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The Effect of Colour Defective Vision on Shade Matching Accuracy

J Ethell*, FD Jarad† and CC Youngson‡

Abstract - *One hundred and forty one male dental students and staff were screened for colour-defective vision. Ten colour-defective and 20 non colour-defective subjects then carried out a shade matching exercise using nine selected shades and another, matched, shade tab (to test for consistency) from Vita shade guides. All shade matching took place under standard lighting conditions. Each subject also completed a short questionnaire relevant to shade matching. There were no significant differences found between colour-defective and non colour-defective subjects in shade matching abilities. Although both subject groups were similar in their shade matching abilities, individuals with colour defective vision perceived it to be a slightly more difficult exercise.*

KEY WORDS: Colour defective vision, Shade matching

INTRODUCTION

Colour is defined as the result of the physical modification of light by colourants, as observed by the human eye and interpreted by the brain [1]. Colour can be described as a three dimensional quantity and can be specified by the three basic colourimetric terms for colour sensation, Hue, Value and Chroma [2]. Hue distinguishes one colour family from another e.g. red from yellow, green from blue. Value relates to the quality that categorises a colour as light or dark colour. Chroma is the saturation of a particular hue, also known as colour intensity [3].

Visual colour evaluation of teeth using a colour standard (a shade Guide) is still the most wildly used method in dentistry. Despite their limitations, the use of shade guides is a quick and cost-effective method for recording tooth colour. The tooth colour is determined by the dentist using a shade guide and then the selected shade is either used to select a direct restorative material (e.g. a composite) or communicated to the laboratory for construction of indirect restorations such as crowns, bridges, or dentures [4].

Colour-blindness, more accurately known as colour-defectiveness, occurs in the population as an inherited sex-linked recessive trait involving the x-chromosome [5]. Colour-defectiveness refers to all grades of inability to distinguish or match colours, but the complete loss of colour sense is extremely rare. Approximately 8% of males and 0.4% of females suffer various degrees of colour-defective vision [6]. Colour deficiency can occur in all populations, but is less common in Japanese, Chinese and Africans. The underlying abnormality lies in the absence or deficiency of the photo pigments in the retinal core receptor cells [7]. Different types of colour defective vision are described depending on which colour the deficiency in colour perception relates to, namely red (protanopia. The commonest deficiencies recognised in human colour vision relate to red and green colour perception [8].

Relatively little research regarding defects in colour vision and), green (deuteranopia) and blue (tritanopia). Partial defects in colour vision are also recognised and these are termed protanomalous, deuteranomalous and tritanomalous respectively dentistry has been published. Those studies that have been conducted to identify the proportion of dentists who have colour-defective vision have found them to be representative of the trends seen in the general population [3,9-11]. The reported values in dental personnel range from 7.8% to 14% [11, 3].

Moser et a l[9] observed that out of 670 dentists, tested with Divorine Pseudoisochromatic plate tests, 9.9% had some degree of abnormal colour vision. No statistically significant relationship of colour deficiency with age was found. Wasson [10] screened 150 (75 male and 75 female) adult subjects (including dental students, hygienists, dentists, dental assistants and staff of a dental school) using standard Pseudoisochromatic Plates-Congenital. 7 male subjects (9.3%) exhibited a colour-vision defect; there was no evident link to the race of the subject and no relationship to age.

In 1990 Davison and Myslinski [11] investigated shade selection by colour-defective dental personnel, compared to subjects with normal vision. Out of 343 students, 19 subjects (males) showed colour-defective vision. To compare shade selection ability, the matching of standard shade tabs was used and assessment was made of the ability to match the separate components of colour (i.e. Value, Hue and Chroma). Analysis of results showed that the colour-defective group made highly statistically significant errors in Hue and in Chroma selection but were similar in assessing value. This agreed with previous work by Barna et a l[3] who examined the influence of selected light intensities on colour perception within the colour range of natural teeth. Colour-defective dentists made significantly more errors in Hue selection.

*BChD.
† BDS. PhD. MFDS RCS (Eng)
‡ BDS.DDSc.FDS.DRD.MRD.FDS(Rest Dent)RCS(Edin)

The problems of shade matching have been reviewed in many studies [12-15]. The Council on Dental Materials, Instruments and Equipment have described the influential factors in shade matching[12]. The observer is the first variable and it was noted that "the ability to distinguish colours is not uniform among observers" but that "the observer can be trained in colour discrimination by the repeated use of standard colour tests." The next variable is the object (tooth) which may modify light and hence colour by transmission, absorption, reflection and scattering. The illuminant and shade matching environment are also important factors; although daylight has some phases of the basic qualities for colour evaluation it constantly changes in quality and quantity and so is not a reliable source[13]. The final variable is the shade guide itself. The range of shades available in most shade guides are inadequate and does not cover the complete colour space of natural tooth colour and the systematic arrangement in their colour space. The commercially available shade guides may also vary between batches [4, 15].

Other problems encountered during shade matching have included inconsistency of matching. Although it has been recognised for many years that the ability of a dental practitioner to match colours and shades correctly is a critical component of restorative dentistry [16], individuals have been found to be unreliable in shade matching [15,17-19] or even reproducing their own shade selection [15,20] although some shades are matched more reliably than others [21]. Okubo [22] highlighted the need for more scientific and consistent shade matching in restorative dentistry.

The aim of the current investigation was to compare the shade matching abilities of colour-defective and non colour-defective subjects and determine the effects (if any) that colour-defective vision has on shade matching.

MATERIALS AND METHODS

Three hundred and fourteen potential participants were available in the dental teaching hospital where the study was being conducted. Colour defective vision is an x-linked recessive triad with approximately 8% of males and 0.4% females affected. One hundred females and 159 males were available. Following local Ethical Committee approval, all male subjects were screened for colour-vision defects using a selection of plates for identifying colour-vision defects [18] (Figure1). Twenty four Ishihara plates were used in total. Subjects were asked to read each plate and identify the number or pattern. If 1 or more plates were read incorrectly, the subject was identified as having a colour vision defect. Ten colour-defective subjects were identified. The level of clinical experience was of each subject was recorded.

Following the identification of the colour-defective subjects they were matched with non colour-defective subjects who had the same level of experience in shade matching. Following statistical advice, and a power calculation, 2 non colour-defective subjects were tested for each colour-defective one to increase the power of the study. 30 subjects were thus available for the study. 2 colour defective vision subjects were available in each of the second, third, fourth and fifth years of study and amongst the teaching staff. All the second year students had at least one term's clinical experience (including selection and placement of composites) prior to participating in the study.

The shade-matching test consisted of 10 shade tabs taken from Vita Lumin® shade guides. Eight differing shades and a pair of "identical" shades were all randomly selected. The pair of shades (C4) was included to test consistency in matching. Nine shades were all taken from the same shade guide (shade tabs selected were B1, A4, D3, C1, B3, A2, C3, D2 and C4). The shades were subsequently noted to be representative of the full range of hues (i.e. A, B, C and D) and values-chroma of the shade guide (i.e. low shade numbers represent high value and low chroma and *vice versa*). The matching C4 shade tab was taken from a different guide. Each shade tab was numbered and the identifier covered by tape. No time limits were set for shade matching but the time taken to complete the task was recorded for each individual.

The subjects were provided with another complete Vita Lumin shade guide, arranged by Value, to match the test tabs. In order to avoid the influence of extraneous light the shade matching exercise was carried out under standard D65 lamp lighting conditions on the bench of a light cabinet.

A questionnaire was completed immediately following the test partly to assess the subjects' perception of difficulties in shade matching. There was a section that asked the subject to record their ease or difficulty in shade matching; followed by a section that questioned their usual clinical technique. Subjects were asked questions including: whether they chose the shades with the teeth wet or dry, whether they asked for assistance whilst shade matching, how difficult they perceived the clinical procedure to be. The subjects were also asked to choose, from two further complete Vita Lumin shade guides arranged by Value or Hue/Chroma groupings, which form they preferred for shade taking. All statistical analysis was conducted using SPSS statistical software.

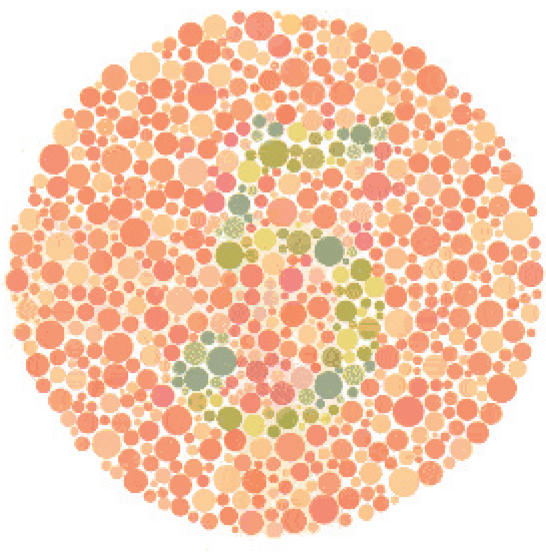

Figure 1. *Example of a plate used to identify colour defective vision (normal colour vision will see the number 5, red-green deficient will see number 2 or 8).*

RESULTS

From the available sample of 159 males, 141 were screened for colour vision status. 10 subjects (7.1%) were found to have a colour vision defect (all red-green deficient). The Mann-Whitney U test was used to determine if there was a statistically significant difference between colour-defective and non colour-defective subjects in shade matching abilities. No significant difference was found between colour-defective and non colour-defective subjects in their shade matching abilities ($p=0.588$). This test was also used to determine if there were any significant differences in correct hue (ABCD) and value matches made. Both of these results demonstrated no statistically significant difference between the colour defective and non colour defective subjects (Hue $p=0.190$, Value $p=0.908$).

Figure 2 shows the distribution of correct shade matches made by the 2 groups (in percentages of cases). The minimum number of correct matches was 3 and the maximum 9. When both groups were combined, the median number of correct matches was 7. The level of clinical experience did not appear to have any effect on the ability to correctly shade match but the sample sizes in each category were too small to allow statistical analysis.

In relation to the questionnaire, a significant proportion of the participants from both groups (60-65%) said that they usually seek the advice of both the patient and the nurse during clinical shade matching. There was no statistically significant difference in the perception of difficulty of shade matching and the times taken to complete the exercise were similar for both groups, With respect to students and staff, when recording their normal clinical practice, 30% from both groups reported that they selected the shade with the tooth wet, 15% from the non colour-defective group and 10% from the colour-defective group selected when both wet and dry. 80% of the non colour-defective group and 60% of the colour-defective group used surrounding light to match shades. Twenty percent of the non colour-defective group and 30% of the colour-defective group reported that their shade selection was usually undertaken using the operating light.

Using the chi-square test there was a statistically significant difference ($p\leq0.001$) in the preference of the arrangement of the shade guide. No colour defective subjects preferred the guide arranged by Hue/Chroma groupings (Table 1).

Table 2 shows that both groups were similarly consistent in their ability to shade match (χ^2 , no statistically significant differences).

DISCUSSION

Males were selected to participate in the study due to the small percentage of females within a population (0.4%) that may have a colour vision defect. 7.1% of the sample was identified as having a colour vision defect, which was slightly lower than previously demonstrated by Moser [9] (9.9%), but close to Davison's [10] findings of 7.8%. The slightly low figure may have been a result of the small sample size available or the genetic mix of the subject population In addition, the standard pseudoisochromatic plates test by Ishihara [23] that was used in this study is only a screening test for colour defective subjects and cannot describe the severity of the condition. Other colour defective tests which give a severity scale are available but are substantially more complex.

Vita Lumin shade guides were used to simulate the materials widely used in clinical shade matching although (to reduce variables inherent in the study) this was performed *in vitro* in a light cabinet rather than in a clinical environment. It was considered that using 2 similar shade guides would control some variables that may affect the perception of colour including colour and the shape of the object. However, although there are subtle differences between

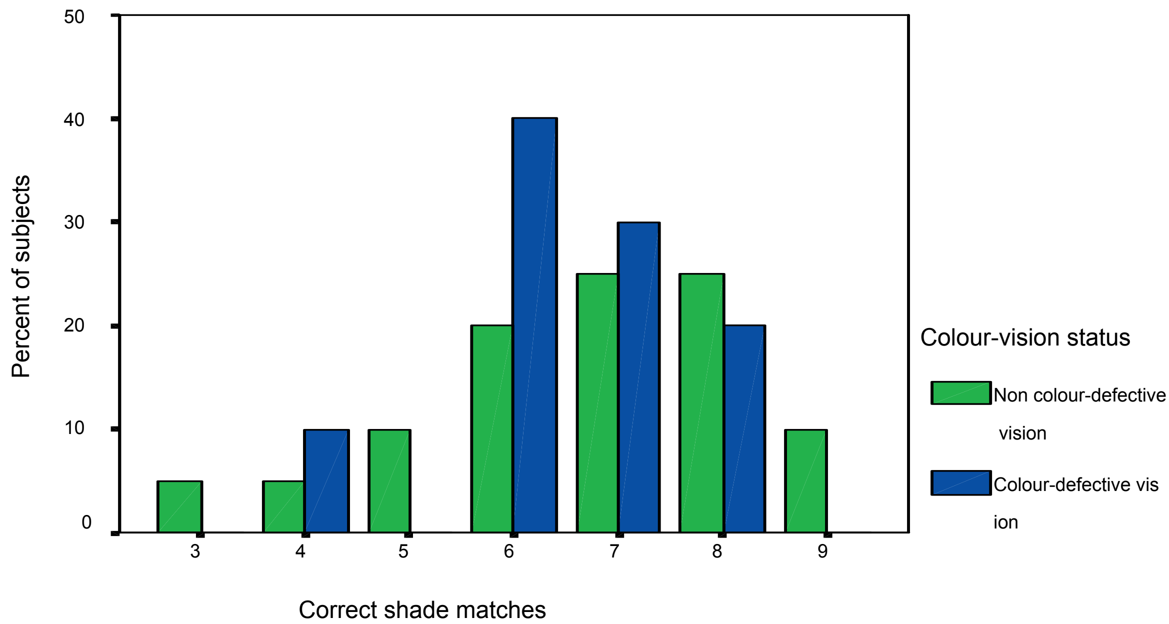

Figure 2. *Correct shade matches: colour defective and non-colour defective group*

Table 1. *Preference of order of shade guide.*

Order of shades	*Colour-vision status*		*% of Total*
	non colour-defective vision (%)	*Colour-defective vision (%)*	
Value	60.0	60.0	60.0
Hue/chroma	20.0	0	13.3
No preference	20.0	40.0	26.7
Total	100	100	100

Degrees of freedom: 2
Chi-square = 26.67
$p \leq 0.001$

Table 2. *Consistency of groups in shade matching.*

Consistency of matching	*Colour-vision status*		*Total % for both groups*
	non colour-defective vision (%)	*Colour-defective vision (%)*	
Consistent	65	60	63.3
Inconsistent	5	0	3.3
Consistent Hue	20	20	20.0
Consistent Value	10	20	13.3
Total	100	100	100

similar shade guides [4,19], these differences may still be considered to be acceptable [24]. The use of colour corrected light (D65) in this study was to control the effects of different illumination as a variable in shade matching [16].

The, randomly selected, "identical" tabs used in the study were both C4 but, as they were taken from 2 separate Vita shade guides, there could be subtle differences between the 2 shade tab. Another method to test shade matching ability could employ identical computer generated images of shade tabs but this would be one stage further away from the clinical situation. That technique may, however, be of use for training in shade matching [19].

The results from the shade matching tests showed no significant difference in matching abilities if the subjects were colour-defective. This does not agree with Davison's [10] highly statistically significant finding of differences between these groups.

That author also found that the colour-defective group made more statistically significantly errors in Hue but Value was unaffected. In the current study the colour-defective group did have more correct matches for Value rather than Hue but these results were not statistically significant. Sproull [14] considered Value to be the most important parameter of shade matching. Although the matching ability of both groups was not evaluated for Chroma, in isolation, it may be argued that by looking at matching patterns for Value, we were also evaluating Chroma. This is because the Vita Lumin shade guide basic arrangement is 4 different Hue groups and within these groups Value and Chroma are both linked.

The lack of statistical significance between colour and non colour defective subjects in the current investigation could be explained by the fact that in this study both observer groups matched a selection of shade tabs (simulating teeth) using a shade guide. This mimics the clinical setting. However, in contrast, many previous studies asked the observers to match duplicates of Munsell colour system chips. Although an ideal assessment of colour matching this does not represent shade matching in dentistry. This mean that in those studies important variables including tooth curvature and discrepancies in shade guides were not considered [3, 11]. Limiting factors in the current study that should be considered include the relatively small sample size, or wide variation in the colour of the shade tabs used, or because the shade guide had been arranged by Value (the standard form of supply in the teaching hospital), the arrangement that colour-defective vision subjects significantly prefer.

The majority of both groups were consistent in their matching abilities (65% of the non colour-defective group and 60% of the colour defective group). However, this does not agree with previous work[15, 20] although this might be due to the distinctive low value and high chroma of the (randomly) selected shade (C4) that represents an extreme rather than the most commonly encountered examples. This can be further explained by looking at the 3 dimensional colour space, where the value is represented by the long axis of the sphere and chroma is represented by the radius which increases from the value axis. Therefore, low chroma shades are clustered near the long axis with small colour differences, whereas high chroma shades will be spread out away from the centre, near the circumference. Although this shade was chosen randomly (to avoid unconscious bias in the study design) a limitation is that only one shade was selected.

The results from the questionnaire were able to highlight some of the problems associated with shade matching and showed similarities to results from previous studies. Firstly, slightly more of the colour-defective group, compared to the non colour-defective group, perceived shade matching as "quite difficult" rather than just "difficult". Secondly, the colour-defective group (who were all aware of their colour defective vision before taking part in the study) showed a general perception of caution when shade matching. They would seek the advice of others, more than the non colour-defective group. Even though they perceived difficulty, the results of the shade matching test showed they were not significantly worse at shade matching.

The background lighting and condition of tooth surface during shade selection has been reviewed in previous studies and several recommendations were made. 80% of the non colour-defective group and 60% of the colour-defective group used surrounding, light to match shades. For the 20% of the non colour-defective group and 30% of the colour-defective that selected under operating light, it should be advised they also use ambient light to help select a shade.

There was no demonstrable difference in the number of correct shade matches made based upon the level of clinical experience. This finding is in broad agreement with Davison [11] and Barna et al [3] who found no difference between individuals with more or less than 10 years in dental practice and Lagouvardos et al [22]. On the other hand, McMaugh [25] compared the matching ability of observers with varying levels of experience in the dental team and found a clear difference in the matching ability between the most and least experience. Therefore the results must be considered within the limitation of this study and a recommendation of conducting a multi-centre study were a large sample size can be evaluated. This may allow to find more definite answer to contradictory findings. More colour-defective subjects were identified in the first year of clinical training and within teaching staff. Interestingly, 1 of the most junior subjects was able to match 9 shades correctly and 1 of the teaching staff was only able to match 3 shades correctly.

Lighting conditions during shade selection has been reviewed in previous studies[4,13,16] and recommendations made to use two different lights to avoid metamerism (a colour that matches satisfactorily under one light source but unsatisfactorily under another). The use of a colour correct light or day light (more variable) with a relatively even spectrum energy has also been recommended. However the questionnaire highlighted the use of inadequate lighting during the clinical procedure by the subjects. There were mixtures of responses by the groups about the condition of the tooth surface. Thirty percent from both groups selected the shade with the tooth wet. It is important to undertake colour matching before the teeth become dry as previous work has demonstrated that all parameters of colours change following drying, with the teeth becoming lighter and less saturated [26] However the specular reflection associated with the enamel surface (especially when wet) can also influence one's perception of the shade. This accounts for some of the apparent shade change following biscuit bake try-in when the porcelain is glazed. This highlights the need for basic colour teaching and practical training to be included in the dental curriculum.

Only 10 colour-defective subjects were identified, hence the shade test had a small sample and this made it less likely that statistically significant results would be obtained. It is worth noting however that the results were very similar in both groups and that these are representative of the general population implying that clinically significant differences do not exist. The matching ability of the observers in this study was relatively comparable with other in vitro studies that have also been performed under tightly controlled conditions [15,17-19]. In the wider clinical setting, however, dentists will probably perform less well under the prevailing, variable, conditions. This is usually acceptable due to the fact that human perception is very tolerant and can adapt to a small colour changes.

A D65 lamp was used as illuminant as this lamp had a standard colour temperature (6500°K) which equates to "typical daylight" and was considered the most appropriate for objectively selecting the shades.

CONCLUSIONS

- Male dental students and dentists at a dental teaching hospital had a prevalence of colour-defective vision similar to that found in the general population.
- There was no significant difference found between the shade matching abilities of colour-defective and non colour-defective dentists and dental students.

MANUFACTURER'S DETAILS

Vita Zahnfabrik. H.Rauter GmbH & Co.KG. D-79713. Bad Sackingen. Germany

ADDRESS FOR CORRESPONDENCE

Professor Callum Youngson, Unit of Restorative Dentistry, Department of Clinical Dental Sciences, Liverpool University Dental School, Pembroke Place, Liverpool, L3 5PS, UK. E-mail c.c.youngson@liverpool.ac.uk.

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