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Applying the Ishihara test to a PC-based screening system

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Abstract

Aim: A commonly used method to examine the ability of the visual system to discriminate colours is based on isochromatic plates, such as the Ishihara plates. This article will introduce a computer-based method to determine red–green colour deficiencies based on presenting Ishihara plates using a CRT monitor.

Method: The spectral emission of the reflected daylight of the plates was compared with the spectral emission of the plates presented on a CTR monitor. The screening efficiency of the Ishihara plates was assessed by testing 10 subjects with normal and 10 subjects with abnormal colour vision, using the Ishihara plates and using the computer-based approach.

Results: It was experimentally shown that despite the differences between the spectral emission of the CRT monitor and the reflected daylight of the Ishihara plates, the computer-based method discriminates subjects with colour deficiencies from subjects without colour deficiencies.

Conclusions: Using a CRT monitor for screening purposes, a reduced number of Ishihara plates is recommended to assess colour vision. The suggested method uses nine instead of 15 plates and a criteria of two not correctly detected plates to determine colour deficiency.

Keywords: Colour deficiency; Ishihara-Test; Computer-based screening

1. Introduction

Medical examination of human sensory functions often require many resources. The reduction of these resources within these examinations without decreasing the efficiency is the aim of two-step-medical screening by Krueger [1]. Conspicuous subjects should be detected in a rough pre-test, using a few resources. These subjects should later be intensively examined.

The integration of these pre-tests on to a computer can improve the quality of the results and decrease the time to analyse the data. In this context the use of computer-based approaches to test the visual system is an advantage, because the stimuli can be directly presented on the computer monitor. The degree of automation is also an advantage in this screening approach. The automation reduces the bias of the examiner on the results, which can lead to an improved reliability of the examinations.

Krill [3] established that 8% of men and 0.5% of women in the European and North American populations have a red–green colour deficiency. People with abnormal vision can be classified as anomalous trichromates or dichromates. In screening procedures (such as [4]), this classification is usually not performed.

The testing of red–green colour deficiencies is common in the examination of the visual system. Cavanagh et al. [5] mention that at least two approaches are accepted to detect colour anomaly, Ishihara-Plates and the American Optical Pseudoisochromatic plates. Birch [6] states that the Ishihara test is the most widely used. Several experiments [7–9] have shown a high reliability of the Ishihara-Test to detect red–green colour deficiencies. Additionally, Long and Tuck [10] mentioned that other methods, such as the Nagelanomaloscop or the Farnsworth–Munsell 100-Hue Test, require skilled examiners and highly calibrated devices.

An approach to validate screening procedures was introduced by Cochrane and Holland in 1971 [11]. This validation is guided by different criteria: simplicity, acceptance, and reliability of the procedure. The validation is mainly focused on the analysis of sensitivity and specificity. *Sensitivity* is the percentage of abnormal subjects correctly identified as abnormal. *Specificity* is the percentage of normal subjects correctly identified as normal [6].

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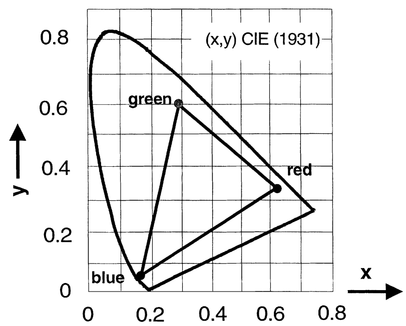

Fig. 1. Schematic description of colours representable on a CRT monitor concerning the CIE 1931 system. The dots assigned with red, green and blue point to the primary colours of the CRT.

The objective of this computer-based approach to assess colour deficiency is to achieve both a high sensitivity and specificity. The computer-based test of colour vision is integrated as a module in a computer-based screening system covering a wide range of standard vision tests, such as visual acuity, stereopsis, phoria and contrast sensitivity [12].

1.1. Technical restrictions of CRT monitors for representation of colour

Technical restrictions of cathode ray tubes (CRT) in computer monitors imply that not all perceivable colours can be adequately presented on a monitor (e.g. see [13]). The generation of colour is done by mixing light emitted by three phosphors in the red (R), green (G) and blue (B) regions. This leads to an RGB coordinate system to describe colours on a computer monitor by the intensities of the cathode rays emitting from the three phosphors. A detailed description of the process is given by Travis [14]. Derefeld and Hedin [15] investigated the spectral emission of colours on CRT monitors. The study showed that certain shades of orange, yellow and blue–green colours cannot be represented on a monitor using the CRT technology. This leads to the assumption that the spectral emission of the Ishihara plates on a CRT monitor will be different from the spectral emission of reflected daylight on paper plates. This is caused by the many orange and red dots on the Ishihara plates.

The differentiation of colours can be done when using the CIE 1931 colour coordinate system [16]. Distances in this system do not reflect equidistant perception. This was later taken into account in 1971 with the evaluation of the CIELUV coordinate system [17]. The metric of this coordinate system is based on the equidistance of perception.

Menozzi [2] compared the possible representable colours using a CRT computer monitor with all perceivable colours. Concerning the CIE 1931 coordinate system the comparison can be illustrated schematically in Fig. 1.

The colours representable using a standard CRT monitor are within the triangle of Fig. 1, which is spread by three points. These points show the colours which are produced by the primary cathode rays. These technical restrictions result in problems when transferring a colour vision test onto a computer.

Colour effect on visual pigments: Colours that differ in their spectral emission but which are equally perceived are called *metameric* colours. When using the Ishihara plates presented on the CRT monitor, it has to be ascertained that metameric colours of the Ishihara plates are generated compared to the colours reflected from the original plates.

1.2. Objective of the work

This article presents a method to assess red–green colour deficiencies by using Ishihara plates using a CRT computer monitor. As mentioned before, there are differences between the spectral emission of light emitted by a monitor and the reflected daylight of the Ishihara plates. Rather than a balanced spectral emission of daylight at different wavelengths, the spectrum of a CRT monitor results in peaks (see Fig. 2). This indicates why the results of the traditional Ishihara test and the Ishihara test using a CRT monitor might be different. A hint that the differences in the spectral emission might not have a major impact can be got from the study of Long and Tuck [10] who determined in their study, that the illumination of the plates and other constraints have only a minor impact on the results of the Ishihara test.

Edsel et al. [18] implemented the Ishihara test on a PC, but they did not accurately take the restrictions of the monitor into consideration. No detailed information is given for the setting of the monitor, which makes it difficult to reproduce the results. However, the result of the presented

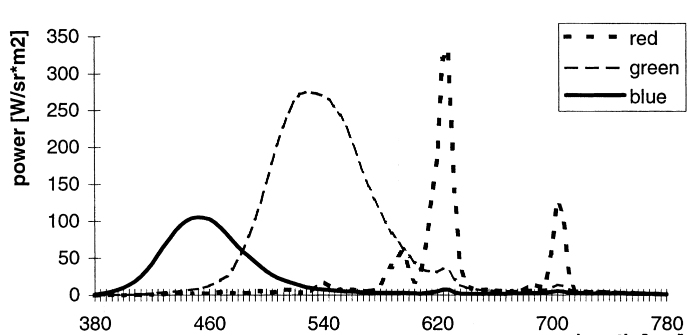

Fig. 2. Spectral emission of the EIZO monitor used. The three curves represent the spectral emission of the primary colours of the cathode ray tubes.

Table 1
Luminance, CIE 1931 and CIELUV-coordinates of the RGB primary colours of the EIZO monitor. The values x, y, u',v' are established as mean values out of five measurements.

Colour	Luminance Cd/m^2	CIE 1931		CIELUV	
		x	y	u'	v'
Red	25.9	0.628	0.344	0.428	0.527
Green	76.2	0.295	0.602	0.122	0.562
Blue	9.14	0.152	0.076	0.168	0.189
White	101.7	0.319	0.344	0.198	0.475

experiment was encouraging, because subjects with colour deficiencies could be discriminated from the tested population.

So, the proposal was made that despite the technical restrictions when using a CRT monitor to represent the Ishihara plates, subjects with colour deficiencies can be discriminated from a population. The evaluation of this proposal was divided into two parts. First, the influence of the technical restrictions of the CRT monitor was analysed for the representation of the Ishihara plates. Secondly, an analysis is carried out by using an experiment whether the technical restrictions have an impact on the discrimination of colour deficient subjects from a tested population.

2. Technical restrictions of the Ishihara test using a CRT monitor

2.1. Method

The Ishihara plates were scanned using a Hewlett Packard ScanJet II cx [19] and the software, using standard settings. Those settings concern grey values and colours and lead to 24-bit colours, and a 300 dpi resolution without changing the size of the plates during the digitisation process.

The Ishihara plates were presented on a 17 in. EIZO Flexscan F550i W [20] monitor. This CRT monitor was driven by a 16-bit colour graphic card. One way to characterise monitors is by the spectral emission of the emitted light. The EIZO Flexscan F550i-W has the spectral emission as shown in Fig. 2.

The impact of the technical restrictions on the perception of colours of the plates was analysed by measuring the CIELUV coordinates. The plates were analysed by a colour-normal male by eye for different perception of colours. In this approach colours were discriminated and later measured and justified using the PR-650 SpectraScan SpectranColourimeter [21]. The colours were defined as equal, if they did not show more than $\pm$ 0.003 difference within each of the (u',v') coordinates of the CIELUV coordinate system.

To perform the experiment with the Ishihara plates, standard lighting is recommended. In contrast to this recommendation, the experience of the authors shows that the Ishihara test is often performed in uncontrolled daylight. This was why in this study the determination of the colours of the plates was performed in daylight, once in the morning and once in the evening. The measurements of the colours at the monitor was carried out in darkness to remove reflections. The determination of the colour was performed using five measurements and the mean value was assigned to the colour. Using these determined colours it was analysed whether metameric colours were generated using the CRT monitor to present the Ishihara plates.

The screening system was implemented using MS Visual Basic 4.0 on a standard PC. This supports different PC operating systems such as Windows 3.XX, Windows 95 and Windows NT.

2.2. Results

The examination of the plates showed 26 different colours, that are used within Ishihara plates no. 2–15. The colours of the dots were measured using daylight, once in the morning and once in the evening. The mean luminance was approximately 3000 lx.

The same colour dots were measured on the EIZO monitor showing a colour temperature of 5800 K that leads to the settings from Table 1 with no external light switched on.

The colour of the dots are listed in Table 2. The colours are assigned using the coordinates of the CIELUV system.

The spectral emission of the reflected daylight of the plates was measured as well as the spectral emission using the CRT monitor for representing the plates. The mean differences of the 26 colours

$$\left(\bar{x} = \sum_{\text{colours}} \sqrt{(\Delta u')^2 + (\Delta v')^2}\right)$$

and the standard deviation (σ) was calculated for different daylight conditions and the presentation on the CRT monitor. The measurements performed in the morning and evening using daylight and the measurements of the CRT were compared with each other. The results are illustrated graphically in Fig. 3.

The results show that there is a shift in the colour at daylight during the day. The largest difference arises when comparing the measurement of the morning with the measurement using the CRT monitor. The least difference arises while comparing the evening measurement with the measurement using the CRT monitor representation.

2.3. Discussion

The representation of the Ishihara plates on a CRT monitor has disadvantages compared to the original plates. One reason is the discrete number of pixels of the monitor, which does not allow an exact representation of circles. This is the reason why it is not always possible to show curves of the circles accurately; but the numbers on the Ishihara plates are built using circles.

Table 2
The CIELUV coordinates are shown for the determined 26 colours of the Ishihara plates 2–15. The established values are mean values out of five measurements. Columns 2 and 3 show the values of daylight in the morning, columns 4 and 5 show the values of the measurements in the evening and columns 6 and 7 show the values taken from the PC measurement. Column 8 shows the difference in the colours between the morning and evening measurement, column 9 shows the difference between the PC and the morning measurement and column 10 shows the difference the evening measurement and the PC. The mean $\overline{X}$ and standard deviation σigma;/it > of all differences and of the 26 colours are listed in the final rows.

Colour	Ishihara plates				PC Cieluv PC (3)		Distances $\sqrt{(u'_1 - u'_2)^2 + (v'_1 - v'_2)^2}$		
	Cieluv morning (1)		Cieluv evening (2)						
	u'	v'	U'	v'	u'	v'	(1)– (2)	(1)– (3)	(2)– (3)
1	0.208	0.485	0.231	0.516	0.243	0.516	0.039	0.047	0.012
2	0.208	0.471	0.232	0.506	0.243	0.506	0.042	0.049	0.011
3	0.187	0.485	0.204	0.517	0.211	0.512	0.036	0.036	0.009
4	0.186	0.49	0.205	0.521	0.208	0.516	0.036	0.034	0.006
5	0.19	0.478	0.207	0.509	0.211	0.506	0.035	0.035	0.005
6	0.212	0.466	0.241	0.504	0.241	0.502	0.048	0.046	0.002
7	0.213	0.481	0.234	0.505	0.249	0.512	0.032	0.048	0.017
8	0.181	0.472	0.191	0.506	0.198	0.502	0.035	0.034	0.008
9	0.182	0.477	0.244	0.5	0.202	0.509	0.066	0.038	0.043
10	0.216	0.475	0.242	0.507	0.259	0.514	0.041	0.058	0.018
11	0.219	0.483	0.242	0.512	0.257	0.515	0.037	0.05	0.015
12	0.177	0.47	0.194	0.505	0.197	0.502	0.039	0.038	0.004
13	0.178	0.472	0.196	0.508	0.203	0.503	0.04	0.04	0.009
14	0.178	0.462	0.194	0.498	0.196	0.497	0.039	0.039	0.002
15	0.182	0.472	0.202	0.508	0.203	0.505	0.041	0.039	0.003
16	0.221	0.496	0.249	0.522	0.256	0.523	0.038	0.044	0.007
17	0.205	0.506	0.231	0.53	0.229	0.534	0.035	0.037	0.004
18	0.277	0.477	0.273	0.51	0.268	0.512	0.033	0.036	0.005
19	0.186	0.461	0.209	0.504	0.208	0.496	0.049	0.041	0.008
20	0.225	0.491	0.258	0.521	0.268	0.52	0.045	0.052	0.01
21	0.2	0.478	0.227	0.513	0.236	0.509	0.044	0.048	0.01
22	0.197	0.467	0.224	0.507	0.228	0.502	0.048	0.047	0.006
23	0.17	0.475	0.189	0.513	0.183	0.507	0.042	0.035	0.008
24	0.211	0.471	0.239	0.508	0.242	0.505	0.046	0.046	0.004
25	0.192	0.485	0.217	0.518	0.222	0.514	0.041	0.042	0.006
26	0.18	0.479	0.205	0.516	0.199	0.51	0.045	0.036	0.008
$\overline{X}$							0.041	0.047	0.014
σ							0.007	0.019	0.02

It seems that the assessed 26 different colours in plates no. 2–15 seem to be quite low, but Lakowski [22] proved that colours are repetitively used in the plates. Regarding the shift in the colours during the day, there is a mean difference of,$\bar{x}_{\Delta \text{ (morning;evening)}} = 0.041$, between the measurements in the morning and in the evening. This mean shift is three times larger than the difference between the measurement in the evening daylight and the measurement at the monitor ($\bar{x}_{\Delta\text{(morning;CRT)}} = 0.041$). These differences showed that metameric colours of the plates cannot be achieved using reflected daylight and the CRT monitor.

The used EIZO monitor is distributed by the manufacturer with three different standard colour modes. Pressing a button, these standard settings can be recalled as reference values. An examination showed that the minimal mean difference could be achieved by using a colour mode[1] and therefore this mode is used as the standard. The colour temperature was 5800 K.

Other monitors might cause different shifts of the colours. This requires an analysis to find a reference setting for each monitor that causes the least difference for the reflected daylight from the plates. The colour temperature of 5800 K can be taken as a reference.

The Ishihara test applied to computer-based screening is a module in a larger screening system to examine the visual system [12]. This requires that the monitor settings can also be used in other vision tests, such as in the assessment of visual acuity [23] or contrast sensitivity. Here, the recommendations of the Visual Function Committee of [24] 80–320 Cd/m^2 for the test area are taken into consideration. A reason to choose a mean luminance of the PC-monitor of 100 Cd/m^2 is the near future application of contrast sensitivity analysis. Laboratory examinations for this application show 100 Cd/m^2 to be a reasonable value. Nevertheless, other luminances for the monitor seem also to be reasonable.

As a reference setting for a monitor, the values from Table 1 are recommended. The reason is that this is a standard setting provided by the manufacturer. This approach is also taken using the scanner, on the assumption that different devices do not cause major differences.

[1] According to the manufacturer, this setting results in a white colour, whose hue is closest to that on paper.

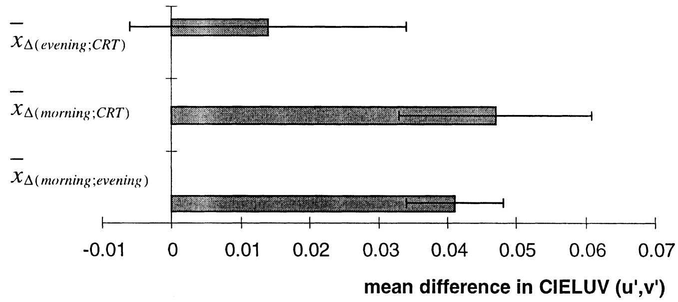

Fig. 3. The mean differences in the 26 different colours of the Ishihara plates are presented for the CIELUV-coordinates. The values are compared for the measurements in the morning and evening at daylight and the measurements on the CRT monitor. The standard deviation is shown.

The fact that a monitor can be controlled allows a higher degree of repeatability of the examination results using emitted light by controlled constraints. This can be seen as an advantage of the CRT monitor presenting the Ishihara plates, because daylight cannot be controlled. This study shows a large mean shift in the colours for CIELUV coordinates during the day.

Further work should examine whether the shift in the colour lies on confusion lines for colour. Subjects with weak colour discrimination mix up colours on these lines. Lakowski [22] showed for certain plates a change for the location of background and figure. Following these confusion lines, half of the background and half of the number represented on the Ishihara plates for normal subjects becomes the figure, and the other half of the figure and background becomes the background for dichromates. The probability of false perception for anomalous trichromates is related to the distance of the colours to be discriminated. This distance is calculated by projection of the colours onto the confusion lines.

As shown, metameric colour could not be generated for the Ishihara plates when presented on the CRT monitor. This leads to the required determination of the influence of distance shift when transferring the plates onto a monitor.

3. Experimental use of the Ishihara test on a CRT monitor

3.1. Method

The idea of the Ishihara test is based on the assumption that differences in colour and contrast on the plates are perceived differently by subjects with colour deficiency and those without colour deficiency. The accuracy of the colour design in terms of compliance with isocromatic data for red–green colour deficiency was established by Lakowski for the 10th edition. The 10th edition used in the experiment has 24 plates. Here, the first plate is used for illustration of the principle to the subject. The plates 2–15 show numbers which are differently perceived by normal subjects and by subjects with an abnormal colour vision. The plates 16 and 17 can be used for classification of colour deficiencies. The plates 18–24 represent trajectories which are differently perceived by subjects with and without colour deficiencies. Those plates can be used for children or illiterates. A more detailed description is given by Haskett and Hovis [25].

The Ishihara test is carried out by showing the plates for a maximum of 3 s in daylight at a viewing distance of 75 cm. The plates have a size of 12×12 cm^2. The sequence of the presented plates is fixed by the numbering. A subject is classified as colour deficient if four or more plates 2–15 are detected incorrectly.

The experiment was carried out using plates no. 1–15. The Ishihara test is to be used as a screening application, and this is why a classification of an assessed deficiency is not required. The subjects had to perform the test, once with the PC[2], and once with the original Ishihara plates[3]. The sequence of the tests was divided: one-half of the subjects performed the PC-Colour test first, the other half started with the Ishihara test. The subjects were 20 male subjects aged between 25 and 42 y. In this experiment 10 of these subjects were classified as colour deficient and 10 of the subjects were not classified as colour deficient when using the Ishihara test.

Using the PC-Colour test the plates were presented applying the same restrictions (duration, size, viewing distance) as in the Ishihara test. Using the PC-Colour test, the plates were presented in a random order to reduce learning effects. The subjects transmitted their answers by using the keyboard. The subject answered by typing the number pad of the keyboard, or if the subject did not detect any number, the subjects indicated this by typing ‘0’.

The luminance of the monitor ranged between 95 and 105 Cd/m^2 for white colour with the external light switched off.

According to a very recent study by Birch [6] in which 401 colour deficient subjects were examined the sensitivity of the Ishihara test is more than 95.5%. Therefore, the basic assumption in this experiment was that the Ishihara test is

[2] In this article, the Ishihara-Test with representation of the plates on the monitor is referred to as the *PC-colour* test.

[3] The Ishihara-Test with traditional plates is referred to as the *Ishihara* test.

Table 3
Summary of the classification results of both the colour vision tests. 20 subjects were examined. 10 subjects were classified with colour deficiency, 10 subjects were classified as not colour deficient using the Ishihara test. One of the 10 colour deficient subjects was classified as false-positive when using the PC-Colour test.

Ishihara test classification	PC-Colour test Subjects without colour deficiency	Subjects with colour deficiency
Subjects without colour deficiency	10	0
Subjects with colour deficiency	1	9

reliable in discriminating colour deficient subjects from those without colour deficiency. The results assessed when using the PC-Colour test were compared with those of the Ishihara test to draw conclusions about the suitability of the PC-Colour test to be made.

Haskett and Hovis [25] showed that some plates are better detectable than others, i.e. plate 7 is the one which is most misread. This is true for subjects with and without colour deficiencies. The consequence is that a wrong answer to this plate is a low indicator for judgements about colour deficiencies, because this plate causes a large number of wrong answers also for subjects with normal colour vision.

When judging the quality of discriminating ability, Crone [26] defined the screening-inefficiency (SI) of a plate by:

$$SI = \frac{\sum(\text{false positive answers}) + \sum(\text{false negative answers})}{\sum \text{answers}}.$$

It can be expected that the different representation media of the plates cause different answers. This is why in this study the screening-inefficiency is taken into consideration. This can be viewed as an indication if there are plates unsuitable for screening using a CRT monitor.

Testing the systematic difference in the answers (correct/false) of both methods a χ^2-test for nominal-scaled data was used.

3.2. Results

The common criterion to determine anomalous colour vision is a minimal four false detection for plates no. 2–15. Using this criterion, nine of the 10 colour deficient subjects were detected by the PC-Colour test. One colour deficient subject did not detect six plates correctly in the Ishihara test. The same subject did falsely detect three plates using the PC-Colour test. Therefore, the subject was classified as false-negative.

The 10 subjects without colour deficiencies gave nearly identical answers for the 14 plates. There was just one different answer for plate 14 between the two approaches. Therefore all subjects were classified as correct-positive using the PC-Colour test. This leads to a sensitivity of 90% and a specificity of 91%. The summary of the results is shown in Table 3.

The discrimination results of the subjects, when categorised by subjects with normal and abnormal colour vision, does not lead to a significant difference after applying the χ^2-test ($p = 0.65$). Comparing all answers to the set of plates leads to a different result. The Ishihara test results in 154 correct answers and 126 false answers, but the PC-Colour test leads to 200 correct and 80 false answers. Comparing these absolute numbers using the χ^2-test leads to a highly significant difference ($p < 0.001$). This requires a more detailed analysis of each single plate.

The comparison of the answers by the Ishihara test and PC-Colour test show significant differences for some single plates after applying the χ^2-test. The screening inefficiency of all single plates is shown in Table 4.

The mean screening inefficiency and the standard deviation when using the 14 plates for the Ishihara test and the PC-Colour test results in the value illustrated in Fig. 4.

This shows an increased mean screening inefficiency when using the PC-Colour test.

3.3. Disussion

A complete validation of the PC-Colour test is not possible because of the small test population and its equal distribution of colour normal and colour abnormal subjects. This distribution of the tested population did not have the real prevalence of 8% colour deficient males [3].

The different media used to present the plates cause a shift of the colours, which leads to different perception. Nevertheless, the hypothesis is still valid. Despite the different answers for the presentation at daylight and for the presentation onto a PC monitor, there is just one subject false-negative classified. No subject was classified false-positive. This difference is caused randomly.

The results of the examination indicate a reduced specificity of the PC-Colour test. PC-Colour test had 25% higher correctly detected plates for the abnormal subjects than the Ishihara test which means a reduced number of false positive answers. Some of the plates are easier to recognise when presented on a PC monitor. These plates are not well suited for screening purposes. Katavisto [27] defined an Ishihara plate as being suitable for screening purpose, if the screening inefficiency is lower than 0.1. After investigating each single plate used in the PC-Colour test, the Katavisto criteria are applied. This results in seven out of 14 plates, which are suitable for screening purposes when using the CRT monitor. These plates are mainly those that did not cause significantly different answers between the PC-Colour test and the Ishihara test (see Table 4). In total

Table 4
Analysis of the answers to the Ishihara plates for both the colour vision tests. The screening-inefficiency values and the difference in the answers to each plate was statistically analysed applying the (2-test. The following indiced are used: n.s.: $p > 0.05$; *: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$.

Number of Ishihara plates	Ishihara test		PC-Colour test		χ^2 -test	Screening-inefficiency	
	Correctly answered	False answered	Correctly answered	False answered		Ishihara-Colou rtest	PC-Colour test
2	11	9	12	8	n.s.	0.05	0.1
3	11	9	11	9	n.s.	0.05	0.05
4	11	9	19	1	***	0.05	0.45
5	12	8	18	2	**	0.1	0.4
6	12	8	20	0	***	0.1	0.5
7	10	10	10	10	n.s.	0	0
8	12	8	11	9	n.s.	0.1	0.05
9	11	9	13	7	n.s.	0.05	0.15
10	10	10	17	3	**	0	0.35
11	10	10	11	9	n.s.	0	0.05
12	10	10	12	8	n.s.	0	0.1
13	11	9	10	10	n.s.	0.05	0
14	13	7	19	1	**	0.15	0.45
15	12	8	17	3	*	0.1	0.35

there were eight plates which did cause a nonsignificant difference for both colour vision tests. Using the Ishihara test all but plate no. 14 were well suited for screening purposes applying the Katavisto criterion. This is consistent with the findings of Birch [4] who recommended not to use plates with hidden digits for screening purposes such as plate no. 14.

Regarding less strict criteria for a screening inefficiency of 0.25 [25] and the mean screening inefficiency value of all plates, the applicability of the PC-Colour test is given (see Fig. 4).

There are high inefficiency values for several plates using the PC-Colour test, but this can be explained. The tested population does not reflect the real prevalence of colour deficiency which is 8% [3]. Regarding the occurrence of subject with abnormal colour vision in the subject population (50%) and also the answers of the normal subjects, which cause only one false-negative answer, it can be expected that the screening inefficiency will decrease. This is caused by the definition of screening inefficiency, because the denominator will be increased by a fixed nominator.

The average screening inefficiency value for the 14 plates using the Ishihara test ($\bar{x}_{\mathrm{SI(Ishihara\ test)}} = 0.057$) is nearly one-fourth smaller than using the PC-Colour test (see Fig. 4). But, if only these eight plates of the PC-Colour test, which did not cause a significant difference between both the colour vision tests, are used, then the mean screening inefficiency of the PC-Colour test decreases to $\bar{x}_{\mathrm{SI(PC\ Colour\ test)}} = 0.062$ and a standard deviation of $\sigma_{\mathrm{SI(PC\text{-}Colour\ test)}} = 0.052$. These values are nearly identical to the ones taken from the Ishihara test.

The results of the experiment showed that the plates 4, 5, 6, 10, 14, 15 cause a significant difference for the answers between both colour vision tests (see Table 4). This questions the suitability of these plates for screening purposes. This reduced qualification is supported by high screening inefficiency values. The results by Birch [6] also show that the plates that hide the numbers, in our experimental Ishihara test plates no. 14 and 15, have minor qualification for screening purposes. Haskett and Hovis [25] state the suitability of plates no. 6 and 10. These results are based on experiments without a PC. Our experiment shows a high degree of screening qualification for plates no. 7, 10, 11, 12.

Regarding the overall result, just one false classified subject occurred. The subject was classified as false-negative (see Table 3). An opportunity to classify this subject as correct positive could be to reduce the criteria from a minimum of three to four falsely detected plates for the PC-Colour test. This would cause the same classification result

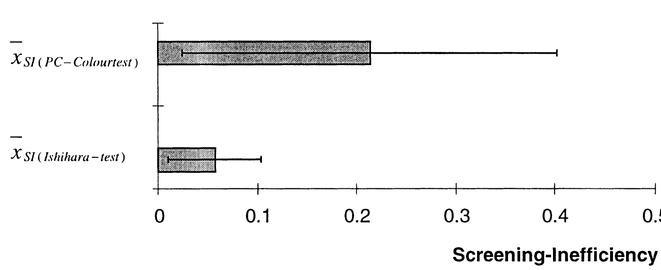

Fig. 4. The mean screening inefficiency values of the Ishihara plates no. 2–14 are illustrated when using the PC-Colour test and the Ishihara test. The standard deviation is shown.

Table 5
Correct false determined plates by subjects with colour deficiencies using the Ishihara test (column 2), the PC-Colour test using 14 plates (column 3)and PC-Colour test using eight plates (column 4).

Subject	Ishihara test (criteria: 4/14)	PC-Colour test (criteria: 4/14)	PC-Colour test (criteria: 2/8)
1	12	8	7
2	14	10	8
3	13	11	8
4	13	8	8
5	10	7	7
6	14	7	7
7	6	3	2
8	14	8	8
9	14	10	8
10	13	8	7
# determined colour deficiencies	10	9	10

when using the Ishihara test (see Table 5). However, one point has to be taken into consideration: the application is made for screening purposes. Therefore, it is not reasonable to use those plates that are not suitable for screening. Plates with high screening inefficiency values should not be used. This means, if all plates which caused significantly different answers between both colour vision test and those have high screening inefficiency are not used in the PC-Colour test, the illustration plate no. 1 and plates no. 2, 3, 7, 8, 9, 11, 12, 13 remain.

The common criteria to determine colour deficiency uses at least four false answers at the presentation of plates no. 2–15. This results in a relation between false answers and all possible answers of $4/14 = 3.5$. Applying this ratio to the eight evaluated plates, the criterion has to be decreased to at least two false detected plates to establish a similar threshold $8/3.5 \approx 2.2$.

Subject no. 7 with colour deficiency was classified false-negative using the 4/14 criterion. If now only the answers to the eight plates, which did not cause a significant difference in the answers to both colour vision tests, were analysed and the 2/8 criteria is applied, subject no. 7 is also classified correct-positive. In this case the result of the PC-Colour test is identical to that of the Ishihara test. This result is summarised in Table 5.

This leads to the following recommendations for applying the Ishihara plates in a computer-based approach using a CRT monitor for testing colour vision in a screening application.

- In addition to the illustration plate no.1 plates no. 2, 3, 7, 8, 9, 11, 12, 13 will be presented in random order.
- At least two false answers for these plates leads to a classification of the subject as colour deficient.
- The luminance of the monitor should be about 100 Cd/m^2. The colour temperature should be 5800 K, that lead to the settings of Table 2.

This procedure speeds up the examination, because this approach uses just nine instead of 15 plates presented to the subject.

4. Conclusions

This article presents a PC-based screening approach to assess red–green colour deficiency by presenting the Ishihara plates on a CRT monitor.

An identical spectral emission of the reflected daylight of the plates and the emission at a monitor based on CRT technology is not possible. This is caused by technical constraints of the CRT technology. Nevertheless, calibration of the monitor allows a controlled spectral emission for the Ishihara plates represented at a CRT monitor in contrast to the uncontrollable daylight.

An experiment was performed on 20 subjects. The subjects were tested using the original Ishihara plates and using the computer-based colour vision test that presented the Ishihara plates on the CRT monitor. The experimental results showed that all but one of the 10 abnormal subjects classified by the Ishihara test were also classified as colour deficient using the PC-Colour test. Applying the χ^2-test showed that this difference is not significant.

The sensitivity and specificity of the PC-Colour test are reduced in comparison with the Ishihara test. This is supported by a higher screening inefficiency for some plates and the mean screening inefficiency value of all plates. Therefore, this article suggests that only those plates with a low screening inefficiency values should be used within the PC-Colour test. These plates did not cause a significant difference for the answers to both colour vision tests.

The criteria to determine colour deficiency should be reduced to at least two false answers for those eight plates (no. 2, 3, 7, 8, 9, 11, 12, 13). This leads to a shorter examination that does not reduce the sensitivity and specificity, as proven in the experiment.

The aim of this work was to implement a rapid colour vision screening test on a computer-based platform using a CRT monitor. It was shown that the approach using the Ishihara plates and reducing the number of plates fulfils the requirements of the objective.

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