample. Those who had impaired colour vision might have been more likely to participate resulting in a higher prevalence in the study population than that in the population from which the participants were drawn.
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- Using an unnamed pseudoisochromatic test does not allow an estimation of the likely accuracy of the test, resulting in the possibility of misclassification errors. The direction of effect of any such errors is unclear.
- Participants were paid, which also provides a potential selection bias.
- Given these limitations the generalisability of the study requires considerable caution.

Osuobeni, 1996

The prevalence of colour deficiency was also studied in Saudi Arabian boys aged 11 to 18 years (mean age not stated). There were 410 participants. The Ishihara pseudoisochromatic test and Farnsworth's Dichotomous Panel D15 were used to evaluate colour impairment. More than five typical red-green errors on Ishihara or two or more crossings in the same direction on Farnsworth were deemed as failures. The study was cross-sectional (Grade III evidence) in design.

The prevalence of disorder was found to be 2.92%.

Limitations included:

- The participation rate was not stated
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- The method of participant selection was not stated.

- The generalisability should be considered limited given the location of the study.

Rawlinson, 1993

The prevalence of impaired colour vision was evaluated in a population of dental undergraduates (age range and mean age not stated). A cross-sectional study (Grade III evidence) with 235 participants was used.

There were 2.1% with impaired red green colour vision and 0.9% with impaired blue yellow colour vision.

Limitations included:

- The participation rate was not stated.
- The study used the City University Colour Vision Test (CUCVT) and red green impairment might have been more accurately diagnosed with anomaloscopy since this test had a sensitivity of 67% in another study (Birch, 1997b).
- The study was conducted in England so has unclear generalisability.

Perez-Carpinell et al., 1994

The prevalence of impaired colour vision in subjects with trisomy 21 has been assessed. There were 72 participants aged between seven and 22 years (mean age not stated). Testing was done with Ishihara's plates and with anomaloscopy. The study was cross-sectional (Grade III evidence) in design.

There was evidence of impaired colour vision in at least one eye in 23% of participants. However, of those able to be assessed by anomaloscopy, 12.5% had impaired binocular colour vision.

Limitations of the study included:

- 67% of participants were able to understand anomaloscopy and 79% could interpret Ishihara's plates.
- It was not possible to calculate the prevalence of impaired colour vision by gender.
- The participants were selected from one school and it was not clear whether they were representative of the population with trisomy 21.
- The study was set in Spain so has unclear generalisability to New Zealand.

Morton, 1975

The results of colour vision screening pre-induction to the armed forces (age range 17-26 years, mean age 21 years) were reported for the period 1939 to 1941 in Oregon and Colorado (Morton, 1975). Results were abstracted from the personal files (Grade III evidence). The majority of colour vision tests were performed with the AO-HRR test but occasionally Ishihara or Dvorine tests were used. The sensitivity of AO-HRR was 79% and specificity was 85% in a study conducted elsewhere (Hill et al., 1982).

Of the 1226 male participants, 4.2% were diagnosed with impaired colour vision.

Limitations of the study included:

- There was a possible selection bias since the armed forces rejected those with severe colour vision deficiencies. Therefore, those with known colour vision impairment were less likely to apply resulting in an underestimation of the true prevalence for the population.
- Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
- The retrieval rate of personal files was not stated.
- There was no account of possible misclassification through either the colour vision tests used or through coding errors.
- The study was conducted in the United States so the generalisability was unclear.

Littlewood and Hyde, 1993

The prevalence of impaired colour vision was assessed as part of a controlled trial without randomisation (Grade II-1 evidence) evaluating the validity of screening tests. There were 414 participants aged less than 90 years (mean age not stated). Those who failed Ishihara's test and anomaloscopy were considered to have impaired colour vision. The participation rate was 97%.

Ten percent of males and 0.5% of females were diagnosed with colour vision deficiencies.

Limitations of the study included:

- Only those who failed Ishihara's test had the diagnosis confirmed with anomaloscopy.
- Participants were selected through consecutive attendance at an ophthalmology practice which might have resulted in a selection bias.
- The generalisability to New Zealand was unclear.

Mann and Turner, 1956

A cross-sectional study design (Grade III evidence) was used to examine the prevalence of impaired colour vision in Australia. There were 503 males and 307 females tested with Ishihara's test (age range and mean age not stated).

Overall, 7.4% of males and 0.7% of females had impaired colour vision.

Limitations of this study were:

- The study was conducted in two specific geographical regions of Australia associated with goldfields and other industry. This might have resulted in a selection bias.
- The participation rate was not stated.
- The results were not confirmed with anomaloscopy so misclassification of some participants was likely.
- The generalisability was unclear.

Geddes, 1946

The prevalence of impaired colour vision was described in a group of Fijians, Fijian Indians and New Zealanders in a cross-sectional study (Grade III evidence). Ishihara's test was used.

There were 608 Fijian males between six and 35 years of age (mean age not stated), 148 Fijian Indian males between six and 14 years (mean age not stated) and 2000 New Zealand males (age not stated).

Overall, 0.8% of the Fijians, 8.1% of the Fijian Indians and 6% of the New Zealanders had impaired colour vision.

Limitations of the study included:

- The participation rates were not stated.
- Selected groups (army and selected schools) were used for the Fijian arm of the study providing a potential selection bias. For the New Zealand study, visitors to a Centennial Exhibition were recruited.
- Anomaloscopy was not used for confirmation providing a potential misclassification bias.

Grieve, 1946

The results of colour vision testing on 16,180 candidates (age range 18-30, mean age not stated) for aircrew in the Royal Air Force (RAF) were presented in a descriptive study (Grade III evidence). Ishihara's test was used for screening purposes and the results of this test are used in this report.

There were 1068 participants (6.63%) with impaired colour vision.

Limitations of the study included:

- Those with impaired colour vision were less likely to reply given the restrictions on acceptance for that group. Therefore, this rate is likely to be the lower limit of normal.
- There was a possible misclassification bias since the results were not based on anomaloscopy.
- The generalisability was unclear.

Grosvenor, 1970

The prevalence of impaired colour vision in New Zealand Maori and New Zealand Europeans has been reported. A cross-sectional study design was used (Grade III evidence) and participants were enrolled from schools (age range and mean age not stated). Ishihara's test was used to examine colour vision.

There were 817 European boys, 53 of whom failed the test (6.5%). There were 395 Maori males with nine failures (2.3%). These results were not subjected to statistical analysis in a manner that would be considered acceptable today. Therefore, the χ^2 test was used by the author of this report to compare these results. There was a statistically significant difference in the rate of impaired colour vision between the Maori and European groups (p=0.003).

Limitations of the study included:

- There was possible selection bias resulting from the non-random selection of participating schools.
- There was possible misclassification bias since anomaloscopy was not used.
- The definition for Maori was taken from the school records and required "an individual with one half or more blood" rather than self-identification.
- Sample sizes for other ethnic groups were too small to estimate prevalence data.
- The participation rate was not stated.

Koliopoulos et al., 1976

A study of the prevalence of colour vision deficiencies in 29,985 Greeks aged between 13 and 17 years (mean age not stated) was conducted. A cross-sectional design was used (Grade III evidence). Colour vision deficiencies were detected using Ishihara's test.

There were 21,231 males, 7.95% of whom had impaired colour vision. Only 0.42% of the 8754 female participants had impaired colour vision.

Limitations of the study included:

- The participation rate was not stated.
- Methods of selection were not stated.
- Anomaloscopy (the gold standard diagnostic test) was used to confirm the diagnosis in those who failed the screening test. Those who passed the screening test were not confirmed.
- The generalisability was unclear.

Post, 1962

A non-systematic review (Grade III evidence) of the prevalence of impaired colour vision included a

category titled "white groups, immigrants overseas" and included studies based in Australia, Brazil and the United States. The studies were conducted between 1922 and 1957 and the results were for males with red-green colour deficiency.

There were 3827 participants and 7.6% had impaired colour vision.

Limitations of this review included:

- A lack of details concerning the testing methods used in the different studies.
- The methods of participant or study selection were not stated.
- No participation rate was stated.
- Uncertain generalisability.

Kherumian et al., 1956

The prevalence of impaired colour vision was assessed in 5651 students (age range and mean age not stated) of the University of Paris. The American Optical Company test (a pseudoisochromatic test) was used for screening and was confirmed with a range of other pseudoisochromatic tests. The study was cross-sectional (Grade III evidence) in design.

Of the 2721 men, 9.33% were considered to have impaired colour vision. After exclusion of various acquired defects, 0.51% of women were identified with impaired colour vision.

Limitations of this study included:

- A screening test was used rather than anomaloscopy in the diagnosis.
- University students could represent a biased group of the population.
- Different methods were used between male and female participants (relating to exclusion of acquired defects in women).
- The study has uncertain generalisability.

Miles, 1943

A study conducted in the New York Museum of Science and Industry evaluated the rate of colour vision impairment in visitors (age range and mean age not stated) using a cross-sectional design (Grade III evidence). The Ishihara pseudoisochromatic test was used.

Of the 7966 men, 7.1% had impaired colour vision and 1.3% of the 3010 women had impaired colour vision. The author of this study also presented the results of colour vision testing in 5716 men attending Yale. There were 7.2% with impaired colour vision in this group.

Limitations of this study included:

- Using volunteers in the museum study provides a potential selection bias. The method of selecting participants from Yale was not stated.
- The participation rate was unknown.
- Anomaloscopy was not used in the diagnosis of impaired colour vision.
- The generalisability of these results was unclear.

Table 2.   Summary of studies examining the prevalence of colour vision impairment

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Modarres et al., 1996) Iran	Cross-sectional Grade=III	Ishihara	12-14	2058	Prevalence (colour vision impairment): Males=8.18% Females=0.43% OR[1] 20.46 (95%CI 7.7, 76.9)[2]	• Participation rate not stated. • Participants were not selected randomly. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
(Al-Amood et al., 1981) Iraq	Cross-sectional Grade=III	Ishihara	Not stated	2066	Prevalence (colour vision impairment): Males=8.19% Females=3.2% $\chi^2 = 20.74$, $p < 0.0001$	• Participation rate not stated. • Participants were not selected randomly. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
(Kim et al., 1989) Korea	Cross-sectional Grade=III	AO-HRR[3]	14-15	9438	Prevalence (colour vision impairment): Males=5.9% Females=0.44% $\chi^2 = 228.8$, $p < 0.0001$	• Participation rate not stated. • Participants were not selected randomly. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
(Macfarlane et al., 1987) Australia	Cross-sectional Grade=III	Ishihara	6-11	1007	Prevalence (colour vision impairment): 3.7%	• Participation rate 87%. • Non-random participant selection. • Male and female rates not differentiated. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.

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[1] OR = Odds ratio (male to female comparison)

[2] 95%CI calculated using Fishers exact test

[3] AO-HRR=Hardy-Rand-Rittler pseudoisochromatic test

Table 2. **Summary of studies examining the prevalence of colour vision impairment** (*continued*)

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Feig and Ropers, 1978) Germany	Cross-sectional Grade = III	Ishihara	10-19	5565	Prevalence (colour vision impairment): 7.8 % (all males)	• Participation rate not stated. • Selection process was unclear. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
(Choi et al., 1995) United States	Cross-sectional Grade = III	Ishihara	6-7	1134	Prevalence (colour vision impairment): 2.6 % (all males)	• Participation rate approximated 99 %. • High Hispanic and Asian population. • Study limited to one school district. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
(Buckalew et al., 1989) United States	Cross-sectional Grade = III	Pseudoisochromatic test	20-69	112	Prevalence (colour vision impairment): Males = 8% Females = 3% OR 2.16 (95%CI 0.3, 24.6)[2]	• Participants were volunteers. • Precise colour test was not identified. • Participants were paid. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy.
(Osuobeni, 1996) Saudi Arabia	Cross-sectional Grade = III	Ishihara	11-18	410	Prevalence (colour vision impairment): 2.9 % (all males)	• Participation rate was not stated. • Impaired colour vision was not confirmed with a diagnostic test such as anomaloscopy. • Selection process was unclear.
(Rawlinson, 1993) England	Crosss sectional Grade = III	City University Colour Vision test	Not stated	235	Prevalence (impaired red-green vision): 2.1% Prevalence (blue-yellow axis): 0.9%	• Participation rate not stated. • Anomaloscopy not used.

Table 2. **Summary of studies examining the prevalence of colour vision impairment** *(continued)*

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Perez-Carpinell et al., 1994) Spain	Cross-sectional Grade=III	Ishihara Anomaloscopy	7-22	72	Prevalence (by anomaloscopy): 12.5%	• Participants with trisomy 21. • Participation rate 67%. • Uncertain whether participants were representative of the trisomy 21 population.
(Morton, 1975) United States	Descriptive Grade=III	AO-HRR Ishihara Dvorine	Mean=21	1226	Prevalence (all males): 4.2%	• Possible selection bias since the study was conducted in US armed forces. • Possible misclassification through coding and test results.
(Littlewood and Hyde, 1993) Australia	Cross-sectional Grade =III	Ohkuma, Ishihara, Anomalo-scopy	Approx 5-85	414	Prevalence: Males 10% Females 0.5% OR 12.0 (95%CI 2.9, 106.6)^2	• Participation rate 97%. • Anomaloscopy only used for confirmation of screen positive participants.
(Mann and Turner, 1956) Australia	Cross-sectional Grade=III	Ishihara	Not stated	503 males, 307 females	Prevalence: Males 7.4% Females 0.7% OR 12.1 (95%CI 3.1, 104.3)^2	• Potential selection bias. • Participation rate not stated. • Potential misclassification.
(Geddes, 1946) Fiji and New Zealand	Cross-sectional Grade=III	Ishihara	6-35 in Fiji, Not stated in NZ	608 Fijian males, 148 Fijian Indian males, 2000 NZ males	Prevalence: Fijians 0.8% Fijian Indians 8.1% New Zealanders 6% $\chi^2 = 29.7, p<0.0001$	• Potential selection bias. • Anomaloscopy was not used. • Participation rate not stated.
(Grieve, 1946) England	Cross-sectional Grade=III	Ishihara	18-30	16, 180 males	Prevalence: 6.63%	• Possible selection bias (RAF[4] candidates). • Anomaloscopy was not used.

[4] RAF = Royal Air Force

Table 2.   Summary of studies examining the prevalence of colour vision impairment *(continued)*

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Grosvenor, 1970) New Zealand	Cross-sectional Grade=III	Ishihara	School children	817 European males, 395 Maori males	Prevalence: Europeans 6.5% Maori 2.3% (significant difference, p=0.003)	• Possible selection bias resulting from the non-random selection of participating schools. • Anomaloscopy not used. • Maori definition relied on proportion of "Maori blood". • Small numbers in other ethnic groups.
(Koliopoulos et al., 1976) Greece	Cross-sectional Grade=III	Ishihara. Failures confirmed by anomaloscopy	13-17	21,231 males, 8,754 females	Prevalence: Males 7.95% Females 0.42% $\chi^2 = 646.5$, p<0.0001	• Selection methods were not stated. • Participation rate was not stated. • Anomaloscopy confirmed screening failures.
(Post, 1962) Australia, Brazil, USA	Non-systematic review Grade=III	Not stated	Not stated	3827	7.6%	• No selection details. • No participation rate. • Unclear testing methods.
(Kherumian et al., 1956) France	Cross-sectional Grade=III	American Optical Company test	University students	5651	Prevalence: Males 9.33% Females 0.51% $\chi^2 = 240.3$, p<0.0001	• University students only (possible selection bias. • Anomaloscopy not used. • Different methods for males and females.
(Miles, 1943) United States	Cross-sectional Grade III	Ishihara	Not stated	7,966 male museum visitors, 3,010 female museum visitors, 5,716 Yale men	Prevalence: Male (museum) 7.1% Female (museum) 1.3% Male (Yale) 7.2% $\chi^2 = 140.5$, p<0.0001[5]	• Museum participants were volunteers. • Unclear selection methods for the Yale group. • Anomaloscopy not used. • Unknown participation rate.

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[5] χ^2 for male versus female museum visitors comparison

WERE THERE OTHER STUDIES INVESTIGATING THE PREVALENCE OF IMPAIRED COLOUR VISION?

A review article (Grade III evidence) provided data on the prevalence of impaired colour vision from five original studies (Pokorny et al., 1979). Only one of these studies could be retrieved so four could not be critically appraised. These four articles are summarised in **Table 3.** The author of this report determined the χ^2 values presented in this table.

Table 3. **Prevalence of impaired colour vision in studies that were not available for critical appraisal.**

Reference	Sample size	Results
(Waaler, 1927) Norway	18121	Prevalence: Male 8.01% Female 0.40% $\chi^2 = 651.1$, p < 0.0001
(von Planta, 1928) Switzerland	5000	Prevalence: Male 7.95% Female 0.43% $\chi^2 = 201.9$, p < 0.0001
(Schmidt, 1936) Germany	12467	Prevalence: Male 7.75% Female 0.36% $\chi^2 = 396.9$, p < 0.0001
(Francois et al., 1957) Belgium	1243 (Males)	Prevalence: Male 8.30%

WHAT PROPORTION OF PEOPLE ARE UNAWARE THEY ARE COLOUR VISION IMPAIRED?

Four studies were identified that evaluated the rate of people unaware they had a colour vision impairment. These studies are summarised on **Table 4 (p. 17)**.

An Australian based study investigating the effect colour vision impairment had on everyday tasks found 71% of dichromats and 36% of anomalous trichromats were aware of their colour vision impairment by the time of leaving secondary school (Steward and Cole, 1989). If it is assumed that there are three times as many anomalous trichromats as dichromats (Koliopoulos et al., 1976) this would suggest 55% of the colour-impaired population were unaware of the problem. A potential limitation of this result is the possibility of recall bias given the study population was aged between 11 and 65 years. Details of this study are presented on **p. 19**.

In a study evaluating the sensitivity and specificity of slides in colour vision testing, three of 11 (27%) colour vision impaired university students (age range and mean age not stated) were previously unaware of their impairment (Ganley and Lian, 1997). This study was limited by using pseudoisochromatic tests only. More reliable results might have been obtained with anomaloscopy. More details about this study are provided on **p. 31**.

In a study evaluating various types of tests for pre-employment screening, 41 of 100 participants that failed the Ishihara pseudoisochromatic test were previously unaware of any problems with colour vision (McElearney et al., 1992). More details are provided about this study on **p. 22**.

A study investigating vision screening in eight and ten-year-olds identified 29 children with impaired colour vision (Cummings, 1996). In two of these cases (5.2%) the impaired colour vision had not previously been documented. More details are provided about this study on **p. 43.** It was not clear what proportion of children or parents were previously aware of the impairment.

Table 4. **Summary of studies evaluating the rate of people unaware they are colour vision impaired**

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Steward and Cole, 1989) Australia	Cross-sectional Grade=III	Ishihara Farnsworth F2	11-65	102	29% of dichromats and 64% of anomalous trichromats were unaware of a colour vision defect at the time they left secondary school	• Potential recall bias. • Participation rate 100%. • Confirmatory testing not done.
(Ganley and Lian, 1997) United States	Cross-sectional Grade=III	Ishihara AO-HRR	19-56	111	27% were unaware of their colour vision impairment	• Confirmatory testing not done. • Participation rate not stated.
(McElearney et al., 1992) England	Cross-sectional Grade=III	Ishihara	Not stated	100	41% were unaware of their colour vision impairment	• Confirmatory testing not done. • Participation rate was unclear. • All males. • Pre-employment testing.
(Cummings, 1996) England	Cross-sectional Grade=III	Ishihara	8 and 10	29	5.2% had abnormal colour vision that was not previously documented	• Small sample size. • Confirmatory testing not done.

SUMMARY

There was little data on the prevalence of impaired colour vision in New Zealand. The literature retrieved was problematic in terms of the populations surveyed. Generalisability to New Zealand is always a difficult issue in studies conducted elsewhere. Therefore, given the range of countries from which prevalence data has been published, it was not possible to have any degree of confidence in estimating the prevalence in New Zealand. Other studies that evaluated the prevalence in particular populations (Rawlinson, 1993; Perez-Carpinell et al., 1994, Morton, 1975) were problematic given their potential selection biases.

Generally the studies reported prevalence based on screening tests rather than diagnostic tests, few of the studies documented a participation rate and the participants were not randomly selected. Different studies used different pass/fail criteria for the same screening test.

Bearing these issues in mind, the prevalence figures should be treated with considerable caution.

A summary figure for the prevalence of impaired colour vision was derived by aggregating (weighting by sample size) all the data except those where the results were not differentiated by gender (Macfarlane et al., 1987) and the study investigating prevalence in trisomy 21 (Perez-Carpinell et al., 1994). The four studies that could not be critically appraised were included. By doing this a prevalence of 7.3% was identified in males.

This data is helpful in terms of:

- Identifying the magnitude of the problem.
- Estimating other data such as positive and negative predictive values in conjunction with particular colour vision screening tests.

However, it was also important to estimate how many unidentified cases of impaired colour vision were detected through screening. There were three studies evaluating this question and in each case a significant proportion of participants were previously unaware of their impaired colour vision. However, this data was not derived from a New Zealand population. The results of these studies are likely to be highly dependent on whether the participants were screened prior to conduct of the study. The ideal situation would be to conduct this study in a country with no screening programme so the impact of removing a programme could be estimated.

In the three studies evaluating the proportion unaware of their colour vision impairment a weighted mean (by sample size) of 40% were unaware of the deficit.

It is therefore concluded that bearing in mind the limitations previously described:

Of the approximately 7% of the male population with congenitally impaired colour vision approximately 40% of that population appears to be unaware of the defect prior to leaving secondary school.

Disability

INTRODUCTION

Generally, screening programmes are introduced for conditions with a significant public health impact. A significant public health impact requires consideration of the prevalence (see previous section), morbidity and mortality resulting from the condition. Other disabilities resulting from the condition should also be considered when evaluating a screening programme. The question of whether colour vision screening might detect other diseases before they would otherwise be detected was also considered since earlier treatment of such conditions might have resulted in improved health status.

In considering colour vision screening, most of the impact concerns the disability category. Impaired colour vision has implications concerning the performance of household activities, educational activities and occupational activities. Consideration should also be given to morbidity and mortality through the indirect mechanism of road traffic crashes that occurred as a result of the impaired colour vision. Impaired colour vision might also have implications concerning social and emotional development (Evans, 1992).

WHAT EFFECT DOES IMPAIRED COLOUR VISION HAVE ON DAILY HOUSEHOLD ACTIVITIES?

One study was identified that evaluated the effect colour vision impairment had on daily household living. That study is summarised in **Table 5 (p. 21)**.

Steward and Cole, 1989

This study enrolled 102 patients who were colour vision impaired (tested using the Ishihara test and the Farnsworth F2 plate). The participants were aged between 11 and 65 years (mean age not stated) and had consecutively presented to an optometrist. The study had a 100% response rate.

Dichromats reported significantly more difficulty with everyday tasks (such as selection of coloured goods, household tasks, plant and flower recognition, and with the selection of ripe fruits and vegetables) than anomalous trichromats. The results were similar with driving difficulties. Forty nine percent of dichromats reported "ever experiencing difficulty distinguishing the colour of traffic lights." Other common complaints were confusion between traffic lights and streetlights as well as difficulty seeing brake lights on other cars.

Colour vision impairment influenced career choices in 43% of dichromats and 29% of anomalous trichromats. Having colour difficulties with everday work was a common complaint (46% of dichromats and 15% of anomalous trichromats).

Limitations of the study included:

- This study was uncontrolled.
- Comparison with a group with normal colour vision would have been desirable. However, it provided estimates of the prevalence of impairment in performing functional living tasks, although we do not know how this compares to the normal colour vision population.
- The study was set in Australia so generalisability to New Zealand was unclear.

WHAT EFFECT DOES IMPAIRED COLOUR VISION HAVE ON EDUCATION?

Two cohort studies and one review was identified that examined the relationship between impaired colour vision and education. These studies are summarised in **Table 5 (p. 21)**.

Lampe, 1973

A cohort study (Grade II-2 evidence) compared educational outcome in colour deficient schoolchildren with schoolchildren who were not colour vision impaired. There were 161 randomly selected children with normal colour vision (age range five to seven years) and 80 colour vision impaired children (age range five to seven years). Both groups were identified at kindergarten and first grade level and outcome was assessed with the Stanford Achievement test a year later.

There was no significant difference in outcome between the two groups for either year.

Limitations of the study included:

- There was no baseline data to compare the two groups.
- Anomaloscopy was not used to assign colour vision status. The prevalence of impaired colour vision in boys was low at 3.5% indicating a possible misclassification error. If impaired colour vision was underdiagnosed, any difference in outcome might have been diluted.

- The outcome data was measured a relatively short time after school entry so systematic differences in outcome might not have developed.
- The generalisability of the study is doubtful since this study was conducted in the United States during 1967 to 1969.

Mandola, 1969

Twenty colour deficient boys at primary school were compared with 20 randomly selected boys of the same age range (seven to 12 years, mean age not stated) with normal colour vision. There were no significant differences in outcome (based on Stanford Achievement tests, intelligence test scores and teachers' marks for writing).

Limitations of the study included:

- no baseline data
- small sample size
- imprecise outcome measures
- imprecise measure of colour deficiency
- uncertain generalisability.

Voke, 1978b

In an early non-systematic review (Grade III evidence) of defective colour vision and education, there was no evidence describing an association between poor educational achievement and colour vision impairment. In a study of career choice in 355 colour-impaired children between 10 and 18 years of age, 62% had chosen careers that were deemed inappropriate for their impairment. It was noted that Ishihara's test is particularly sensitive but is not useful in differentiating between mild and severe impairment (which has more practical, long-term implications than the mere presence of colour vision impairment).

Table 5.   Disability associated with colour vision impairment

Reference	Study design and evidence grading	Setting	Age (years)	Sample size	Results	Comments
(Steward and Cole, 1989) Australia	Cross-sectional Grade=III	Patients presenting to an optometrist	11-65	102	Dichromats more likely to report confusion with everyday tasks, driving and influencing career choices than anomalous trichromats.	• Comparison with a group with normal colour vision might have been useful. • Participation rate 100%.
(Lampe, 1973) United States	Cohort Grade=II-2	School	5-7	241	No significant difference in Stanford achievement tests in impaired versus normal colour vision	• No baseline data. • Anomaloscopy not used. • Outcome data measured a relatively short time after school entry.
(Mandola, 1969) United States	Cohort Grade=II-2	School	Primary School	40	No significant difference in Stanford achievement tests in impaired versus normal colour vision	• No baseline data. • Anomaloscopy not used. • Outcome data measured a relatively short time after school entry. • Small sample size.
(Voke, 1978b) England	Non-systematic review Grade=III	Colour impaired children	10-18	355	62% had chosen careers deemed inappropriate for their colour vision impairment	• Inappropriate careers were not listed. • Participation rate not stated.

WHAT EFFECT DOES IMPAIRED COLOUR VISION HAVE ON OCCUPATIONAL PERFORMANCE?

The studies that evaluated the role colour vision impairment had on occupational performance are summarised in **Table 6 (p. 24).**

While the Ishihara pseudoisochromatic test (and other similar screening tests) are useful for identifying colour vision impairment, the degree of impairment is critical when considering occupational factors. The pseudoisochromatic tests are not suitable for this task and it has been suggested that there is no ideal test for occupational purposes (Voke, 1978a). This was documented in a non-systematic review (Grade III evidence) so should be treated with caution.

Mertens and Milburn, 1996

This study assessed the need for normal colour vision in air traffic control tasks. There were 121 participants with normal colour vision and 123 with impaired colour vision as diagnosed by Nagel anomaloscopy.

Four air traffic control tasks were used to assess suitability for performance of that role. These tasks had been previously validated as representing tasks that occur in the performance of air traffic control duties. Overall, 6.6% of normal trichromats failed the tests compared with 95.1% of those with impaired colour vision. This was a significant difference (p<0.0001). The probability of error increased with the severity of deficiency.

Limitations included:

- There was a lack of statistical comparison between those with normal colour vision and those with impaired colour vision by the authors of the study but χ^2 testing by the author of this report confirmed the significance of the difference between the two groups.
- It was unclear from the study how participants were selected.
- The study was conducted in the United States so its generalisability was unclear, although given the nature of the test was probably not too good.

Kuyk et al., 1986

Similar results were found in another study of air traffic control (Kuyk et al., 1986). The 110 participants were given a battery of colour vision tests (Dvorine, Ishihara, F-M 100 Hue and Panel D-15)

to determine and classify impaired colour vision. Nine participants were classified as protans and 22 as deutans. Four tests that simulated daily air traffic control tasks were used to assess the validity of clinical testing.

The ability of all severe protans (seven participants) was significantly reduced on all tests compared with those with normal colour vision (p<0.001).

Limitations of the study included:

- There was insufficient power to assess the presence of a dose response curve.
- The participation rate was not stated and the method of selecting participants was unclear.
- This study was conducted in the United States so has unclear generalisability.

Kuyk et al., 1987

The results for the deutans (Kuyk et al., 1987) were presented separately from the protans (Kuyk et al., 1986). Mild deutans were able to perform the four tasks with the same ability as the normal vision participants but moderate deutans were rated at 79% of normal performance and severe deutans at 62% of normal. Overall, the Farnsworth D-15 relative error score was the best predictor of deutan performance, explaining 60% of the variance. When combined with the Dvorine test 72% of the variance was explained.

This study had the same limitations as the previous one.

McElearney et al., 1992

A descriptive study (Grade III evidence) evaluated the Ishihara test, the Electrical Supply Industry test (ESI) and the Giles Archer Lantern test in pre-employment screening for colour vision impairment for aircraft mechanical occupations. There were 1020 male participants.

One hundred participants failed the Ishihara test but 61 of these passed both the ESI and lantern tests and a further 23 passed one of these tests. No one who failed the ESI or lantern tests passed the Ishihara test. In this study, 83% of the candidates who failed some part of the screening battery were placed successfully.

Limitations of the study included:

- There was a lack of ability to determine the appropriateness of the placements.
- It appeared as though the participation rate was 100% (since colour vision screening was part

of the pre-employment battery) although this was not categorically stated.

- The study was set in England so its generalisability to New Zealand is unclear.

Vingrys and Cole, 1988

A review of colour vision examining the need for standards in the transport industry was conducted in Australia. In the laboratory setting five trials were identified that found colour defective observers made significantly more errors in recognition of coloured signal lights and they had significantly slower reaction times.

Six studies were identified that compared motor vehicle crash statistics between those with normal colour vision and those with impaired colour vision. Four of the studies did not find any significant differences between the two groups. One study that identified significantly more crashes in the colour-impaired group was criticised for not detailing the relative gender ratios in the two groups. The other study showed that protans had almost twice as many rear end collisions as a proportion of their total crashes compared with normals ($p<0.05$) and deutans ($p<0.02$) under wet conditions.

It was unfortunate that the methods employed in identifying these studies was not detailed and it would have been useful to calculate the power of the studies with the negative results.

Donderi, 1994

This study assessed the importance of colour vision in search and rescue operations at sea. The Dvorine pseudoisochromatic plates and the F-M 100-hue test were used to evaluate colour vision. Search and rescue performance was evaluated by arbitrarily defining "opportunities" to detect life rafts (dependent on viewing distance and weather conditions). There were 57 participants and 588 watches.

Fewer errors on colour vision testing was correlated with better life raft detection rates in daylight and night searches. On multiple regression analysis (controlling for the weather and visual acuity and using percentage of rafts detected as the dependent variable) the correlation coefficient for colour errors in daylight search was –0.40 ($p<0.002$). That is, those individuals who made fewer colour errors located more life rafts (everything else controlled for) during daylight hours.

Limitations included:

- There was a possible misclassification error in percentage of rafts detected due to the arbitrary nature of defining "opportunities" for sighting.

- There was a possible misclassification error on the colour vision testing due to expected errors on testing that are not related to colour vision.
- Other factors were not considered in the multiple regression analysis, such as duration of watch.
- The study was conducted under exercise conditions.
- The study was conducted in Canada so the generalisability was unclear.

Table 6. Implications of colour vision impairment on occupational choice

Reference	Study design and evidence grading	Setting	Age (years)	Sample size	Results	Comments
(Mertens and Milburn, 1996) United States	Non-randomised controlled trial Grade=II-1	Air traffic control	Mean age=32	244	Failure rate for four air traffic control tasks: Normal trichromats: 6.6% Impaired colour vision: 95.1%	• Unclear selection process. • Participants were not familiar with air traffic control tasks.
(Kuyk et al., 1986) United States	Non-randomised controlled trial Grade=II-1	Air traffic control	Not stated	110 (7 protans)	Reduced ability to perform four air traffic control tasks amongst the protans compared with the normal population (p<0.001)	• Insufficient power to detect a dose response relationship for severity of colour vision impairment. • Participation rate not stated.
(Kuyk et al., 1987) United States	Non-randomised controlled trial Grade=II-1	Air traffic control	Not stated	110 (22 deutans)	Deutans ability to perform four air traffic control tasks compared with the normal population: Mild deutans: 79% of normal Severe deutans: 62% of normal Farnsworth D-15 was the best predictor of performance.	• Insufficient power to detect a dose response relationship for severity of colour vision impairment. • Participation rate not stated.
(McElearney et al., 1992) England	Descriptive study Grade=III	Aircraft mechanical occupations	Not stated	100 failed Ishihara test	83% of the candidates who failed Ishihara were placed successfully. Placement was partially dependent on the results of the ESI[6] test and the Giles Archer Lantern Test.	• The appropriateness of the placements could not be determined from the study. • Participation rate not stated.

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[6] ESI = Electrical Supply Industry test

Table 6.   Implications of colour vision impairment on occupational choice *(continued)*

Reference	Study design and evidence grading	Setting	Age (years)	Sample size	Results	Comments
(Vingrys and Cole, 1988) Australia	Non-systematic review Grade=III	Transport industry	N/A	N/A	Six studies comparing motor vehicle crash rates in colour vision impaired and normal. Two studies found a higher rate of motor vehicle crashes in the colour-impaired group. Protans had almost twice as many rear end motor vehicle crashes as normal (p < 0.05) and deutans (p < 0.02) in wet conditions.	• Method of study selection not discussed. • No power calculations presented in the studies with negative results.
(Donderi, 1994) Canada/ United States	Non-randomised controlled trial Grade=II-1	Sea search and rescue	Not stated	57	More errors on colour vision screening was inversely correlated with better detection rates of life rafts in day and night search exercises (r=-0.40, p < 0.002)	• Possible misclassification errors on percentage of rafts detected due to arbitrary assignment of "opportunity" for sighting and due to errors on vision testing that were not related to colour vision problems. • Duration of watch was not considered in the multiple regression analysis.

WHAT EFFECT DOES IMPAIRED COLOUR VISION HAVE ON MOTOR VEHICLE CRASH RATES?

One review of motor vehicle crash rates was identified in the search (Vingrys and Cole, 1988). This non-systematic review was discussed in the section on occupational issues.

In a study in Germany, 2058 motor vehicle crashes caused by male drivers were investigated for the effect impaired colour vision had on the crash rates (Verriest et al., 1980). A descriptive design was used (Grade III evidence). Motor vehicle crashes were caused by a colour deficient driver in 8.4% of cases. The authors suggested that since this figure approximates the prevalence of impaired colour vision among males there was no evidence for an increased risk among that group.

However, protans had a higher proportion of their crashes resulting from rear end collisions (43% versus 26% in normals, p<0.05). This suggests the type of crash rather than the rate of crashes is different in the colour normal and colour deficient populations.

Limitations of this study included:

- The assumption that the prevalence of colour vision impairment is 8.4% in male drivers in Germany was not backed up by data. Therefore, the reliability of the authors' claim concerning no excess risk in colour-impaired males must be doubted.
- The rate of motor vehicle crashes with data on colour vision status of the driver responsible (the study was retrospective) was not discussed.
- The generalisability was unclear.

WHAT SPECIFIC CONDITIONS ARE ASSOCIATED WITH A DISTURBANCE OF COLOUR VISION?

Prior to establishing whether any conditions are likely to be detected first by colour vision screening it was necessary to identify conditions that result in impaired colour vision.

van Everdingen et al., 1992

A family study of an X linked progressive cone dystrophy suggested colour vision testing could detect the disorder prior to the onset of symptoms. This was on the basis of three family members aged 10, 16 and 20 years who were presumed to have the condition (based on a family tree) and who had abnormal colour vision. The three patients were not diagnosed with other conditions that could explain the colour vision findings and they were part of a family with extensive documentation of X linked progressive cone dystrophy.

It would have been helpful if these patients were followed to monitor development of other characteristic findings. It was also disappointing that the prevalence of this condition was not discussed.

Verrotti et al., 1995

Abnormal colour vision is observed in diabetes prior to the onset of angiographically diagnosed diabetic retinopathy. A cohort study comparing diabetic children (aged 8-13 years) with children with no personal or family history of diabetes found significantly worse colour vision (as measured by total errors on the F-M 100-hue test) at initial entry to the study (p=0.0004) and at seven years follow-up in the diabetes group.

Only two patients developed fluorescein angiographic signs of retinopathy so it was not possible to examine the relationship between colour vision and retinopathy.

Hardy et al., 1992

Hardy et al suggest the colour vision impairment in diabetics may not be associated with vascular disease. This was the conclusion of a cohort study (Grade II-2 evidence) comparing 38 type 1 diabetics with 38 age-matched non-diabetics. The diabetic group (which had no evidence of retinopathy) had significantly more errors on testing with the F-M 100-hue test than the controls (p<0.001). There was no association with duration of diabetes or with biochemical measures of diabetic control (glycated haemoglobin, HbA_{1c}). Since vascular abnormalities are associated with both those factors, it was suggested that impaired colour vision occurs as a result of diabetes *per se* rather than preceding retinopathy.

It should be acknowledged that this evidence is indirect so the authors' conclusion should be treated with caution in the latter study. However, the results of the two previous studies reveal conflicting results and therefore colour vision testing cannot be recommended as a means of early detection of retinopathy on current evidence.

Based on this study it would be unlikely that diabetes would first be detected by colour vision screening. The study had insufficient power to satisfactorily assess its role in the routine evaluation

of diabetics. It was set in Italy so its generalisability to New Zealand was unclear.

SUMMARY

Given that there is no satisfactory treatment for colour vision deficiencies (**See p. 2**) it would be desirable to know whether a knowledge of having impaired colour vision results in fewer educational, occupational and motor vehicle crash problems compared with those who do not know they are colour vision impaired. It is very difficult to answer this question and there was an absence of such studies identified in this report.

Therefore, it was concluded that:

It was not possible to identify the impact colour vision screening has on reducing educational and occupational difficulties or motor vehicle crash rates.

It would also be useful to have an understanding of the same outcome measures in a group with impaired colour vision and a group with normal colour vision. Some literature does exist on this subject. There were six such studies in a review of motor vehicle crash rates. There were no articles identified that compared health status in the two groups.

Of the six studies comparing road traffic crash rates, four found no significant difference between the impaired and normal colour vision groups. This might have been due to a lack of power in these studies. Of the two with a positive result one was criticised for the lack of detail concerning relative gender proportions. The other found rear end collisions in wet weather were responsible for almost double the proportion of crashes in those with impaired colour vision compared with normals. Given these inconsistent results, it was concluded that:

There was insufficient evidence to either agree or disagree with the hypothesis that those with impaired colour vision have more road traffic crashes.

Three sources of data did not find any relationship between impaired colour vision and educational attainment. However, the data was characterised by short follow-up so it was concluded that:

Further research was required to assess the role impaired colour vision has on educational attainment.

Bearing in mind the limitations discussed, the data from occupational studies provided some support for:

Those involved in air traffic control and sea search and rescue operations should have normal colour vision. Research on other occupations which normally restrict those with impaired colour vision was not identified in this report but it should not be assumed that such restrictions are unnecessary.

In considering health status issues it was useful to consider whether colour vision screening might be the first method of detecting other adverse health outcomes. This required a consideration of conditions that result in abnormal colour vision. Such conditions included diabetes, optic atrophy, optic neuritis, cone dystrophies and various medications. Of these conditions only the cone dystrophies appeared to be relevant to this question. Cone dystrophies are extremely rare at pre-adolescent years so it was concluded that:

There was insufficient evidence for the use of colour vision screening as a method of first detection of an adverse health outcome other than impaired colour vision.

Screening tests

INTRODUCTION

A range of colour vision tests exist (Birch, 1993). These tests can be classified into:

- anomaloscopes
- pseudoisochromatic tests
- hue discrimination tests
- lanterns
- others

The anomaloscopes are regarded as the gold standard test for impaired vision on the red-green axis and are therefore used for diagnostic purposes.

The pseudoisochromatic tests are the most common screening tests. Specific types include:

- Ishihara
- American Optical Hardy-Rand-Rittler (AO-HRR)
- Dvorine
- F2
- Ohkuma
- Standard pseudoisochromatic plates 1st and 2nd editions (SPP-1 and SPP-2)

The hue discrimination tests include:

- Farnsworth D15
- Desaturated D15
- Farnsworth-Munsell 100-hue (F-M 100-hue)

These tests are commonly used for classification and grading as well as vocational purposes.

The lantern tests, such as Giles-Archer, are used for vocational purposes.

Other tests include the City University Colour Vision Test (CUCVT). This test provides for the screening of impaired colour vision on the blue-yellow axis as well as the red-green axis so is also useful for acquired defects. It was derived from the Farnsworth D15 test and contains the same Munsell hues with the addition of a neutral grey (Birch, 1997b).

Viewing conditions have different effects on different colour vision tests (Somerfield et al., 1989). In this study 120 participants were randomly assigned to one of 12 viewing conditions (varied by viewing distance and duration). The tests employed were Ishihara pseudoisochromatic test, the Standard Pseudoisochromatic plates for congenital vision defects (SPP-1) and for acquired defects (SPP-2) as well as the CUCVT.

The proportion of errors on the tests significantly increased (p<0.0001) as viewing duration decreased and viewing distance increased. The rate of errors varied with the different tests. The Ishihara test was least susceptible to error under different conditions.

Limitations of the study included:

- A small number of participants with impaired colour vision.
- The colour vision status of each participant was not assessed through anomaloscopy so the possibility of misclassification bias should be considered.

Measures that should be evaluated in the development of a screening programme include a range of items that relate to the validity of the screening test. These include:

- sensitivity
- specificity
- repeatability
- acceptability

The positive predictive value and negative predictive value should also be tested. These two measures are not strictly an assessment of validity since they depend on prevalence as well as sensitivity and specificity, but they are important factors for considering a test as suitable as a population-based screening test.

WHAT IS THE SENSITIVITY AND SPECIFICITY OF CURRENTLY USED SCREENING TESTS FOR COLOUR VISION IMPAIRMENT?

Seven studies were identified that examined the sensitivity and specificity of specific colour vision tests in the same study. These studies are summarised in **Table 8 (p. 32)**.

Pease and Allen, 1988

The Pease-Allen Colour Test (PACT) was evaluated with a view to using it in children aged four to six years.

This evaluation consisted of:

1. Screening with PACT and other colour vision tests in an adult population with 233 adults aged between 20 and 63 years (mean age=28 years). The results were compared with Nagel anomaloscope findings.

2. A group of 47 adults with red-green colour deficiency on the basis of anomaloscope findings.

3. A group of 109 children aged three to six years using the AO HRR test as a gold standard.

In group 1, PACT had a sensitivity of 87% and specificity of 100%. Kappa, the coefficient of agreement, was 0.92 for PACT. The Ishihara test plates had a sensitivity of 96%, specificity of 100% and kappa was 0.98. Agreement was less for F-2, AO-HRR and Panel D-15. In the children 3.6% of boys and 1.9% of girls were identified as colour defective with PACT which compared with 10% on F-2 testing and 38.5% using traditional criteria for AO-HRR.

Limitations of this study were:

- The comparison group was inappropriate for testing the validity of the screening test in the young age group.
- The authors attempted to compare the results of PACT, F-2 and AO-HRR with those expected in the child population but it is unclear if the population selected was representative of the general population. It was interesting that the rate of identification of those with colour impairment in the adult population was higher than would be expected from standard prevalence data.

Lee et al., 1997

The Kojima-Matsubara colour vision test plates were evaluated by comparing with anomaloscopy. The first stage of this evaluation involved 20 colour normal adults and 13 red-green deficient adults aged 22 to 31 years.

Specificity and sensitivity were 90% and 7.7% respectively based on interpretation recommended by the manufacturer. Therefore, this test cannot be recommended.

Mantyjarvi, 1991b

The Velhagen Pflugertrident pseudoisochromatic plates were evaluated by comparing the results with 425 students who were also tested with anomaloscopy. The participants were aged between 16 and 26 years.

The sensitivity of the test was 61.3% and specificity was 100%. Because of the low sensitivity the test was considered inappropriate for screening purposes.

Limitations included:

- There was no direct comparison with other screening tests.
- The participation rate was 85.3%.
- Generalisability was uncertain since the study was conducted in Finland.

Dain et al., 1997

The performance of the Hahn pseudoisochromatic test was compared with other tests including Ishihara's pseudoisochromatic test, Standard pseudoisochromatic plates, Farnsworth-Munsell D-15 plates, Farnsworth Lantern and anomaloscopy.

There were 58 colour vision impaired participants (who had been referred to an optometry colour vision clinic) and 68 participants with normal colour vision. The age range was nine to 59 years (mean age = 27 years).

Three screening tests performed well (compared to anomaloscopy). The Ishihara test had a sensitivity of 98% and specificity of 100%, SPP sensitivity 99% and specificity 98% and Hahn sensitivity and specificity was 100%. The authors were unable to separate the validity of these three tests.

Limitations included:

- The colour-impaired population in this study was not representative of the entire population with impaired colour vision as a result of the case mix attending the study clinic.
- The participation rate was not stated.
- There was evidence (based on results of other studies using other editions) that colour reproduction differed between different editions of the Hahn test potentially resulting in differences in validity between the different tests.
- The generalisability was unclear given the limitations discussed concerning the study population. The study was set in Australia.

Hill et al., 1982

Four colour vision screening tests were evaluated in 439 four to 11-year-old boys. Each participant performed the Ishihara 1966 (pathway), AO-HRR, Guys and Matsubara pseudoisochromatic tests. Their results were compared with anomaloscope findings.

The sensitivity, specificity and negative predictive value are presented in **Table 7 (p. 31)**.

Table 7. Validity of four pseudoisochromatic tests in a group of four to 11 year old boys

Test	Sensitivity	Specificity	Negative predictive value
Ishihara (Pathway)	79%	85%	32%
AO-HRR	79%	85%	32%
Guys	93%	56%	12%
Matsubara	75%	64%	15%

The study had the following limitations:

- There was no breakdown of results by age so it was unclear whether the validity of the test differed between different ages in the study population.
- The method of participant selection was not stated.
- The country in which the study was conducted was not stated although the study authors were from England and Scotland.

Adams et al., 1984

The AO-HRR pseudoisochromatic plates and Farnsworth F-2 tests were compared in children from kindergarten to secondary school age (Adams et al., 1984). There were 2827 participants.

The failure rates were higher than expected at 6.1% for AO-HRR and 9.2% for the F-2 test. However, with the exception of kindergarten and grade 1 all other failures were not significantly different from that expected. In high school, using AO-HRR as a reference test, the F-2 test had a sensitivity of 87.9% and specificity of 99.7%.

Limitations of the study included:

- The comparison group was unclear. In this case comparing with the expected rate of colour impairment is problematic since the participants were not randomly selected introducing the possibility of a selection bias.
- The participation rate was not stated.
- This study was conducted in the United States so the generalisability was unclear.

Ganley and Lian, 1997

The use of projected colour slides was compared with the plate version of two colour vision tests (Ishihara and AO-HRR tests) in 111 university students.

The sensitivity of the Ishihara projected slides (when compared with the Ishihara plates) was 100% and specificity was 98.1%. This contrasted with the AO-HRR slides that had a sensitivity of 100% and a specificity of 20.8% when compared with the AO-HRR plates.

Limitations of the study included:

- The percentage participating in the projected slide session was not recorded.
- 77% of those attending the slide screening attended the plate testing.
- There was a potential order bias since all participants viewed the slides first.
- There were potential limitations on reproduction of the plates in the slides which could be improved with other slide films or speeds.
- Each slide was screened for 15 seconds, whereas it is recommended that each plate should be shown for no more than four seconds and there were probably differences in the angle required to view the contents of the slides.
- There was a lack of comparison with anomaloscopy.
- Generalisability was uncertain.

Table 8.   Summary of studies evaluating the sensitivity and specificity of colour vision screening tests

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Pease and Allen, 1988) United States	Non-randomised controlled trial Grade=II-1	Pease-Allen colour test, Ishihara, AO-HRR, Panel D-15, F-2	20-63	233	PACT[7]: sensitivity-87%, specificity-100% (compared with anomaloscopy). Ishihara test: sensitivity 96%, specificity 100%.	• Invalid comparison group for children aged 3-6 years. • Comparison with expected prevalence in the population is an imprecise method of estimating accuracy of the screening test.
(Lee et al., 1997) United States	Non-randomised controlled trial Grade=II-1	Kojima-Matsubara test plates, anomaloscopy	22-31	33 (20 colour normal)	Specificity (Kojima-Matsubara): 90% Sensitivity: 11%	• This test cannot be recommended.
(Mantyjarvi, 1991b) Finland	Non-randomised controlled trial Grade=II-1	Velhagen Pflugertrident Test Anomaloscopy	16-26	425	Sensitivity: 61.3% Specificity: 100%	• Participation rate 85.3%. • No comparison with other screening tests.

(Dain et al., 1997)
Australia
	Non-randomised controlled trial
	Grade=II-1
		Hahn pseudoisochromatic test,
		Ishihara,
		Standard pseudoisochromatic test,
		Farnsworth-Munsell D-15,
		Farnsworth Lantern,
		Anomaloscopy.
			9-59	126 (58 colour impaired)	Validity (compared with anomaloscopy):
					Hahn – Sensitivity-100%
					    Specificity-100%
					Ishihara-Sensitivity-98%
					    Specificity-100%
					Standard-Sensitivity-99%
					    Specificity-98%
						• Colour impaired population was not representative of the general colour impaired population.
						• Participation rate not stated.
						• Suggestion that colour reproduction in different editions of Hahn changes the validity of this test.

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[7] PACT = Pease Allen Colour Test

Table 8.   **Summary of studies evaluating the sensitivity and specificity of colour vision screening tests** *(continued)*

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Hill et al., 1982) Country not stated	Non-randomised controlled trial Grade=II-1	Ishihara (path-way), AO-HRR, Guys, Matsubara	4-11	439	Validity (compared with anomaloscopy) Ishihara – Sensitivity 79% Specificity 85% AO-HRR - Sensitivity 79% Specificity 85% Guys Sensitivity 93% Specificity 56% Matsubara Sensitivity 75% Specificity 64%	• No breakdown of results by age. • Selection methods not stated. • Participation rate 99.8%. • Uncertain location of study population.
(Adams et al., 1984) United States	Non-randomised controlled trial Grade=II-1	AO-HRR Farnsworth F-2	4-17	2827	F-2 (compared with AO-HRR): Sensitivity 87.9%, specificity 99.7%.	• Comparison test was not an ideal choice. • Participation rate not stated.
(Ganley and Lian, 1997) United States	Non-randomised controlled trial Grade=II-1	Ishihara and AO-HRR plates ver-sus slides	19-56	111	Sensitivity (Ishihara slides v. plates): 100% Specificity (Ishihara slides v. plates): 98.1% Sensitivity (AO-HRR slides v. plates): 100% Specificity (AO-HRR slides v. plates): 20.8%	• Participation rate not stated. • No experimentation with different slide films. • Each slide screened for a prolonged period. • No comparison with anomaloscopy.

WHAT IS THE SENSITIVITY OF CURRENTLY USED COLOUR VISION SCREENING TESTS?

Some studies only provided sufficient information to allow the calculation of sensitivity alone. These are summarised in **Table 10 (p. 36)**.

Birch, 1997c

The Ishihara test plates were compared with anomaloscope findings in 401 male subjects who were red-green colour deficient. The participation rate was 100%.

The sensitivity was determined for the number of errors on the transformation[8] and vanishing[9] designs. These results are presented in **Table 9**.

Table 9. Sensitivity of the transformational and vanishing designs of Ishihara test plates.

Number of errors	Sensitivity
12	88.2%
8	95.5%
6	97.5%
3	99.0%
2	100%

Based on these results and another that investigated specificity (Birch and McKeever, 1993) using six mistakes as the cut off, the specificity would be 95.5% and sensitivity 94%. These figures were derived by a weighted estimate based on the prevalence of specific colour vision deficiencies in the general population.

Limitations of the study included:

- The colour-impaired participants in this study were not representative of the colour-impaired population. This group tended to have more severe colour impairment since they were referred for advice about careers. The author attempted to overcome this limitation by weighting the results.

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[8]Transformation design = different results are obtained for colour normal and colour deficient populations
[9] Vanishing design = viewing number becomes less distinct at the margins

- The study was conducted in England so has uncertain generalisability.

Birch, 1997a

In this study the AO-HRR plates were evaluated by comparison with anomaloscope findings. There were 401 male colour deficient participants and the sensitivity of the test was 98%.

Limitations of this study included:

- Not testing a sample of participants with normal colour vision, therefore the specificity of the test could not be established.
- The participants were not a true cross-section of the colour-impaired population since there was an over-representation of dichromats. This indicates excess severity suggesting the true sensitivity of the test might be lower than these results indicate.
- The participation rate was not stated.
- Generalisability was unclear since this study was performed in a London clinic.

Lanthony, 1994

The validity of the Farnsworth D-15 desaturated panel was assessed. There were 248 participants with congenital colour vision impairment.

Only six participants (2.4%) produced falsely negative results (compared with anomaloscopy) on testing with the D-15 desaturated panel.

The study was limited by:

- The lack of a population with normal colour vision resulting in an inability to evaluate the specificity.
- It was unclear whether the participants were representative of the impaired colour vision population.
- The participation rate was not stated.
- The study was conducted in France so has uncertain generalisability to New Zealand.

Birch, 1989

Farnsworth, in designing the F-M 100-hue test, did not consider it appropriate for screening purposes. The validity of this assumption was assessed by Birch (1989). There were 238 subjects with impaired colour vision (diagnosed by anomaloscopy).

The sensitivity on F-M 100-hue testing was 70% suggesting this test was not suitable for screening purposes.

Limitations of the study included:

- This was a retrospective study so it relied on correct coding. It was likely that any misclassification errors due to incorrect coding would be random so a systematic bias due to this limitation was unlikely.
- The participation rate was not stated.
- Estimation of the validity of the test was incomplete due to the lack of a group with normal colour vision.
- The study was set in England so had unclear generalisability.

Coren and Hakstian, 1995

A colour screening inventory (consisting of 10 questions) was compared with the F-M 100-hue test in 268 volunteers with a mean age of 19.9 years.

A non-linear relationship was found between the two tests with a correlation ratio, eta of 0.69. This suggests the colour-screening inventory explained 48% of the predictive variance in the colour discrimination scores.

Limitations of the study included:

- A younger age group was not tested so the effectiveness of this inventory cannot be assessed in a more appropriate age group (for screening purposes).
- This level of variance explained by the inventory was relatively high but clearly it does not fully explain the results so the two tests are not interchangeable.
- The study did not appear to be blinded which is problematic especially since the developers of the inventory performed the study.
- There was no comparison of the sensitivity and specificity of the two tests with a gold standard measure for impaired colour vision.
- The study was set in Canada so has uncertain generalisability.

Table 10.   Summary of studies investigating the sensitivity of colour vision screening tests

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Birch, 1997c) England	Non-randomised controlled trial Grade=II-1	Ishihara, anoma-loscopy	Mean age=28	401 (male)	Using six mistakes as the cutoff: Specificity: 95.5% Sensitivity: 94%	• Colour impaired in this study were not representative of the general colour-impaired population. • Participation rate 100%.
(Birch, 1997a) England	Non-randomised controlled trial Grade=II-1	AO-HRR Anomaloscopy	Mean age=28	401 (Male, colour impaired)	Sensitivity (AO-HRR) 98%	• No specificity data. • Dichromats over-represented (suggesting excess severity of colour impairment).
(Lanthony, 1994) France	Non-randomised controlled trial Grade=II-1	Panel D-15 de-saturated	Not stated	248	Sensitivity (compared with anomaloscopy): 97.6%	• Impaired colour vision participants only. • Uncertain representativeness of the impaired colour vision population. • Participation rate not stated.
(Birch, 1989) England	Non-randomised controlled trial Grade=II-1	F-M[10] 100-hue	Mean age=27	238	Sensitivity of 70% on F-M 100-hue test	• Possible coding errors. • No colour normal participants. • Participation rate not stated. • Uncertain generalisability.
(Coren and Hakstian, 1995) Canada	Non-randomised controlled trial Grade=II-1	F-M 100-hue test versus colour screening inven-tory	Mean age=19.9	268	48% of the predictive variance in colour discrimi-nation scores explained by the inventory.	• Average age of 19.9 years limits the usefulness of the inventory for screening purposes. • Blinding not stated.

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[10] F-M = Farnsworth-Munsell

WHAT WAS THE REPEATABILITY OF COMMONLY USED COLOUR VISION SCREENING TESTS?

The test-retest reliability of the Ishihara test has been evaluated (Johnson, 1992). A controlled trial design (Grade II-1 evidence) was used to evaluate 102 participants with colour vision impairment aged between 17 and 35 years. The mean error score was 10.1 on test one and 10.07 on test two. This difference was not significant, indicating good retest reliability.

Limitations of the study included:

- Participants with normal colour vision were not included.
- Participants were not randomly selected.
- The study was set in the United States so has uncertain generalisability.

WERE OTHER METHODS OF ASSESSING THE VALIDITY OF COLOUR VISION SCREENING TESTS USED?

The validity of colour screening tests were also assessed by other methods. These results are summarised in **Table 11 (p. 39)**.

Kon and De Alwis, 1996

A new set of pseudoisochromatic plates were designed and tested by a group in Guildford, England. This test was used for both red-green axis disorders and blue-yellow axis disorders. The plates were graded.

In this study, 14 patients with congenital red-green colour blindness (diagnosed by Ishihara pseudoisochromatic plate) were compared with 14 age-matched controls with no colour impairment and 11 patients with optic neuritis were compared with 11 age-matched controls with no colour vision defects.

The results for those with red-green colour blindness were fully discriminating from their aged matched controls, as were those in the optic neuritis section of the study. In the latter, there were significant differences for both vision axes.

Limitations included:

- The sample size was small.
- Comparison with a confirmatory measure such as anomaloscopy was not made.

- There was no comment on blinding of the testers to the participants colour vision status.
- The method of participant selection was unclear.
- The participation rate was not documented.

The results of this study would need to be repeated by an independent group before consideration should be given to the use of this screening test. The addition of an ability to diagnose blue-yellow disorders and to grade the severity are of doubtful significance in a screening test conducted in school-aged children since assessing severity is not the role of a screening test and blue-yellow defects are rare.

Hovis et al., 1996

The SPP-1 and SPP-2 test plates were compared in 386 participants aged between four and 74 years. The participants were volunteers from a vision care clinic at a Canadian University and patients at a private practice in Canada.

There were 24 red-green impaired participants (6%). The level of agreement between the two tests was kappa=0.93 and supplementary testing of the discrepancies suggested the SPP-2 results were correct in two out of the three cases. This result suggested that the SPP-2 test, that had been recommended for acquired defects only, could also be recommended for detection of congenital defects. However, it was interesting that one of the supplementary tests for investigating the discrepant results was Ishihara's test suggesting the authors had more faith in this test for screening congenital colour vision defects.

Limitations included:

- Anomaloscopy was not used in all discrepant cases.
- The introduction of a potential selection bias through the non-random selection of participants.
- The participation rate was not stated.
- Generalisability should be treated with caution since it was set in Canada.

Birch and McKeever, 1993

In this study, newer pseudoisochromatic plates were tested in England. These tests included Ishihara 1989 edition, Ohkuma test cards and the Ishihara test for unlettered persons, 1990.

There were 500 participants (471 with normal colour vision) and most were aged between 18 and 22 years. The Ishihara test for unlettered persons was evaluated on 292 participants (263 with normal vision).

The results were evaluated by comparing the degree of overlap in errors for those with normal and impaired colour vision. The Ishihara test 1989 edition performed best with a gap of two errors between the two groups. In contrast there was an overlap of two errors in the Ohkuma test and one error in the Ishihara test for unlettered persons.

Limitations of the study included:

- It would have been useful if the authors had presented the results in terms of sensitivity and specificity based on the instructions for interpretation given to the user.
- There was no comparison with a gold standard test such as anomaloscopy.
- The participation rate was not stated.
- The use of participants in other age ranges would have been useful to assess generalisability to these other populations.

Table 11. **Summary of studies evaluating the validity of colour vision screening tests with other outcome measures**

Reference	Study design and evidence grading	Colour vision test	Age (years)	Sample size	Results	Comments
(Kon and De Alwis, 1996) England	Non-randomised controlled trial Grade=II-1	Pseudoisochromatic plates (new design)	20-57	50	Tested for disorder on the red-green axis and the blue yellow axis. The results were fully discriminating in all groups (compared with normal controls)	• Small sample. • No anomaloscopy. • Participation rate not stated. • Method of selection not stated.
(Birch and Platts, 1993) England	Non-randomised controlled trial Grade=II-1	Ishihara, Ishihara (unlettered), Velhagen Pflugertrident	3-11	513 (18 with deficient colour vision)	Children with colour deficiency unable to complete tests: Ishihara-11% Ishihara (Unlettered): 6% Velhagen Pflugertrident: 22%. Velhagen Pflugertrident sensitivity: 61%	• Anomaloscopy not used. • Unclear method of participant selection and participation rate.
(Hovis et al., 1996) Canada	Non-randomised controlled trial Grade=II-1	SPP[11]-1 and 2.	4-74	386	Kappa 0.93 between SPP-1 and SPP-2	• Participation rate not stated. • Participants selected by volunteering. • Lack of a consistent confirmatory test used to confirm colour vision status.
(Birch and McKeever, 1993) England	Non-randomised controlled trial Grade=II-1	Ishihara 1989, Ohkuma, Ishihara for unlettered persons 1990	18-22 (most)	500	Ishihara 1989-no overlap in number of errors between those with normal and impaired vision. Overlap of two errors for Ohkuma and one for Ishihara (unlettered).	• Sensitivity and specificity would have been more useful. • Only 29 with impaired colour vision. • Younger age group would have been useful. • No comparison with anomaloscopy.

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[11] SPP = Standard Pseudoisochromatic Plates

HOW DO YOUNG CHILDREN PERFORM ON COLOUR VISION TESTING?

Mantyjarvi, 1991a

The Velhagen Pflugertrident test, Lanthony Tritan Album and the Ishihara test were evaluated in 84 children aged two to six years in Finland. The children were randomly selected from an outpatient department of an eye clinic.

The proportion correctly understanding and interpreting the tests is shown in **Table 12**. There were 20 participants in each age group except the two-year-olds, which only had four participants.

Table 12. **Proportion of children who understood and correctly interpreted different colour vision tests in different age groups.**

Age (years)	Velhagen	Lanthony	Ishihara
6	100%	100%	100%
5	100%	100%	100%
4	80%	100%	90%
3	20%	80%	40%
2	0%	0%	0%

Limitations of the study included:

- The absence of children with colour vision impairment. In a study sample of 84 which was randomly selected this absence was surprising given the prevalence of colour vision impairment.
- The results have unclear generalisability to New Zealand.

Birch and Platts, 1993

Three types of colour vision screening test were evaluated for the detection of impaired colour vision in children aged between three and 11 years of age. There were 495 children with normal colour vision and 18 children with deficient colour vision.

Of the children with colour deficiency, two were unable to complete the Ishihara test, four the Velhagen Pflugertrident test and one could not complete the symbol section of the Ishihara test for unlettered persons while one other could not complete the pathway section of that test. The Velhagen Pflugertrident test had low validity with only 11 of

the 18 children being found to be colour deficient on the other tests being identified with this test.

Limitations of the study included:

- There was no gold standard test with which to compare the results.
- The method of selection of the participants was not stated.
- The study was set in London so has unclear generalisability to New Zealand.

Ekert et al., 1995

A cross-sectional study (Grade III evidence) evaluated the use of the pathway plates in Ishihara's pseudoisochromatic plates for children aged 49 months to 86 months (Ekert et al., 1995). The results of those unable to interpret the plates are shown in **Table 13**.

Table 13. **Proportion of children who were unable to interpret the Ishihara test plates, by age group.**

Age (Years)	Percentage unable to interpret plates (Male)	Percentage unable to interpret plates (Female)
4-5	22.5	9.6
5-6	8.2	3.3
>6	5.4	2.7

Limitations of the study included:

- The colour vision status of the participants was not known, therefore the sensitivity and specificity of the Ishihara test plates cannot be estimated on the basis of this study.
- This study was set in Croatia so has unclear generalisability to New Zealand.

Swanson and Everett, 1992

A colour vision test, the Anomaloscope Plate Test (APT-5), designed for use in children was evaluated in the United States (Swanson and Everett, 1992). There were 1794 children aged three to 13 years in the study. Those failing the test were evaluated with anomaloscopy.

Of the children aged three to four years, 7.2% were classified as untestable, 0.2% of children aged five and six were untestable but all other participants were evaluable. Forty children who failed the screening were tested with anomaloscopy. Fourteen of these were normal by anomaloscopy, suggesting a false positive rate of 35%.

Limitations of the study included:

- It was unfortunate that the sensitivity and specificity of the test could not be calculated given the lack of information on those participants testing negative on screening.
- It would have been useful to compare this test with other tests commonly used for screening such as the Ishihara pseudoisochromatic test.
- Only 37.5% of those failing screening were evaluated by anomaloscopy, providing a potential selection bias.
- The generalisability of the study was unclear.

Marre et al., 1990

The Velhagen Pflugerhaken test was evaluated in a group of four to seven-year-old boys in Germany. It was compared with anomaloscopy. Anomaloscopy was performed in those failing the test who were between 5½ and seven years. It was conducted two years after the screening test.

The false positive rate was 6.5% in this group.

This study was limited by:

- Results were only compared in the older age group. In general, there are more false positive results in colour vision screening in children under the age of five.
- It was not possible to calculate the sensitivity and specificity since anomaloscopy was not performed on those passing the screening test.
- In absolute numbers there were only three false positives so the numbers in this category were small, resulting in a potentially inaccurate measurement.
- The participation rate of those failing the screening test was 90% at follow-up.
- The study was conducted in Germany so has uncertain generalisability.

SUMMARY

There were three studies that measured the sensitivity and specificity of more than one colour vision screening test against anomaloscopy. Ishihara's test was included in all three of those studies. In each case, there was no evidence that Ishihara's test was less valid than any other screening test. One of the three studies surveyed a younger age group (4-11 years) and the sensitivity and specificity for all the screening tests was lower in that study than the other two. The design used in these three studies should produce the most reliable results. Therefore it was concluded that:

There was currently insufficient evidence to recommend a change in the colour vision screening test currently in use within New Zealand (Ishihara's pseudoisochromatic test) on the basis of its validity. Cost-effectiveness information is needed to compare the costs of the various screening tests against sensitivity and specificity criteria.

The sensitivity and specificity of Ishihara's pseudoisochromatic test supported this conclusion. After excluding the study that included a preschool population (since colour vision screening appears to be less reliable in this population) there were three studies that documented the sensitivity and three the specificity of this test type. The sensitivity ranged between 94% and 98% and the mean was 96%. The specificity ranged between 95% and 100% and the mean was 98.5%.

However, it should be recognised that these three studies also had limitations and those limitations (discussed under the particular studies) should be borne in mind when interpreting this conclusion.

Further support for this conclusion was provided by the single study identified that investigated the repeatability of a screening test. Ishihara's test showed good retest reliability in this study.

Consideration was given to the best age at which to perform colour vision screening. Ideally, screening should be performed at a time when it will make a difference to the three potential sequelae of impaired colour vision: educational and occupational difficulties and increased problems with driving. From the educational viewpoint, a test preceding school entrance would be useful. However, the screening tests appeared to have lower validity in these younger age groups. It was unfortunate that there were no results presented directly comparing the performance of Ishihara's test in various age groups. However, it was concluded that:

There was insufficient evidence to recommend a change in the age at which colour vision screening should occur in New Zealand.

Screening programmes

ARE SCREENING PROGRAMMES FOR COLOUR VISION ABNORMALITIES EFFECTIVE?

Ideally screening programmes are evaluated with a randomised-controlled trial. No such studies were identified in this report. The studies that were identified are summarised in **Table 14 (p. 45)**.

Holroyd and Hall, 1997

An appraisal of screening for colour vision impairment was conducted in Sheffield. This programme was conducted in 11-year-old pupils in conjunction with visual acuity testing.

It was observed that colour vision screening does not fulfil all the Wilson and Jungner criteria. No specific treatment is available and facilities for definitive diagnosis and accurate counselling would be inadequate if all screen positive cases were referred for specialist opinion. Both these issues apply in New Zealand.

A cross-sectional study design (Grade III evidence) was used in this study. Questionnaires were completed by boys aged 12 to 16 years, by school nurses and by a random sample of optometrists.

A total of 791 questionnaires were distributed to pupils with 784 being suitable for analysis (99%). Thirty-three (4.2%) boys stated they had impaired colour vision. Only two remembered seeking further advice on the positive test result. Medical records were examined for 557 boys and 5.2% had colour vision impairment recorded in the notes.

The authors postulated that many cases of colour vision impairment were missed since the prevalence was below the accepted figure of 8%. They also commented that there was no clear guidance on further action or referral. Despite this, the boys felt it was useful to know about their colour vision impairment given the potential implications concerning career options.

The study had a range of limitations:

- The ideal study design for assessment of screening programmes is a randomised-controlled trial to minimise the effects of bias. This study does not have a control group so the effectiveness of the screening programme cannot be estimated.
- The study was conducted in six selected schools. These schools were selected on the basis of diverse social backgrounds but it would have been more appropriate to select the schools randomly.
- Comparison of recorded prevalence rates with expected prevalence rates (as used in this study) is inadequate in assessing the effectiveness of a screening programme.
- The study was conducted in England so has uncertain generalisability.

Gordon, 1998

In this review (Grade III evidence) of colour blindness, it was noted that colour vision impairment is not treatable but the purpose of screening was a desire to prevent adverse effects from this condition rather than to treat it.

The influence of colours in education was discussed given the implications this has on the best age for colour vision screening. While it was noted that colours are used particularly in the teaching of young children no evidence was found that those who had impaired colour vision had inferior school achievement. It was therefore suggested that the age recommended by the Joint Working Party of the British Paediatric Association (11-14 years) remains the most appropriate for testing but colour vision testing should be performed in children with learning disabilities.

This study should be treated with caution since it was not a systematic review.

Cummings, 1996

An evaluation of a visual screening programme for eight and 10-year-old males and females in Cambridge was conducted.

There were 1809 children in this descriptive study (Grade III evidence) but only the 560 children with abnormal visual acuity had colour vision results recorded. Colour vision was tested with Ishihara plates.

Twenty-nine (5.2%) had abnormal colour vision but only two of these cases had not previously been documented. The authors noted that the age of 11 years had previously been advised as the most appropriate for colour vision testing but the majority of children (approximately 80%) in this study had a definitive result recorded at the five-year test.

Limitations of this study included:

- This study design was not the most appropriate for evaluating a screening programme.
- The study was uncontrolled.
- A direct comparison between screening programmes for different age groups was not made.
- The study was set in England so its generalisability was uncertain.

Stewart-Brown and Haslum, 1988

A review of vision testing conducted in schools in England and Wales during 1984 was published. The article focussed predominantly on visual acuity but noted that 96% of the 165 responding health districts tested for abnormal colour vision. The response rate was 81%. The authors were surprised that 48% of the districts that tested colour vision did so more than once.

SUMMARY

Screening programmes are best evaluated with a randomised controlled trial design. Unfortunately there were no such studies identified for colour vision screening. There were four relevant studies identified but they evaluated aspects of screening programmes rather than the whole programme. Three studies used a cross-sectional design and the other was a non-systematic review. Therefore, it was concluded that:

It was not possible to evaluate the effectiveness of a colour vision screening programme on the basis of current research. This was identified as an area requiring further research, incorporating a randomised controlled trial as the most appropriate research design for this purpose.

It was noted that economic analyses of colour vision programmes were not identified in the conduct of this report. Therefore, it was concluded that:

The cost-effectiveness of colour vision screening could not be estimated due to the lack of research in this area. This was an area requiring research attention.

Table 14.   Summary of studies that evaluated colour vision screening programmes

Reference	Study design and evidence grading	Setting	Age (years)	Sample size	Results	Comments
(Holroyd and Hall, 1997) England	Cross-sectional Grade=III	11 year old screening	12-16 (at completion of survey)	791	33 boys stated they were colour vision impaired. Two remembered seeking further advice.	• Participation rate 99%. • Medical records available on only 70% of the sample. • Better methods of evaluating a screening programme are available (RCTs are best). • Schools were not selected randomly.
(Gordon, 1998) England	Non-systematic review Grade=III	N/A[12]	N/A	N/A	Colour vision screening was aimed at preventing adverse effects from the impairment rather than treating it. No evidence for inferior school performance in the colour impaired	• Search methodology not stated. • No evaluation of screening programmes.
(Cummings, 1996) England	Cross-sectional Grade=III	School	8 and 10	560	5.2% had abnormal colour vision and 7% of these were previously unrecorded.	• Not an evaluation of a screening programme. • Colour vision test results recorded only in those with impaired visual acuity.
(Stewart-Brown and Haslum, 1988) England and Wales	Cross-sectional Grade=III	School testing	N/A	165 health districts	96% of the 165 health districts tested colour vision in their schools. 48% tested more than once.	• Response rate was 81%. • Not an evaluation of the effectiveness of screening.

[12] N/A = not available

Conclusions

Colour vision screening is currently performed on 11-year-old boys in New Zealand. Impaired colour vision can have implications concerning education, occupation and health. Approximately 7% of boys have a congenital colour vision deficit.

The Health Funding Authority currently funds colour vision screening but, at a time when health resources are scarce, the value of such a programme should be critically appraised. Funding of a colour vision programme has an opportunity cost in terms of other potential health programmes not being funded.

A summary of the evidence is provided in **Table 16 (p. 53)**.

This report has attempted to evaluate the impact of colour vision defects on education, occupation and health but the literature did not allow an evaluation of the critical question: "Does a knowledge of impaired colour vision reduce the impact of that impairment on educational achievement, occupational opportunity and health status in a cost-effective manner?"

It needs to be recognised that colour vision screening is different from other screening programmes currently funded in the health sector. These differences include:

- With the majority of cases of impaired colour vision being congenital, there is not a recognisable latent phase to the condition and the natural history of congenital colour vision defects is one of a constant rather than an evolving defect.
- There is no known cure for impaired colour vision and the only corrective measures are of low effectiveness.

This latter difference is particularly problematic in terms of continuing a colour vision screening programme since Wilson and Jungner's criteria clearly are not fulfilled. However, one should ask whether these criteria are appropriate for a condition that has more significant implications in sectors other than health. Clearly there are differences between colour vision screening and other screening programmes such as cervical screening. Therefore, in terms of the criteria assessing treatment, it would be interesting to assess whether the knowledge of being colour vision deficient results in a better safety record (encompassing road and occupational issues) than would otherwise have been the case.

Screening criteria for non-health related issues were not identified from a search of the literature.

There was also an interesting philosophical question pervading this report which was beyond its scope. That was: "Should a screening programme that has implications beyond the health sector be purchased by the health sector?" If the answer was no, how should this issue be addressed?

Currently colour vision is tested by hearing and vision testers in the school setting. Potential options for the programme include, but are not limited to:

- maintaining the status quo
- stopping the screening programme
- performing colour vision tests in the context of a well-child check in the general practice setting

The third option is likely to result in a decreased cost to the funder. However, this decreased cost would result from a decrease in testing and the greatest decrease in access to testing is likely to occur in families of low socio-economic status. Therefore, this option has difficulties with equity.

This report has been written using an explicit search strategy and appraising the literature retrieved as a result of that search. Problems inherent in the documents retrieved were identified.

A report such as this is reliant on the quality of the studies that are relevant to the topic being researched. In a review of a screening programme an evaluation of selected criteria is required. The basic criteria evaluated in this report were:

- What is the natural history of impaired colour vision?
- What treatment options exist for impaired colour vision?
- The prevalence of impaired colour vision.
- What disabilities result from impaired colour vision?
- Are there any valid screening tests for impaired colour vision?
- Are screening programmes for impaired colour vision effective?

Those with impaired colour vision of congenital origin do not experience any change to their colour vision throughout life. If the impairment is acquired such a change can occur but the proportion of those detected with acquired defects at the 11-year test is low.

Long wavelength pass filters have been proposed for the correction of colour vision abnormalities. The only study identified evaluating this therapeutic modality was descriptive in nature. This study

design is inadequate for the evaluation of effectiveness of a therapy (randomised controlled trials are ideal). However, only 17% of users were interested in purchasing the filters after a one-week trial. Therefore, it was concluded that:

There were no adequate treatment options for the correction of impaired colour vision on current evidence.

The best study design for the evaluation of prevalence is a cross-sectional design. There were 20 studies identified in the search for this question. Eighteen of the studies were cross-sectional in design. It was unfortunate that 17 of the 20 studies relied solely on pseudoisochromatic test results for the diagnosis of impaired colour vision rather than through use of anomaloscopy, which is the gold standard for diagnosis.

In general, the participants were not randomly selected and the participation rate was not stated in the majority of studies. The prevalence in the male population ranged from 0.8% to 9.3. Lower rates were observed in Koreans, Hispanics and Saudi Arabians. The weighted (by sample size mean) prevalence of impaired colour vision in males was 7.3%. The prevalence of impaired colour vision in the female population was much lower with the prevalence ranging between 0.4% and 3.2% in the studies identified.

From the point of view of a screening programme it may be more important to know what proportion of people are not aware of their colour vision impairment. There were three studies identified that evaluated this question. The study design was appropriate in each case. The results were not confirmed by anomaloscopy. In two studies, between 27% and 41% of participants were unaware of their colour vision defect prior to employment. In the other, 29% of dichromats and 64% of anomalous trichromats were unaware of a colour vision defect at the time of leaving secondary school. No such study has been replicated in New Zealand.

It is therefore concluded that, bearing in mind the limitations previously described:

Of the approximately 7% of the male population with congenitally impaired colour vision approximately 40% of that population appears to be unaware of the defect prior to leaving secondary school.

Disability resulting from impaired colour vision or detected by abnormal colour vision test results can be considered under a range of headings:

- impact on household activities

- impact on education
- impact on occupational choice
- impact on motor vehicle crash rates
- impact on health status

Given that there is no satisfactory treatment for colour vision deficiencies (See **p. 2**) it would be desirable to know whether a knowledge of having impaired colour vision results in fewer educational, occupational and motor vehicle crash problems compared with those who do not know they are colour vision impaired. It is very difficult to answer this question and there was an absence of such studies identified in this report.

Therefore, it was concluded that:

It was not possible to identify the impact colour vision screening has on reducing educational and occupational difficulties or motor vehicle crash rates.

Ideally, these subjects would also be evaluated in a comparative study including participants with impaired colour vision in one arm and those with normal colour vision in the other arm. While this question is of importance for all the headings outlined above, it is of particular importance when dealing with areas in which a danger to human life exists.

Four such study designs were identified in the occupational field. There were six such studies in a review of motor vehicle crash rates. Three studies investigating the impact colour vision had on educational attainment found no evidence that children with impaired colour vision had poor educational outcomes compared to those with normal colour vision. There were no articles identified that compared health status in the two groups. Other study designs were also identified but these should be considered inferior and therefore were not considered in the formation of conclusions.

Of the six studies comparing road traffic crash rates, four found no significant difference between the impaired and normal colour vision groups. This might have been due to a lack of power in these studies. Of the two with a positive result, one was criticised for the lack of detail concerning relative gender proportions. The other found wet weather rear end collisions in those with impaired colour vision were responsible for almost double the proportion of crashes compared with normals. Therefore, given these inconsistent results, it was concluded that:

There was insufficient evidence to either agree or disagree with the hypothesis that those with

impaired colour vision have more road traffic crashes.

Three sources of data did not find any relationship between impaired colour vision and educational attainment. However, the data was characterised by short follow-up so it was concluded that:

Further research was required to assess the role impaired colour vision has on educational attainment.

Bearing in mind the limitations discussed, the data from occupational studies provided some support for:

Those involved in air traffic control and sea search and rescue operations should have normal colour vision. Research on other occupations which normally restrict those with impaired colour vision was not identified in this report but it should not be assumed that such restrictions are unnecessary.

Different occupations have different requirements regarding employment opportunities for those with impaired colour vision. The Ishihara test, which is currently used for screening purposes in New Zealand, is recognised as being a sensitive test and many occupations with restrictions in terms of impaired colour vision do not need such stringent criteria. There is no single test that can be recommended for the testing of colour vision for all occupations.

In considering health status issues it was useful to consider whether colour vision screening might be the first method of detecting other adverse health outcomes. This required a consideration of conditions that result in abnormal colour vision. Such conditions included diabetes, optic atrophy, optic neuritis, cone dystrophies and various medications. Of these conditions only the cone dystrophies appeared to be relevant to this question. Cone dystrophies are extremely rare (Buyse, 1990) at pre-adolescent years so it was concluded that

There was insufficient evidence for the use of colour vision screening as a method of first detection of an adverse health outcome other than impaired colour vision.

The most extensive literature on colour vision screening concerned the validity of the screening tests. Ideally, these tests should be examined in a randomised-controlled trial by comparing the screening tests with a gold standard. In colour vision testing the gold standard for red-green colour blindness is anomaloscopy. Ideally, participants would be randomly selected and they would be

tested with both the screening test and the gold standard. There were 19 studies identified and all used the appropriate design. However, anomaloscopy was only used in 10 studies.

In three cases more than one screening test was used allowing a comparison between different screening tests. The Ishihara test was included in the battery of screening tests in these cases. In one of these studies (Dain et al., 1997) three tests could not be separated as the best performing test. These were the Ishihara, Hahn and Standard pseudoisochromatic tests. In all cases the sensitivity and specificity were greater than 95%. In the second study (Pease and Allen, 1988), Ishihara's test had the best performance of the five tests used. It was 96% sensitive and 100% specific. In the third study (Hill et al., 1982), Ishihara and AO-HRR tests were equivalent in terms of sensitivity (79%) and specificity (85%) but Guys test was more sensitive (93%) although less specific (56%) and the Matsubara test was inferior in both respects. The age group tested in this study was younger than the former study. In another study (Mantyjarvi, 1991b) the Velhagen Pflugertrident test had a sensitivity of 61% and specificity of 100% compared with anomaloscopy. Other tests evaluated had results that were clearly inferior to Ishihara's test.

In general, Ishihara's test performed at least as well as other screening tests it was compared against. The one difference worth commenting on was that between the Ishihara's test and Guys test. In that case, Guys test had a higher sensitivity but lower specificity. The sensitivity and specificity rates were lower in that study than all other studies investigating Ishihara's test and the age group tested was 4 to 11 years. There were no other evaluations of Guy's test identified.

A single study investigated the repeatability of Ishihara's test (Johnson, 1992). The repeatability of the test was excellent in that study but it would be desirable to have this repeated in other settings.

Therefore, it was concluded that:

There was currently insufficient evidence to recommend a change in the colour vision screening test currently in use within New Zealand (Ishihara's pseudoisochromatic test) on the basis of its validity. Cost-effectiveness information is needed to compare the costs of the various screening tests against sensitivity and specificity criteria.

The sensitivity and specificity of Ishihara's pseudoisochromatic test supported this conclusion. After excluding the study that included a preschool population (since colour vision screening appears

to be less reliable in this population) there were three studies that documented the sensitivity and three the specificity of this test type. The sensitivity ranged between 94% and 98% and the mean was 96%. The specificity ranged between 95% and 100% and the mean was 98.5%.

On the basis of the results in this report, assuming a sensitivity of 96% and specificity of 98.5% when using Ishihara's test and a prevalence of 7.3% in 11-year-old boys then the positive predictive value is 83% and the negative predictive value is 100%. The positive predictive value indicates that 83% of those testing positive on screening truly have impaired colour vision. Clearly, therefore, it is im-

portant that this group should have further testing if colour vision screening is to be employed and the result gives an indication of the efficiency of screening.

Table 15 (p. 51) presents a sensitivity analysis of the positive and negative predictive values across a range of prevalence figures and sensitivity and specificity values (for the screening test).

The two studies that provided New Zealand data both found a prevalence of impaired colour vision among New Zealand males of 6% when ethnicity was standardised to 1996 census figures.

Table 15. **Sensitivity analysis of the effect varying sensitivity, specificity and prevalence values have on the positive and negative predictive values for colour vision screening**

Prevalence	Sensitivity=90%, Specificity=90%		Sensitivity=95% Specificity=95%		Sensitivity=96% Specificity=98.5%		Sensitivity=99% Specificity=99%	
	PPV[13](%)	NPV[14](%)	PPV(%)	NPV(%)	PPV(%)	NPV(%)	PPV(%)	NPV(%)
8%	434	99	62	100	85	100	90	100
7.3%	42	99	60	100	83	100	89	100
6%	37	99	55	100	80	100	86	100
5%	32	99	50	100	77	100	84	100

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[13] PPV = positive predictive value
[14] NPV = negative predictive value

The issue of the best timing for screening was also considered. In general, it would seem logical to screen colour vision abnormalities at as young an age as possible provided there is no decrease in the performance of the screening test.

It was considered that colour vision screening should occur before the minimum driving age. There appeared to be a decrease in validity of the screening tests prior to six years of age although direct comparisons were lacking. After that age there was insufficient evidence to choose any particular age group. Bearing that in mind, and considering the other testing that occurs at 11 years of age, it was concluded that:

There was insufficient evidence to recommend a change in the age at which colour vision screening should occur in New Zealand.

Screening programmes are best evaluated with a randomised controlled trial design. Unfortunately there were no such studies identified for colour vision screening. There were four relevant studies identified but they evaluated aspects of screening programmes rather than the whole programme. Three studies used a cross-sectional design and the other was a non-systematic review. Therefore, it was concluded that:

It was not possible to evaluate the effectiveness of a colour vision screening programme on the basis of current research. This was identified as an area requiring further research, incorporating a randomised controlled trial as the most appropriate research design for this purpose.

It was noted that economic analyses of colour vision programmes were not identified in the conduct of this report. Therefore, it was concluded that:

The cost-effectiveness of colour vision screening could not be estimated due to the lack of research in this area. This is an area requiring further research attention.

Table 16.   Summary evidence table examining screening for impaired colour vision

Screening criteria	Level of Evidence	Results	Comments
Prevalence	Grade = III	Males (no restriction by country): 7.3% Males (New Zealand): 6%	• Results weighted by sample size. • Sample size: 96,692 (total), 3212 (New Zealand). • Cross-sectional design normally used (most appropriate design for this question). • Participation rates poorly documented.
Disability	Grade = II-1	Impaired performance of certain occupational tasks (air traffic control and sea search and rescue). Overall, minimal evidence for higher accident rates or poor educational performance amongst the impaired colour vision population.	• Limited studies retrieved comparing occupational performance in groups with normal and abnormal colour vision. • Educational studies were characterised by measuring outcome at a young age . • Power of the studies on accident rates was not assessed.
Treatment	Grade = III	No adequate treatment of colour vision deficiencies	• One study of filters identified. • Inappropriate study design (no control group).
Screening test validity	Grade = II-1	Ishihara test: Sensitivity: 96%, specificity 98.5% (excluding preschool children). No other screening test demonstrated significantly greater performance than Ishihara's test. No direct comparisons of screening test validity in different age groups but sensitivity and specificity was lower in studies including preschool children.	• Appropriate study designs used. • Only three studies that compared more than one screening test with anomaloscopy. • Total sample size in these three studies was 798. • Calculated PPV: 83% and NPV 100% assuming prevalence of 7.3%, sensitivity 96% and specificity 98.5%.
Screening programmes	Grade = III	Insufficient data to evaluate the effectiveness of colour vision screening programmes.	• Inappropriate study designs. • Related to aspects of screening programmes rather than evaluating the overall outcome of screening.

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Appendix 1

SEARCH STRATEGIES

MEDLINE/HEALTHSTAR

Screening

color vision defects/
color perception/
vision screening/
mass screening/
screen:.tw.
color vision.tw.
colour vision.tw.
1 or 2 or 6 or 7
3 or 4 or 5
8 and 9
limit 10 to (yr=1988 or yr=1989 or yr=1990 or yr=1991 or yr=1992 or yr=1993 or yr=1994 or yr=1995 or yr=1996 or yr=1997 or yr=1998)
limit 11 to english

color perception tests/
color perception tests/mt
limit 2 to (yr=1988 or yr=1989 or yr=1990 or yr=1991 or yr=1992 or yr=1993 or yr=1994 or yr=1995 or yr=1996 or yr=1997 or yr=1998)
limit 3 to human
letter.pt.
4 not 5

Treatment

color vision defects/dt,pc,rh,th
limit 1 to human
limit 3 to (yr=1988 or yr=1989 or yr=1990 or yr=1991 or yr=1992 or yr=1993 or yr=1994 or yr=1995 or yr=1996 or yr=1997 or yr=1998)

Prevalence; Disability; Natural history

color perception tests/
color perception/
color vision defects/
color vision.tw.
colour vision.tw.
color blind:.tw.
colour blind:.tw.
or/1-7
prevalence/
incidence/
sn.fs.
prevalen:.tw.
incidence.tw.
or/9-13
8 and 14
letter.pt.
15 not 16
limit 17 to human

from 18 keep …
natural history.tw.
progress:.tw.
clinical course.tw.
or/20-22
disease progression/
prognosis/
or/20-25
8 and 26
27 not 17
limit 28 to human
from 29 keep …
color vision defects/et
color perception/de,ge,re
31 or 32
17 or 28
33 not 34
from 35 keep
disabled/
disabilit:.tw.
career choice/
employment/
learning/
educat:.tw.
learning disorders/
education/
or/37-44
8 and 45
from 46 keep
from 18 keep

EMBASE

color blindness/
color vision/
color vision defect/
color vision test/
color discrimination/
adolescen:.tw.
adolescence/
adolescent/
or/6-8
or/1-5
9 and 10
from 11 keep
mass screening/
screening/
screen:.tw.
or/13-15
16 and 10
17 not 11
limit 18 to human
from 19 keep
12 or 20
exp occupational medicine/
10 and 22
23 not 19
from 24 keep 3,7
25 or 21

1 or 3
exp incidence/
prevalence/
(incidence or prevalence).tw.
or/28-30
27 and 31
32 not 26
from 33 keep
disability/
work disability/
physical disability/
perception disorder/
or/35-38
27 and 39
from 40 keep 2
26 or 34 or 41
color vision defect/di
color blindness/di
43 or 44
color vision defect/et
45 or 46
47 not 42
from 48 keep
12 or 20 or 25 or 34 or 41 or 49

OTHER DATABASES

Because there was not a large amount of material on the other databases, Current Contents, Psychlit, ERIC, Science Citation Index, Social Science Citation Index and OSH-ROM were searched simply using the thesaurus heading *color vision* if available or, alternatively, the keywords *colour vision/color vision*.

Appendix 2

STUDY DESIGNS USED IN THIS REVIEW

The study designs included in this review were:

- Non-randomised controlled trial

- Cohort study

- Case-control study

- Descriptive studies (including cross-sectional studies and ecological studies).

The remainder of this appendix is based on material contained in Elwood (Elwood, 1988). This is presented in the Table.

Table. **Study designs used in this review**

Study design	Description	Main role	Advantages	Disadvantages
Non-randomised controlled trial	Study in which the investi-gators assign the study population to different com-parison groups.	• Useful for testing the validity of screening tests	• Useful in the evaluation of conditions where ran-dom assignment is not possible • Able to control the number of participants in dif-ferent groups	• Unable to control for unknown confounding and bias. • Potential for bias if the investigators are not blinded.
Cohort study	Observational study that follows exposed and unex-posed participants to defined outcomes.	• Useful for prognosis • Primary method of studying unusual or new exposures	• Good in rare exposures • Allows multiple endpoints to be assessed • Temporal relationship clear • Exposure assessed prior to outcome, avoiding bias	• Often requires many years of follow-up (if per-formed in a prospective manner). • Needs large numbers of participants if the out-come is rare. • Susceptible to selection bias.
Case-control study	Observational study that starts with an outcome event and (generally) retrospec-tively analyse exposures.	• Identification of causes of a new outcome • Useful in evaluations of population screening	• Efficient in terms of sample size required (par-ticularly rare outcomes) • Retrospective method is rapid • Multiple exposures can be assessed • Relatively low resource use	• Unable to calculate absolute or relative risk. • Susceptible to recall bias. • Retrospective methods limits exposure informa-tion. • Adequate control group may be difficult to define or obtain.
Cross-sectional study	Makes observations at one point in time	• Measure prevalence • Assessment of associa-tions	• Relatively simple so participation tends to be rela-tively high • Representative samples of a population can be drawn • Methods can be standardised, reliable and single blind • Can be repeated using similar methods	• Does not allow assessment of causation due to lack of time dimension. • Inefficient when prevalence or exposure is low.

Appendix 3

REFERENCES NOT CONSIDERED FOR APPRAISAL

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Appendix 4

FORMULAE FOR SUMMARY MEASURES OF EFFECT

	Colour vision	
Results of screening test	Deficient	Normal
Positive	a	b
Negative	c	d

Sensitivity = a/(a+c)

Specificity = d/(b+d)

Positive predictive value = a/(a+b)

Negative predictive value = d/(c+d)

Appendix 5

CONSULTANT REPORT

COLOUR VISION SCREENING; A CRITICAL APPRAISAL OF THE LITERATURE

Comments on NZHTA Report 7 by Mark Elder

Conclusions

Essentially this report is excellent. I agree with all the conclusions and there is good evidence to support these conclusions.

Broad Overview

The perception of colours is a complex phenomena. Essentially all colour deficiencies exist in boys because of its genetic linkage. Colour vision deficiency in girls of school age is effectively and practically non existent. Colour vision deficiency occurs in 7% of men. This phenomena is present from birth and never changes through the life of the individual. Acquired colour blindness does exist but is uncommon or has other manifestations that lead people to Ophthalmologists. This would include diabetes, glaucoma, optic nerve diseases, a variety of medications, etc, etc. Almost all of these present much later in adult life and never in childhood. It can be concluded that screening for colour vision problems will be of no use to detecting acquired disease. Therefore school age screening programmes for colour vision are detecting genetic disease. These children have a stable natural history. There is no treatment which alters their visual performance and the use of tinted lenses, etc has no basis in science.

Importance of Colour Vision Screening

Because the natural history of colour vision impairment cannot be altered, the importance of identifying children with colour vision deficits are to ensure that adequate provision and advice is given. This may influence their education and career choice. This report offers strong scientific evidence that a child's education is not impaired if they are colour deficient nor is their education improved if people are aware of it.

It can be concluded that the major benefit of colour vision screening is to ensure adequate careers advice.

Epidemiology - Specific Comments

On page 10, the study by Grosvenor (1970) suggests that Pakeha boys are colour deficient in 6.5% whereas Maori boys are deficient in 2.3%. It is appreciated that the definition of Maori is not easy from a research point of view. This is an odd result because all other studies show no racial variation. This could well be revisited from an academic point of view.

Page 16, etc reveals that a significant number of people are unaware of their colour vision problems. There is no data for New Zealand. The essential outcome of our colour screening programme is awareness that the individual is deficient in colour perception. In other words, awareness of colour deficiency is the key parameter that the New Zealand screening programme has been effective. I would recommend that the HFA fund a study to examine this. It would be most appropriate to examine people at school leaving age and a simple poll of 5th Form boys combined with assessment of the same group with the Ishihara Test would be logistically easy and indeed vital data. I would strongly recommend such a study be performed.

Careers and Colour Vision; Specific Comments

Page 19 shows that Steward and Cole, 1989, demonstrate that knowledge of colour vision significantly influenced career choices.

On page 20 the study of Voke, 1978b, shows that 62% of people chose inappropriate careers for their visual impairments.

Therefore it is important to identify colour vision deficits before a child embarks on a career pathway. If a child is advised too young then they may well forget, whereas if they are too old then it may be too late to change their pathway.

This aspect of knowledge of a colour vision deficit and appropriate career counselling probably needs to be directed at the parents. I would recommend that such advice and current counselling be reassessed.

Specific Career Choices

This report details the importance of colour vision to specific occupations such as air traffic control, electrical work, search and rescue. There are others such as train drivers, and pilots etc. It is my opinion that it is up to individual organisations to perform their own screening procedures for such applicants. Indeed this is done for pilots and train drivers and I believe air traffic controllers. From a clinical perspective there is no doubt that normal colour vision is vital for a number of occupations but this is well beyond the brief of a school screening programme.

The evidence for colour vision playing a significant role in motor vehicle accidents is lacking. It is my opinion that other variables such as speed, alcohol, road construction, weather conditions, driver fatigue, spatial awareness, etc, etc far outweigh the effects of colour vision. It is my opinion that colour vision does not need to be assessed for our current driving licence.

Means of Testing Colour Vision

This reports analysis on sensitivity, specificity, repeatable and the use of these tests in children is excellent and I agree with their conclusions.

Age of Testing

The age of testing is based on whether colour vision deficits will affect education or career. I agree with the work of Gordon, 1989, (page 43), that the most appropriate age for testing is 11-14 years. The caveat is that any child with a learning disability should have the opportunity for colour vision assessment.

It is important to appreciate that any child with learning impairment may be disabled for any number of reasons. It is my opinion that these children all need an adequate hearing test to exclude hearing disabilities and an adequate assessment of their visual acuity and colour vision. However this is beyond the brief of this report.

Cost-Effectiveness

This report does not deal with any of the fiscal aspects. There is no data as to the current incremental costs of colour vision screening, etc.

The main outcome of the screening procedure will be appropriate knowledge that may influence careers. It would be very difficult to cost account this. For example, what price is there if a person spends one year in an electricians apprenticeship only to find that he cannot distinguish the red from green wires and therefore must retrain in another area. The work of Voke, 1978b, certainly documents the opportunity cost to society for inappropriate career choice.

The last paragraph of page 47 poses the philosophical question as to whether a screening programme that has implications beyond the health sector be purchased by the health sector. The fact that this question has been raised illustrates that the compartmentalising of Government provided social services has pedantically gone too

far. All aspects of health care have benefits extending beyond health care. Every disease and disability affects an individual and society over multiple aspects including health, economics, recreational, spiritual, etc.

Final Conclusions

1.   That this report be accepted in its entirety.

2.   There may be differences between colour vision impairment in Maori children compared to Pakeha and this needs investigating.

3.   A study needs to be performed on 5th Form children comparing their colour vision with their knowledge of their colour vision status (pretest) and their awareness of how this may influence career decisions.

4.   For the boys identified as being colour vision impaired, the pathway and information and implication of this needs to be revisited. For example, what is told to the child and their parents.

5.   Children with learning impairment should have access to colour vision assessment.

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