A Modified Protocol for Color Vision Screening Using Ishihara

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INTRODUCTION: The Ishihara plates are commonly used as an initial occupational screening test for color vision. While effective at detecting red-green deficiencies, the color deficient subject can learn the test using different techniques. Some medical standards such as the European Aviation Safety Agency (EASA) require plate randomization and apply a stricter pass/fail requirement than suggested by Ishihara. This has been reported to increase the false positive rate up to ~50%.

METHOD: Two modifications to the Ishihara protocol are investigated. These involved allowing subjects a second attempt where one or two reading errors were made and the presentation of rotated Ishihara plates.

RESULTS: A reduction of false positive rate to 5.9% was found. Correct identification of certain rotated Ishihara plates was not affected.

DISCUSSION: By using a modified Ishihara protocol, fewer color normal subjects would require unnecessary advanced color vision examination. Further, additional safeguards would be in place to ensure that no subject with a color vision deficiency could pass the Ishihara test.

KEYWORDS: color vision assessment, false positive, Ishihara 24 plate edition.

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The prevalence of congenital red-green color vision deficiencies in the European Caucasian male population is reported at around 8%.[3] The Ishihara test for color deficiency is a widely used screening tool in aviation medical examination and has a high sensitivity in detecting the presence of a congenital red-green color vision deficiency.[2] The European Aviation Safety Agency (EASA) medical requirements for pilot certification state, in EASA MED.B.075(b) Acceptable Means of Compliance, that for color vision testing: 'The Ishihara test (24 plate version) is considered passed if the first 15 plates, presented in a random order, are identified without error.'[9] However, a number of previous studies have reported that individuals with normal color vision can fail this strict criterion. A conservative figure of 9.7% of normal trichromats failing the 24 plate edition has been reported,[12] although other studies report this to be as high as 44.6%[11] and up to 75.8% in children.[8] These types of error are classed as false positives. A number of causes for these errors have been suggested and include digit confusion error where the number is seen but incorrectly interpreted. Digit confusion errors are usually a misinterpretation of 3 and 8, or 7 and 2.[11] The Ishihara guide to interpretation of results states that if 13 of the first 15 plates (up to 2 errors) are read normally, the color vision can be regarded as normal. A poor correlation is reported between the severity of a color vision deficiency and the number of errors made on the Ishihara plates.[12]

It is recognized that the method of administration of a screening test such as Ishihara should not allow individuals with abnormal color vision to pass without further color vision examination. These would be classed as false negative errors. This could potentially occur if the plates were not randomized and the subject had learnt the order by plate number. Randomization is recommended by Ishihara 'if it is suspected that there is a deliberate deception on the part of the subject' and is required in EASA MED.B.075(b).[9] However, it is also possible for a color deficient subject to correctly state the number within each plate by learning the unique patterns of dots on each plate.

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This was successfully demonstrated at the UK Civil Aviation Authority (CAA) AeroMedical Centre by photocopying plates 2-13 of the 24-plate edition and removing the plate numbers in order to eliminate any other identification cues. A member of staff learnt differences in the patterns of dots and was able to correctly identify every plate presented randomly within 3 s.

In order to reduce both false positives and the potential for false negatives while maintaining the zero error pass requirement, two modifications to the Ishihara testing protocol are investigated. Part 1 describes the results of an audit using a modified protocol which aims to lower the false positive rate and which allowed subjects making up to two errors to retake those misread plates after having been shown a sample of the Ishihara typeface style numbers. Part 2 describes the results of rotating selected Ishihara plates in order to minimize any false negative results due to a learning effect. These modifications can be combined into a single testing protocol described within the discussion section.

PART 1: MODIFIED PROTOCOL TO REDUCE FALSE POSITIVE RATE

METHODS

Subjects

The subjects were applicants for initial aeromedical examination at the UK CAA AeroMedical Centre. Color vision screening with Ishihara is required as part of this medical exam and an audit of color vision results was conducted which conformed to the World Medical Association's Declaration of Helsinki.

Equipment

The first 15 plates from the 24-plate edition of Ishihara are examined under a GretagMacBeth (New Windsor, NY) Sol Source D65 daylight lamp. The book is presented normally to the line of vision at approximately 75 cm and a 3-s maximum response time per plate is allowed. Applicants failing Ishihara undergo further color vision assessment using the Color Assessment and Diagnosis (CAD) test. This is a computer based color vision test using a calibrated display screen which is reliably able to detect,[13] diagnose, and quantify color vision deficiencies.[5–7] The CAD protocol involves the use of an initial screening test at 6SN (standard CAD units). If this quick test is passed, a full red-green threshold is not required. Those applicants failing the CAD screening test would have a degree of color vision deficiency[13] and would require full threshold examination. Up to certain degrees of color vision deficiency are considered acceptable for unrestricted aeromedical certification.[6]

Procedure

Six Ishihara plates from a 38-plate edition were selected using, where possible, plates with different numbers from the 24-plate edition. Each dot within the number was colored black and the plates were photocopied, laminated, and placed above the Ishihara testing area. Three plates had two-digit numbers and three had single-digit numbers and together represented samples of numbers from 1-9. Where a subject made up to two errors, they were shown these sample typeface numbers with particular attention paid to the numbers which were confused. The subject was then allowed a second attempt at identifying those numbers initially misread.

Using this technique, it was found that most subjects then correctly identified the Ishihara plate(s) when shown them for a second time. In order to quantify the effect, an audit of the result of all color vision assessments carried out as part of an initial medical examination at the UK CAA AeroMedical Centre from 1 January–30 June 2013 was conducted. This included assessment of the results from all applicants within the audit period of the screening and any advanced color vision tests conducted as part of the initial medical examination. Using data saved on the CAD laptops, all CAD tests carried out as part of an initial medical within the audit period were identified.

It was anticipated that all CAD test results would fall into one of four categories: those with color vision deficiencies who would not be considered color vision safe following full red-green threshold testing; those with color vision deficiencies who would be considered color vision safe following full red-green threshold testing; those making greater than two errors using the modified Ishihara protocol, but who passed the CAD screening test; and, finally, those making one or two errors using the modified Ishihara protocol who passed the CAD screening test. For the purposes of the audit, those subjects who made one or two errors using the modified Ishihara protocol and who passed the CAD screen were considered to have normal color vision in the absence of a full red-green CAD threshold being carried out. Those making more than two errors on Ishihara and passing the CAD screen may have either normal color vision or a degree of color vision deficiency within certificatory limits.

RESULTS

A total of 694 initial subjects were examined from 1 January 2013 to 30 June 2013. This resulted in a total of 40 CAD tests being carried out (**Table I**). The CAD test is able to definitively diagnose the presence of a color vision deficiency once a full threshold test has been completed. If the subject passes the CAD screening test, it can only be concluded that if a color vision deficiency is present, it would be sufficiently mild such that it would be within standards and considered color safe for aviation medical certification. Of the six subjects who passed the CAD screening test and who made greater than two Ishihara errors, four made three errors, one made four errors and one made eight errors. All 11 subjects who undertook full CAD threshold testing were diagnosed with a degree of color vision deficiency.

If all those who passed the CAD screen were assumed to have normal color vision, a total of 11 (1.6%) subjects were considered to have some degree of color vision deficiency and, therefore, 683 of the subjects who were examined had normal color vision, of which 29 were considered to have normal color vision, but required a CAD test. This resulted in a 4.2% false

Table I. Summary of CAD Results Against the Outcome of Ishihara Using the First Protocol Modification.

ISHIHARA RESULT	TOTAL	PASS CAD SCREEN	FAIL CAD SCREEN	PASS CAD AFTER THRESHOLD TESTING	FAIL CAD
Zero errors	653	N/A	N/A	N/A	N/A
1 or 2 errors	23	23	0	0	0
More than 2 errors	17	6	11	6	5
Total	694	29	11	6	5

Only those making errors on Ishihara went on to undergo Color Assessment and Diagnosis (CAD) testing. All subjects who underwent full CAD threshold testing had a degree of color vision deficiency.

positive rate for Ishihara using the modified protocol. This is likely to be a conservative figure as it is possible that some of the six individuals making more than two Ishihara errors had a color vision deficiency and if these six were to be reclassified, a revised false positive rate of 3.4% would result. Chi-squared analysis revealed that the conservative calculation of the false positive rate is significantly lower than previous[12] findings ($\chi^2 = 9.94$, df 1, $P = 0.002$) using the 24-plate Ishihara standard protocol with a zero error pass requirement.

PART 2: MODIFIED PROTOCOL TO MINIMIZE FALSE NEGATIVES

METHODS

Subjects

Subjects were applicants for initial Class 1, 2, or 3 medicals at the UK CAA AeroMedical Centre and were tested, as part of the eye examination, using the 24-plate Ishihara edition with randomized plates and modified protocol as described in Part 1. Only those applicants who had passed Ishihara and did not require CAD testing were included for this part of the study. Subjects were given details of the survey and gave informed consent. The survey conformed to the World Medical Association's Declaration of Helsinki.

Procedure

Six plates (excluding plate numbers 1, 14, and 15) were randomly selected within a second 24-plate Ishihara book and were randomly rotated by 90° either clockwise or anticlockwise. These plates were reinserted into the book and were not changed between each assessment. The data collection period ran from 15 August to 31 October 2013. At the end of their eye examination, subjects undertook a further Ishihara test using the second book containing some rotated plates. Subjects were informed that the result of the second Ishihara book would not impact on their medical certification. Subjects were also informed that some pages presented would contain a number which would not appear in the normal orientation. Any errors made using this second Ishihara book were documented including the number of errors and the type of confusions made; however, no personally identifiable data was used. From 11 September onwards, a different selection of six Ishihara plates consisting of only single-digit numbers were randomly rotated.

RESULTS

During the first selection of rotated plates, a total of 64 assessments were carried out. All subjects had previously made no errors on Ishihara using the 24-plate edition with plates randomized and using the modified protocol described in Part 1. A total of 39 (61%) made errors on the second Ishihara book; 25 subjects made 1 error, 12 subjects made 2 errors, 1 subject made 3 errors, and 1 subject made 4 errors. It was, however, observed that all errors were made on double-digit rotated plates rather than single-digit rotated plates.

For the second selection of rotated plates, a total of 90 assessments were carried out. Again, all subjects had previously made no errors on Ishihara using the protocol described in Part 1. A total of 28 (31%) subjects made errors on 1 or more plates of which 4 were on nonrotated plates (subjects were not offered a second opportunity to correct misread plates in this phase). A total of 29 errors were made on rotated plates. There were 10 errors that arose where the plate containing '6' was misread as '9' and had been rotated by 90°. This is a vanishing plate and no number is visible to the color vision deficient subject. A further 18 errors were made with '3' being named as '8' when rotated (response by a color deficient would be '5' for this plate). Neither of these plates were used in the original selection of rotated plates. There was one further error for a single-digit rotated plate where '3' was named as '60.'

It was calculated that, if the five single-digit plates described in **Table II** were to be rotated, this would alter the overall false positive error rate to 5.9% using the combined modified protocol using randomized Ishihara with rotated plates. This rate remained significantly lower ($\chi^2 = 4.15$, df 1, $P = 0.04$) than the independently reported false positive rate of 9.7%, where 23 out of a sample of 236 color vision normals made error(s) on the Ishihara.[12]

DISCUSSION

The Ishihara test is known to be an extremely sensitive test at detecting congenital red-green color vision deficiencies.[2] The principle of allowing zero errors is likely to increase its sensitivity further, but at the detriment of its specificity, with high false positive rates reported. The modified testing protocol described in Part 1 should maintain high sensitivity while reducing false positive results to around 4%. It is recognized that as these data were collected retrospectively, no intraobserver measure of false positives between the standard and modified protocols

can be made. Additionally, the number of subjects who made one or two errors and who then correctly identified the Ishihara plates on the second attempt was not documented. However, it has been consistently reported in studies employing large cohorts that a percentage of normal trichromats make errors on the Ishihara plates.[1,12] The lower the number of errors allowed to pass the test, the higher the incidence of a false positive result.

It was not possible in Part 1 of the study to determine whether the small group of subjects who made three or more Ishihara errors but passed the CAD screening test do indeed have a color vision deficiency as further examination was not warranted for certificatory purposes. It is reported that up to six errors may be made (on the 38-plate edition) by color normal subjects[4] and it has been recommended that up to four errors be allowed so as not to disadvantage normal trichromats.[12] Where a limit of three errors or less are allowed, 10% of deutan and 1% of protan subjects are reported to pass Ishihara.[12] As five of these six individuals made four or fewer errors, it seems likely that the majority of this group would likely have normal color vision; however, the false positive rate found in this study remains significantly lower than even conservative figures previously reported.[12]

The Ishihara test may not be able to detect subjects with color vision deficiencies who employ other techniques in plate recognition in order to obtain a normal result. This is more likely to occur in environments such as aeromedical examination, where applicants are motivated to gain a favorable medical outcome. It is seen occasionally using the randomized plates where a subject calls the correct numbers in the original order of the book. It has also been shown that subjects with color vision deficiencies could potentially use dot pattern recognition to ensure they read all plates correctly. There is no means of assessing if color vision deficient subjects have achieved this to date as they would have been passed as color normal without further color vision testing.

The rotation of selected plates offers an addition safeguard against this strategy and these results indicate that it would only marginally affect the false positive rate if the plates were rotated as suggested in Table II. By having a zero error pass requirement for the Ishihara screening test, it would make it extremely unlikely that a color deficient subject could recognize rotated Ishihara plates by dot pattern recognition within the 3 s per plate test requirement. A modified testing protocol should include an explanation to the applicant prior to the test that not all the numbers would appear in the normal orientation.

It should be noted that the two versions of the Ishihara plates used in this study were of a different age. The 24-plate edition with randomized plates used in Part 1 was manufactured in 2010 and the edition with rotated plates was manufactured in 2000. Although stored carefully away from direct sunlight, it is possible that the plates in the older edition may have been affected by fading.[10] Additionally, although the plates in both books were randomized, the order of numbers was not the same.

Table II. Suggested Rotation for Five Ishihara Plates.

PLATE NO.	COLOR NORMAL SEES	SUGGESTED ROTATION
2	8	90° clockwise or anticlockwise
4	5	90° clockwise or anticlockwise
8	6	180°
10	5	90° clockwise or anticlockwise
11	7	90° clockwise or anticlockwise

It is not known what the effect that plate order has on outcome, but it is known that some numbers are easier to identify than others.[4,8,11] However, previous studies have not assessed the effect of plate randomization on reading error rate. It is possible that an early presentation of a more difficult number such as '73' may cause a higher error rate than if presented after the single digit '3' and single digit '7' as in the original plate order. However, the use of the modified protocol allowing up to two reading errors to be corrected at a second attempt should help to counter this effect, if present.

It is also recognized that this study has not been able to quantify the effect of plate rotation on the false negative rate. This is because it has always been assumed at the AeroMedical Centre that those passing the Ishihara test have normal color vision and do not require, for certificatory purposes, further color vision examination. Therefore, it can only be concluded that plate rotation will reduce the likelihood of a subject obtaining a normal result by deceit while minimally affecting false positives.

These findings indicate that employing the modified protocol using some single digit rotated plates and allowing up to two errors to be corrected at a second attempt as described would ensure that significantly fewer numbers of subjects would be unnecessarily required to undergo further advanced color vision testing, saving time in a busy clinic environment. Additional measures would be in place to ensure that no individual with a color vision deficiency would be able to falsely obtain an Ishihara pass and avoid undergoing further detailed color vision assessment. Finally, any effect to the time taken to administer the Ishihara test under this suggested protocol is likely to be minimal.

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