Colour discrimination in conservation students: the Farnsworth-Munsell 100–hue test

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Abstract: The matching colour in retouching depends on the ability of the observer to differentiate colour. This ability was measured on 28 volunteer conservation students of varying aged using a specific test of colour discrimination – the Farnsworth-Munsell 100-hue test. Fourteen of the subjects were aged between 18-28, six between 29-38, seven between 39-48, and one was over 49 years. The final results are: 50% of subjects showed a wide-ranging ability to differentiate colour: none of them was colour blind; 7% of the students, however, have low ability to discriminate hues but only one was aware of his deficiency. The author aims to reveal the importance of this test for the conservators, using it as a detector to select eligible subjects with high sensibility in colour discrimination, which is an essential predisposition to perform accurate colour matching in retouching.

Keywords: Farnsworth-Munsell 100-hue test; Colour discrimination; Students; Conservation; Retouching.

Discriminación del color en estudiantes de conservación: el test de *Farnsworth-Munsell 100-hue*

Resumen: La disposición de los colores en la reintegración cromática depende de la capacidad del observador para distinguir los tonos. Esta capacidad se analizó mediante una prueba de discriminación de color realizado en 28 estudiantes de conservación y restauración, de diferentes edades, que se ofrecieron para este estudio. La prueba se llama *Farnsworth-Munsell 100-hue*. Catorce de los estudiantes examinados tenían entre 18 y 28 años de edad, seis entre 29 y 38 años, siete entre 39 y 48, y solo uno tenía más de 49 años. Los resultados obtenidos fueron: 50% de los estudiantes demostraron una capacidad superior para discriminar el color; y 7% de los individuos tuvieron una discriminación de color inferior. Sólo uno de estos estudiantes sabía que tenía esta deficiencia en la identificación del color. El propósito de este trabajo es presentar la importancia que esta prueba puede tener en la reintegración de color, ya que se puede utilizar para identificar y seleccionar a los estudiantes con más sensibilidad a la discriminación de los colores.

Palabras clave: Test de *Farnsworth-Munsell 100-hue*; Discriminación de color; Estudiantes; Conservación y restauración; Reintegración cromática.

Discriminação de cores em estudantes de conservação: o teste Farnsworth-Munsell 100–hue

Resumo: O acerto de cores na reintegração cromática depende da capacidade do observador em diferenciar a cor. Esta capacidade foi analisada através de um teste de discriminação de cor realizado a 28 estudantes de conservação e restauro, de diferentes idades, que se voluntariaram para este estudo. O teste denomina-se *Farnsworth-Munsel 100-hue test*. Catorze dos estudantes analisados tinham entre 18 e 28 anos de idade, seis entre 29 e 38, sete entre 39 e 48 e apenas um tinha acima dos 49 anos. Os resultados obtidos foram: 50% dos estudantes demonstraram ter uma capacidade superior para a discriminação de cor e 7% dos indivíduos revelaram ter uma discriminação de cor inferior. Apenas um destes estudantes conhecia esta deficiência na identificação da cor. O objectivo deste artigo é dar a conhecer a importância que este teste pode ter para a reintegração cromática, uma vez que pode ser utilizado para identificar e seleccionar os estudantes com mais sensibilidade à discriminação de cor.

Palavras-chave: Farnsworth-Munsell 100-hue test; Discriminação de cor; Estudantes; Conservação e restauro; Reintegração cromática.

Introduction

The interpretation and matching of the surrounding colours of a certain loss depends on the ability of the conservator to distinguish hues and also on the capacity to reproduce them. In conservation teaching and training it is often assumed without any formal testing, that all students are competent colour discriminators and that all are able to retouch. This study tries to demonstrate that is necessary to do a formal test that will specify possible vision defects of the conservation students. Therefore, this investigation will use a specific test of colour discrimination – the Farnsworth-Munsell Colour Discrimination - also called Farnsworth-Munsell 100-hue test [figure 1].

Figure 1. Farnsworth-Munsell 100-hue test.

The Farnsworth-Munsell colour discrimination test was created by Dean Farnsworth, a colour scientist who worked for the Munsell Division of the Kollmorgen Corporation[1] during 1940s and '50s (Farnsworth 1957). Is one of the many colour tests (Bruni and Velasco e Cruz 2006) that are being used, in this century, for measuring colour discrimination, i.e., the ability to discriminate between various shades of a given colour, that separate persons with normal colour vision into classes of superior, average and low colour discrimination. According with Dean Farnsworth (1957: 4):

- Superior Colour Discrimination: About 16% of the population makes 0 to 4 transpositions on the first test, or total error scores of 0 to 16. This represents a superior range of competence for colour discrimination.

- Average Colour Discrimination: About 68% of the population score between 20 and 100 on first tests. This is a normal range of competence for colour discrimination.

- Low Colour Discrimination: About 16% of the population make total error scores of more than 100. The first retest may show improvement, but further retests do not significantly affect the score.

With this kind of test it is also possible to measure the zones of colour confusion from colour defective persons. In industry it is used to test employees in colour control laboratories involved in the manufacture of paints and dyes (Farnsworth 1957: 2), textiles and photographic materials, since

these occupations require accurate colour discrimination (Mantyjarvi 2001), representative of most of consumer population. Like other sectors (Aarnisalo 1984) of knowledge, testing colour vision for vocational purposes becomes essential for the optimization of retouching task.

On the other hand, Farnsworth-Munsell (FM) 100-hue test is also used to evaluate patients with diabetes (Utku and Atmaca 1992) mellitusused and persons that work with chemical neurotoxic (organic solvents and metal) (Gooba and Cavalleri 2003). In these cases, tests have evidenced that subjects exposed to high values of organic solvents concentration in ambient air, like petroleum derivatives, can acquire colour vision disturbances and even loss of colour vision (Zdzieszyńska and Goś 1995; Muttray et al. 1995). This loss, according with Zavalic et al., can be chronic and the possible reparation period in colour vision impairment is longer than 64 hours (Zavalic et al. 1998: 135-180). The high exposure to toluene may cause optic neuropathy and retinopathy, both associated with dyschromatopsia[2]. Another solvent, ethanol, is known to induce acute blue-yellow dyschromatopsia (Muttray et al., 1999: 41-45).

This kind of information can be useful because many times the conservator become careless in carrying out the final retouching with resins that are dissolved in organic solvents, like mineral spirits or toluene/ xylene, since the task are made without proper equipment (gloves, mask, glasses, among others).

Methods

The FM 100-hue test includes a total of 85 colours[3] mounted in numbered and removable plastic caps. Each cap is made of a different hue but with the same value and chroma (Farnsworth, 1957: 2; Dain, 2004: 276-293). The caps are separated into four boxes, each containing 21 or 22 caps. In addition, every box contains two pilot colour caps fixed on opposed borders of each box, making a total of ninety-three caps. The task of the subject must do is arrange the 21 or 22 removable caps so that they progressively change in hue, starting from the hue of the fixed cap on the left of the box and ending with the hue of the fixed cap on the right of the box [figure 2]. The closer the subject is to the correct sequence, the better is his colour discrimination.

Figure 2. Detail of one of the subjects arranging one of the four boxes.

In the attempt to achieve the prescribed lighting conditions of Dean Farnsworth, the 28 subjects were divided in two groups: 14 subjects was seated at a table facing the window on the North, in the time between 11:00 a.m. and 12:00 a.m. on a slightly overcast day; another group of 14 subjects was seated at a table with a 6500 Kelvin daylight fluorescent lamp with a colour rendering index (CRI) of 90[4]. With this kind of arrangement, we also tried to reproduce the conditions of the room were the students usually perform retouching classes. The tests were carried out between November of 2011 and January of 2012.

The test score of each subject was calculated using a computer program named FM Hue Test Scoring Software [figure 3]. The counting was done as follows: each simple transposition was counted as 4 points while a "perfect" score was 2; more than one inaccurate position of the colour was regarded as higher point value. Accordingly, the higher the score was, the poorer was the subject's colour discrimination.
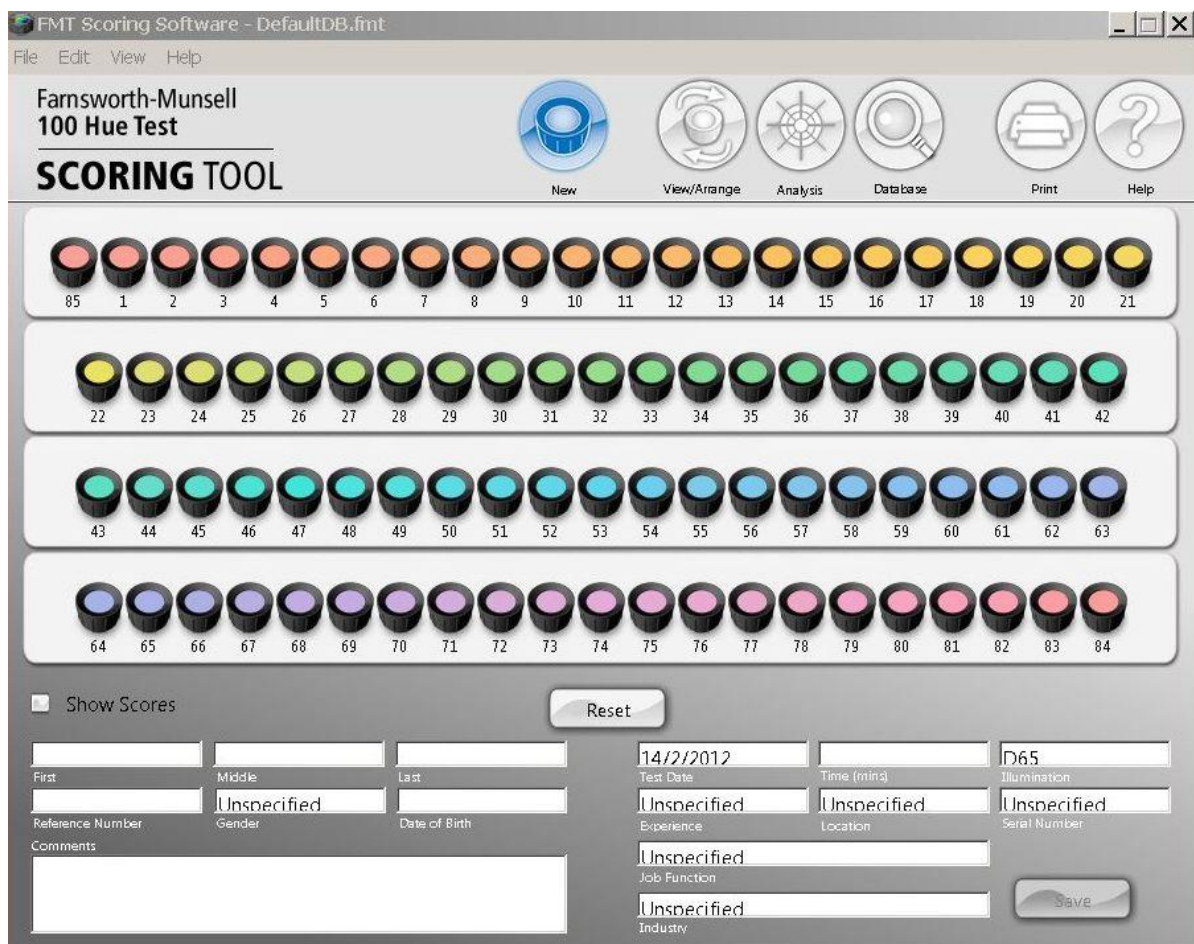

Figure 3. Screen of the FM Hue Test Scoring Software

The FM Hue Test Scoring Software has been developed to speed up and simplify the recording of the FM Hue Test data (cap order). It provides also a set of analytical and administrative tools where the data can be displayed in polar graph or linear graph format and analysed according to a variety of algorithms [figure 4 and 5]. This is one of the many programs that required data to be keyed in manually and runs on Microsoft Windows[5].
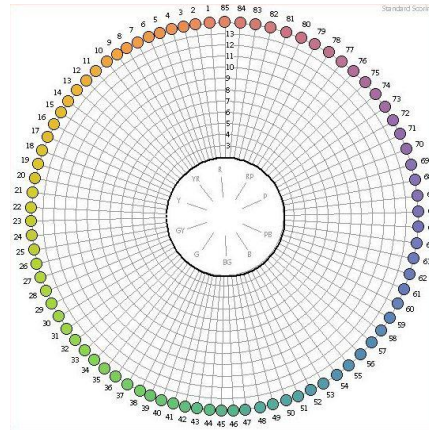

Figure 4. Example of a polar graph of a subject with 'perfect' hue discrimination.
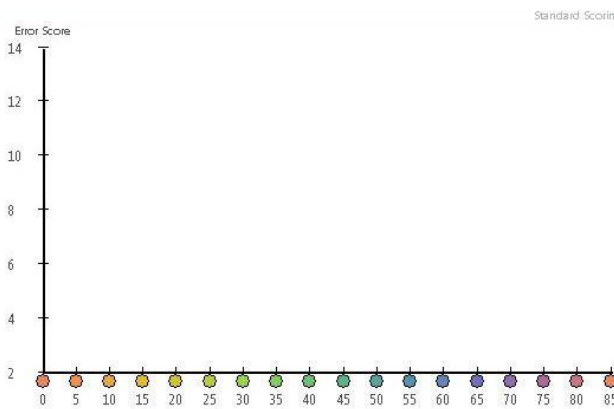

Figure 5. Example of a linear graph of a subject with 'perfect' hue discrimination.

Twenty-eight volunteer conservation students were studied. Fourteen of the subjects were aged 18-28, six were aged 29-38, seven were aged 39-48, and one was over 49 years.

According with previous reports (Verriest, Vandevyvere and Vanderdonck 1962; Verriest, Van Laetham and Uvijls 1982), the performance on FM 100 Hue Test varies with age. Younger children make significantly more misplacement errors than observers in their 20s. The performance of older adults also deteriorates with age. In addition, the development and the subsequent deterioration of the performance with age also vary for red-green and blue-yellow opponent systems. Namely, the blue-yellow sensitivity deteriorates more than red-green sensitivity for observers over 40. Kin-

near and Sahrai researchers did not find a difference as a function of sex and the performance of male and female observers were not significantly different. According with the same authors, the best performance on this test is achieved by those in their late teens and early 20s (Kinnear and Sahrai 2002).

In this study the majority of subjects tested are up to 20 years and above 40 years.

After the test completion, the classification of the participants, i.e., the total number of errors was calculated and compared with those of a standard reference population given by Dean Farnsworth (Farnsworth 1957: 4-6; Rigby *et al.* 1991):

- Superior discrimination: total error 0-16

- Average discrimination: total error from 20 to 100

- Low discrimination: total error > 100

Results

The results obtained with the Farnsworth-Munsell Colour Discrimination have marked two essential features:

• For normal colour vision, it reveals how well a person can discriminate different colours.

• It indicates if a given person has a colour vision defect and identifies where his colour confusion lies.

The results obtained with this study are:

- Of the 28 subjects tested, 14 students (50%) presented superior discrimination, 12 students (43%) present average discrimination and 2 (7%) presented inferior discrimination [figure 6]. Colour vision discrimination was statistically better with these conservation students when compared to standard reference population given by Dean Farnsworth.

- The results obtained with different light sources are: 8 subjects (57%) of the 14 conservation students that did the test with natural light present superior colour discrimination, 5 (36%) average colour discrimination and 1 (7%) low colour discrimination [Figure 7]; of the 14 conservation students seated at a table with a 6500 Kelvin daylight fluorescent lamp, 6 (50%) of them present superior colour discrimination, 7 (43%) average colour discrimination and 1 (7%) low colour discrimination [Figure 8].
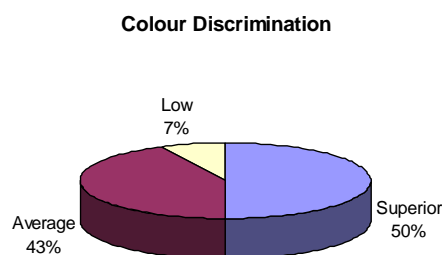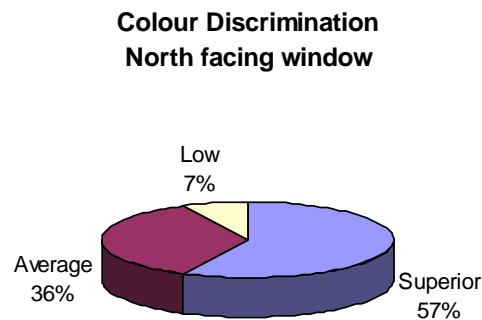

Figure 6. Graph of colour discrimination.

**Colour Discrimination
North facing window**

Figure 7. Graph of colour discrimination of the group seated at a table facing the window on the North.

**Colour Discrimination
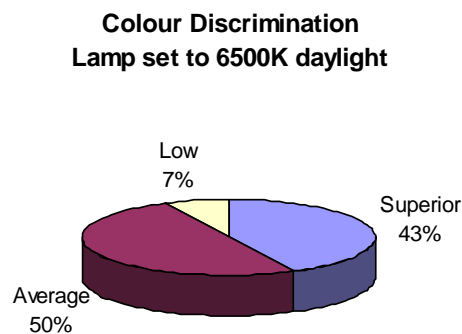Lamp set to 6500K daylight**

Figure 8. Graph of Colour discrimination of the group seated at a table with a 6500 Kelvin daylight fluorescent lamp.

Within this trial of 28 conservation students, there are small statistical differences in the error scores among the two groups: 36% of the subjects have average colour discrimination at the natural light and 43% using 6500 Kelvin daylight fluorescent lamp. Also a difference was seen among the conservation students with superior colour discrimination: 57% of the subjects show superior results at the natural light and only 50% with a 6500 Kelvin daylight fluorescent lamp. Moreover, a slight contrast was noticed in the error scores among different sex. Out of 28 subjects, 11 female students have superior colour discrimination while only 3 male show such quality; likewise, average discrimination was detected on eight females in juxtaposition with only four males. Concerning the age among 28 individuals it is possible to verify that the best performance is achieved by those in their late teens and twenties. The superior colour discrimination of senior students decreases with age [table 1]. One student that preformed the test at the natural light and two students which did the test using a 6500 Kelvin daylight fluorescent lamp did not make any errors. The polar graphs obtained show a perfect circle around its inner circumference, like those of Figure 4 and 5. On the account of two students with low ability discrimination, one was previously unaware of his low ability to discriminate hues [figure 9 and 10].

Table 1. Table with the ages, sex and colour discrimination results.

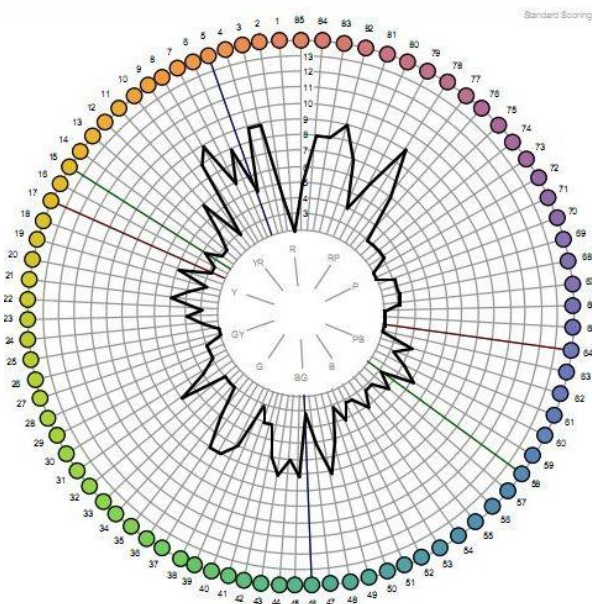| Age	Colour Discrimination					
	Male			Female		
	Superior	Average	Low	Superior	Average	Low
18-28 Years	1	1	1	8	3	0
29-38 Years	2	1	0	2	2	0
39-48 Years	0	2	1	1	3	0
49-52 Years	0	0	0	0	1	0

Figure 9. Test result of the conservation student with low ability discrimination. This subject was previously unaware of his low ability to discriminate hues.

This figure illustrates a person with great difficulty to distinguish shades and it seems to be an anomalous trichromat. For instance this individual seems to have the three cone photopigments and like normal trichromats, require three colours to match all spectral hues with normal colour vision, therefore is called a trichromat (Farnsworth 1957: 4). However, the relative proportions of the three primaries necessary to make a colour match are anomalous. The confusion axis shown in the figure 9, reveal that the "blue" cone photopigment has more abnormal absorption characteristics than others. The severity of the defect varies significantly between individuals.
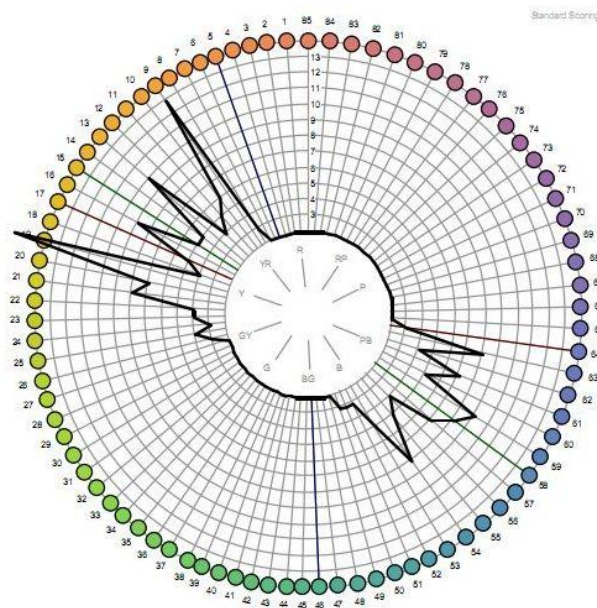
Figure 10. Test result of the conservation student with low ability discrimination. This subject was previously aware of his low ability to discriminate hues.

This graph also shows a person with difficulty while distinguishing hues. The confusion axis illustrates a green line dividing the erroneous data almost directly down the centre of both regions. This student seems to be a dichromat. Dichromats have two cone photopigments instead of three and are able to match all spectral hues using a mixture of just two colours. They are usually classified as protanope (long-wavelength pigment missing), deuteranope (medium-wavelength pigment missing) and tritanope (short-wavelength pigment missing). Because this student is the so-called "green blind", with difficulty seeing in the medium-wavelength, he is classified as "deutanope" or simply "deutan" (Farnsworth 1957: 4).

Conclusion

There are four steps in the retouching methodology: chromatic and formal study, selection of the retouching technique, choice of the retouching material and retouching practice (Bailão 2010; Bailão 2010a; Bailão, 2011). The recognition and the ability to discriminate colour of a given conservator are fundamental in the first step with the chromatic study. In this stage the conservator has to discriminate all the different hues around the loss and even in the entire object. Unfortunately, these abilities are never considered when appointing new beginners in conservation and restoration. Also, a whole career may pass without any formal assessment of colour discrimination. This study has shown that the population of conservation students tested has better performance than a standard reference population. Yet, one of the two persons with low ability discrimination was previously unaware of his low ability to discriminate hues. These two subjects with low ability to discriminate hues were male.

These two conservators' students that have low discrimination colour should seek confirmation of interpretation from more "colour able" colleagues for performing tasks that involve colour recognition. Moreover, it is advisable for them to avoid retouching that requires superior or average colour discrimination. Hence they should consider working in other steps of the conservation process that require less accurate colour vision.

Acknowledgments

Notes

[1]   Munsell is now a division of GretagMacbeth.

[2]   Dyschromatopsia is the inability to see some colours and occurs in about 8% of men and less than 1% of women. Dyschromatopsia is the more common form of colour blindness. Individuals with this condition usually have excellent vision. The person usually cannot tell the difference between shades of red and green. In rare cases, the person cannot tell the difference between shades of blue and yellow. Available at: http://www.medicineonline.com/articles/d/2/Dyschromatopsia/Color-Blindness.html.

[3]   The colour caps have matt surface. This kind of surface is necessary in order to give the same spectral characteristics from any angle, but it is sensitive to fingerprints.

[4]   There are two main attributes that define the value of an artificial light: colour temperature and colour rendering index (CRI). To get proper colour rendition of the 85 colours of the Farnsworth-Munsell 100-hue test the illumination should be daylight balanced and high CRI. The colour temperature of a light source is the temperature of an ideal black body radiator that radiates light of comparable hue to that of the light source. Colour temperature is conventionally stated in the unit of absolute temperature, the kelvin, having the unit symbol K. Colour temperatures over 5000K are called cool colours (blueish white), while lower colour temperatures (2700–3000 K) are called warm colours (yellowish white through red). The colour rendering index (CRI) is a quantitative measure of the ability of an artificial light source to reproduce the colours of various objects faithfully in comparison with natural sunlight. For comparison, sunlight has a CRI of 100 and artificial light sources with a CRI of 80 or higher offer a truer light and display all the colours of the light. (Li, Ronnier Cui 2011).

[5]   Over the past 30 years, many researchers have developed computer programs to perform the reporting of the FM 100-hue test. The most recent computer program (year 2008) was developed in JADE 6.0 and runs on Microsoft Windows. Is a computerised scanning system for the FM 100- hue, designed to address the limitations of existing automated FM 100-hue reporting systems (Hidayat 2008).

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