

Factors influencing the shade matching performance of dentists and dental technicians when using two different shade guides

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IN BRIEF

- Explores a new approach to shade communication for laboratory fabricated all-ceramic restorations.
- Establishes that the FM-100 Hue test is not a good predictor of shade matching performance.
- Highlights the importance of experience in shade guide use.
- Indicates that tooth colour matching performance is not influenced by age or gender.

Introduction In recent years increased patient aesthetic expectations have brought about closer scrutiny of shade taking and communication processes with the aim of increasing the chances of success of obtaining good indirect restoration appearance. When shade matching, the most popular approach is to match the shade of the natural dentition using a shade guide to specify the shade of the final restoration before fabrication. A recent alternative approach is to also specify the shade of the tooth preparation to facilitate its replication in the die upon which the restoration will be made.

Objective To assess (1) the colour vision ability of a sample of dentists and dental technicians and correlate this to their shade matching performance in a simulated clinical situation, and (2) the accuracy and reproducibility of shade matches using two shade guides. **Design** In vitro study. **Method** Consenting dentists and dental technicians within Dundee Dental School and Hospital undertook a Farnsworth-Munsell 100 (FM-100) Hue test and matched (on two separate occasions) the shades of six prepared extracted teeth, containing either a veneer or crown preparation, using both the IPS Natural Die Material shade guide (Ivoclar Vivadent) (IPS) and the Vitapan Classical shade guide (VITA Zahnfabrik) (VC). **Results** Eighteen dental technicians (16 males and 2 females) and 40 dentists (21 males and 19 females) completed the study. The raw data revealed that many subjects were inconsistent in their approach to shade matching. The IPS guide afforded greater reproducibility. No significant effects ($p > 0.05$) of subject gender and age upon overall shade matching performance were demonstrated. Performance in the FM-100 Hue test did not statistically affect ($p > 0.05$) the outcome of matching using the guides. **Conclusions** Within the limitations of this study, (a) the FM-100 Hue test was not a good predictor of dental shade matching performance, and (b) both guides performed well in the areas of shade they covered, with the Vita Classical guide matching well shades of natural unstained teeth and the IPS guide matching more closely stained/discoloured preparations.

INTRODUCTION

In recent years increased patient aesthetic expectations have brought about closer scrutiny of shade taking and communication processes with the aim of increasing the chances of success of obtaining good indirect restoration appearance. When shade matching, the most popular approach is to match the shade of the

natural dentition using a shade guide, of which the Vita Classical is the most commonly used.¹ This is generally applied to specify the shade of the final restoration before fabrication. It has, however, been reported that the aesthetics of final restorations may be compromised by shine through of the underlying tooth substance.^{2,3} This is especially so in the case of thin porcelain veneers where, irrespective of the underlying cement, tooth substance remains visible through the restoration,⁴ spoiling its final appearance. A recent alternative approach is to also specify the shade of the tooth preparation to the dental technician to facilitate its replication in the die upon which the restoration will be made. A shade guide specifically made for this purpose is the IPS Natural Die Material shade guide (Ivoclar Vivadent, Schaan, Liechtenstein). Having a die whose shade

coincides with that of the tooth preparation is of potential assistance to the ceramist who can thus fabricate the restoration to avoid shine through. All shade guides, however, have limitations of accuracy, reproducibility⁵⁻⁸ and, in the case of the Vita Classical guide, deficiencies of shade coverage have been reported.⁹⁻¹¹ In addition, a number of factors including colour vision defects,¹² gender,¹³ age¹⁴ and experience^{15,16} have been shown to affect shade matching performance.

This laboratory-based investigation therefore sought to assess the colour vision of a sample of dentists and dental technicians and correlate this to their shade matching performance, in a simulated clinical situation, when using both the Vitapan Classical shade guide (VITA Zahnfabrik, Bad Sackingen, Germany) and the more recently introduced IPS Natural

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Die Material shade guide (Ivoclar Vivadent, Schaan, Liechtenstein). In addition, the accuracy and reproducibility of shade matches using these guides was assessed. From the outset it is important to appreciate that the shade being matched was that of the tooth preparation and not the final restoration. This differs from previous clinical practice as a consequence of the aspiration to optimise aesthetics of all ceramic restorations by taking into account the shades of the underlying preparation, as well as that of the finished restoration, in their fabrication.

MATERIALS AND METHODS

Ethics

As this study involved human subjects in colour vision and shade matching ability assessments together with anonymous extracted human teeth, collected for teaching and research purposes before September 2006, the opinions of the Scientific Advisor to the Fife Forth Valley and Tayside Research Ethics Service was sought before the commencement of the study. This established that ethical approval was required. An application for this was therefore duly submitted to and subsequently granted by the Fife Forth Valley and Tayside Research Ethics Service (Committee A – Reference Number 09/S1401/43).

Subject recruitment

An invitation letter, project participant information sheet and consent form were distributed to potential participants (dentists and dental technicians) within Dundee Dental School and Hospital. This stated that those with a known colour vision defect were ineligible to participate in the study. All dentists approached worked in the Section of Operative Dentistry, Fixed Prosthodontics & Endodontology and the dental technicians worked in the Conservation or Prosthodontic laboratories of Dundee Dental Hospital and School.

Colour vision testing

All those who consented to participate in the study were screened for their colour acuity and any deficiencies using the Farnsworth-Munsell (FM) 100 Hue test (X-Rite, Grand Rapids, MI, USA). All testing was conducted in the Clinical Skills

Laboratory of Dundee Dental Hospital and School at a time to suit the participants' work schedules (between 09:00 to 17:00). The test was conducted upon a table located 8 m away from the windows under standardised fluorescent ambient lighting (3,600K and 29 foot candles in the testing area) augmented by a Dialite colour dental shade taking lamp (Eickhorst & Co. KG, Hamburg, Germany) that had a colour temperature of 5,500K and flicker-free high frequency operation conforming to CRI +92. Its two lights were switchable fluorescent lamps certified to give an intensity of 130 foot candles at a distance of 25 cm from its reflector.

Prescription glasses, where worn by the subject, were worn during the test providing they were also worn in the shade matching sessions in the later phases of the investigation.

The FM-100 Hue test consists of four longwise cases containing a total of 85 removable incremental hue variation caps that cross the visible spectrum, and 8 fixed caps. These cover all colours of the spectrum (red, orange, yellow, green, blue and purple) and, in order to enable the spectrum to be completed as a circular chart, pink colours derived from mixes of blue and red are also present. All caps have a reference number and are of different hue. The two fixed caps in each case represent the limits of the range of hues presented.

Before administering the test the investigator arranged the colour caps in each tray in a random order. Each subject was presented with these and was asked, using a standard format, to arrange the caps on a panel to panel basis in order according to hue.

Throughout the test the shade taking light was applied by the subject from above so that the angle of illumination was approximately 90 degrees and the angle of viewing approximately 60 degrees. In order to prevent selective cone fatigue of the eyes, subjects rested their eyes periodically by looking at 18% reflectivity Kodak grey card (The Tiffen Company, Hauppauge, USA).

The performance of each participant was scored using the test's computer software. This involved the investigators replicating on the computer's monitor the subject's cap arrangements for scoring purposes and also entering the subject's name, date of

birth, gender and study reference number. In addition, both the subject's experience of shade matching and job function, together with the time taken to complete the test, were recorded.

For each subject the following values were calculated/assigned (X-Rite, 2006):

- a) Total error score – obtained by summing the error score of each cap's placement. A correct cap placement is individually given a score of 2 but before the total error score is calculated, 2 is subtracted from each cap's score. A perfect caps arrangement therefore gives a total error score of zero. Incorrect placement incurs a weighted penalty score according to the severity of error
- b) Classification of colour discrimination ability – based upon the total error score:
Superior colour discrimination = total error score of 0-16
Average colour discrimination = total error score of 20-100
Low colour discrimination = total error score >100.

A suggested diagnosis of colour vision status of the participant was also derived from the data.

Shade matching

For this part of the investigation the subjects were asked to match the shades of six prepared extracted teeth, containing either a veneer or crown preparation, on two separate occasions using both the IPS Natural Die Material shade guide (Ivoclar Vivadent, Schaan, Liechtenstein) (IPS) (nine dentine colour shade tabs) and the Vitapan Classical shade guide (VITA Zahnfabrik, Bad Säckingen, Germany) (VC) (16 shade tabs). The IPS guide was arranged in the manufacturer's arrangement but the VC guide was arranged according to Value from data supplied by the manufacturer.

All sessions were conducted in the same lighting conditions as used for the FM-100 Hue test. To simulate clinical conditions, extracted permanent maxillary teeth (two canines, two lateral incisors and two central incisors), that were suitable for preparation for either laminate labial veneers or for crowns and that represented different and a wide range of shades were selected. To this end, discoloured and

Table 1 Classification of selected shades for both shade guides

Classification	IPS	VC
M = correct match	Selected shade coincides precisely with actual shade.	
C = close match	Selected shade coincides within expert selected close match shades.	a) Value scale: the selected shade fell within the same value group as the actual shade. b) Hue scale: the selected shade fell within the same Hue group as the actual shade.
Z = incorrect match	Selected shade lies out with specification for correct match and close match.	

restored teeth were also considered for inclusion because such tooth discolorations and caries are clinical indications for the provision of such treatments. Once selected, these teeth were set in the correct anatomical relationship in a phantom head jaw that also incorporated posterior acrylic teeth of uniform shade (Senator, Wright Health Group, WD Canada – shade = B2). The natural appearance of the gingival tissues was reproduced in this model using high-precision gingival mask (Gingifast, Zhermach Technical, Badia Polesine Italy). Three of the mounted teeth were prepared for porcelain bonded crowns (UR3, UL1, UL2) and three for labial porcelain veneers (UR2, UR1, UL3). All preparations were carried out using conventional rotary cutting instruments under continuous water coolant irrigation. Once complete, and between periods of use, the model was stored moist in a sealed polythene bag to prevent desiccation of the tooth tissue which would result in alterations in shade between viewing sessions. For this reason the teeth were also wetted periodically during each matching session.

On two separate occasions, at least two weeks apart, each subject was asked to match the preparations to both the Ivoclar Vivadent IPS Natural Die Material shade guide and to the Vitapan Classical shade guide using their preferred method. All such shades were recorded. In preparation for these sessions each subject was given written instructions, before their visit, to ensure uniformity of approach. On each occasion the participant was encouraged to rest their eyes between shades by periodically looking at the 18% reflectivity grey card as used in the colour vision test. In addition, they were asked if they had previous experience of the use of any of the shade guides and the time taken to carry out each match was also recorded, together

with the preference of guide for each subject following each tooth matching.

All such matching was undertaken with the jaw mounted in a phantom head, in a supine position 5 m away from the windows in the Clinical Skills Laboratory. At session one the IPS guide was used first and in session two the VC guide was used first.

For each tooth, the shade selected by the participant on each occasion was recorded together with the time taken to achieve this. The participant's preference of prescribing shade ((a) one shade alone, or (b) a combination of cervical and incisal shades) was also noted. These selections were subsequently compared to the actual shade of each tooth as derived from visual assessment by three experts in shade taking. These experts were blinded to each other's selections. The determination of actual shade of the tooth was based upon the principle of the majority. If all three experts chose the same shade, the selected shade was the correct shade for that tooth. If one expert chose a different shade and the other two experts had the same selection, the latter was considered the actual shade. If all three experts chose 3 different shades, a consensus opinion of the experts was sought to agree the correct shade. All of the experts had achieved a high colour discrimination score in the FM-100 Hue test and subsequently a good score when asked to match in pairs, according to their colour, all 16 individual tabs of two Vita Classical shade guides (32 tabs in total) in the so-called 'Vita-Vita' test.¹⁷

The shade selected by each participant for each tooth, at each session, was then classified as detailed in Table 1.

Statistical comparisons of the participants' selected shades were undertaken using Chi-square testing to establish if the following factors significantly affected shade matching outcome:

- Type of shade guide used
- Method of shade determination (select one shade or select two shades (one cervical and one incisal))
- Gender of subject undertaking matching
- Age of subject undertaking matching. To enable this comparison an age of 40 years was selected to divide the data into two comparison groups (<40 years and >40 years)
- Experience of subject undertaking matching
- Occupation (dentist or technician) of subject undertaking matching.

In addition, the Chi-square test was also used to establish if there was any difference in the distribution of selected shades, as classified according to the criteria in Table 1, on the first and second occasions.

In all the foregoing comparisons the overall numbers of correct matches, close matches and incorrect matches were used across all the teeth. These values were also used to ascertain if the classification of colour discrimination ability, determined in the FM-100 Hue test, significantly affected shade matching outcome.

At the level of the individual tooth, Chi-square testing was undertaken to determine if there was any significant effect of tooth and preparation type upon the distribution of matches.

Free text feedback comments upon shade guide preference, as collated from a written post-activity debrief, were also collated and analysed.

All statistical analyses were undertaken using the statistical package Prism (Version 4.0, GraphPad Software Inc., 5775 Oberlin Drive #110, San Diego, CA 92121, USA).

RESULTS

A total of 64 dentists and dental technicians consented to participate in the study. Of these, 58 completed (37 males and 21 females) all the sessions required. Of these, 18 were dental technicians (16 males and 2 females) and 40 were dentists (21 males and 19 females).

Table 2 collectively summarises the mean age and years of dental experience of those who undertook the Farnsworth Munsell (FM) 100 Hue test. This table also gives the collective mean error score and the mean time taken to complete the

test. The standard deviations of these observations are also given.

Correlation analyses, undertaken to explore any relationship between error score and the parameters subject age, years of dental experience and time taken to complete the test, demonstrated no statistically significant ($p > 0.05$) associations. Table 3 summarises the Pearson correlation coefficients and p -values of these analyses. Perhaps unsurprisingly, the age of the participants and their years of experience were found, by linear regression, to be positively related ($R = 0.95$).

Further correlation analyses of the subjects' error scores versus the categories gender, occupation and level of colour discrimination (as assigned by the FM-100 Hue test), demonstrated significant associations for gender ($p = 0.028$, Spearman $R = 0.2893$), occupation ($p = 0.033$, Spearman $R = -0.2812$) and level of colour discrimination ($p < 0.0001$, Spearman $R = 0.5601$).

Table 4 summarises the mean error scores and their standard deviations of the subjects according to both gender and occupation. A one way analysis of variance of this data revealed no statistically significant difference between the mean scores ($p = 0.1532$). It was thus concluded that despite the indication of an association of gender and occupation upon error score, these factors in the sample tested here did not statistically significantly affect the mean error score.

When shade matching using the two different shade guides, the raw data revealed that many subjects were inconsistent in their approach, adopting, on each matching session, a different approach to matching and recording their findings.

Table 5 summarises the pooled total number of matches undertaken and their outcome, irrespective of the region of the tooth matched. To facilitate comparison these are also expressed as percentages. Chi-square analyses of the raw data demonstrated statistically significant effects ($p < 0.01$) between the matching success of IPS compared to the Vita Classical guide where either the value scale ($\chi^2 = 152.5$, d.f. = 2) or the hue scale ($\chi^2 = 237.8$, d.f. = 2) were used. In addition, statistically significant effects were highlighted for the Vita Classical guide according to whether or not it was used to determine shade by

Table 2 For those who undertook the FM-100 Hue test, the collective mean age, years of experience, error score and time to undertake the test

	Subject age (years)	Experience (years)	Error score	Time (mins) to complete test
Mean	39.7	17.2	56.55	9.38
SD	11.5	12.5	40.93	2.29

Table 3 Pearson correlation coefficients and p -values for comparison of raw error scores versus subject age, experience and time to undertake test

	Pearson R	p
Subject age	0.03	0.82
Subject experience	0.07	0.59
Time to complete test	-0.04	0.79

Table 4 The mean error scores and standard deviations of the subjects according to gender and occupation

	Mean error score	n	Standard deviation
Male	59.89	37	37.94
Female	45.52	21	43.97
Technician	69.56	18	45.28
Dentist	48.00	40	36.74

Table 5 Summary of total number of matching outcomes (irrespective of zone of determination) for both shade guides

Shade guide and parameter used for scoring	Match outcome		
	M	C	Z
IPS	555 (52.7%)	294 (27.9%)	205 (19.5%)
Vita - value	306 (31.6%)	235 (24.3%)	426 (44.1%)
Vita - hue	306 (31.6%)	156 (15.9%)	505 (52.2%)

Key: M = correct match; C = close match; Z = incorrect match.
Numbers in the body of the table are the actual match numbers.
Numbers in parentheses are the percentage of the matches in each category expressed to the nearest first decimal place.
Errors produced by rounding dictate that these values when summated will not always be equal to 100%.

value or hue ($\chi^2 = 22.7$, d.f. = 2). It is clear that the chances of obtaining a match are highest with the IPS guide with value matching compared to the use of hue. The use of the Vita Classical guide resulted in a greater proportion of mismatches among the study participants as compared to the IPS guide.

Table 6 summarises the number of participants who reproduced their selection for each shade guide on both occasions. This analysis was only undertaken for those who adopted the same approach to shade matching on both occasions. A Chi-square test of this data highlighted statistically significant ($p < 0.01$) differences in the distribution of these quantities. When

normalised to percentages it is clear that the IPS guide afforded greater reproducibility as indicated by 68.1% of the same shade being awarded on both occasions compared to only 33.4% when the Vita Classical guide was used.

On recasting the matching outcome data for each guide according to subject gender and age, for Chi-square testing, no significant ($p > 0.05$) effects of these upon overall shade matching performance were demonstrated. In the same way, performance in the FM-100 Hue test did not statistically affect ($p > 0.05$) the outcome of matching using the guides. When the same outcome data were cast according to the tooth and type of preparation

Table 6 Reproducibility of each shade guide irrespective of zone of determination

Number of participants who selected:	IPS Guide	Vita Classical
Same shade on both sessions	230 (68.1%)	116 (33.4%)
Different shades on both sessions	153 (39.9%)	231 (66.6%)
Total	383	347

The total number in the body of the table for each shade guide represents the number of participants who selected one shade or cervical and incisal shades on both occasions. Where an individual used a cervical and incisal shade matching approach they were afforded a count of 2 if both the cervical and incisal shades were the same on both occasions. If only one of these shades was the same (either cervical/incisal) they were given an entry of 1 in the categories of same shade on both sessions and also in different shade on both sessions.

Table 7 The preferred guide as stated in the free text comments

Occupation/Guide	Vita Classical preferred	IPS preferred
Technician	8	7
Dentist	14	15

Numbers in the body of the table are the actual numbers of responses

Table 8 The summated free text comments of the participants concerning shade guide preference

Sentiment expressed	Technician	Dentist
Use IPS for dentine hue, Vita for overall shade taking	0	1
Range of tooth colour greater with Vita	3	8
Better shade gradation with Vita	2	3
IPS best for darkly discoloured preparations	6	12
IPS shades too intense and saturated	2	2
Vita preferred for natural teeth	0	2
More shades needed to boost IPS coverage	0	1
Range of choice in Vita too great	0	2
Neither guide covers all tooth colours	0	1
Fewer IPS shades lead to greater reproducibility and more rapid selection	1	6
IPS easier to use	0	1
Familiarity of Vita liked	1	0
Vita glaze can reflect light too much	1	0
IPS curved incisal edge better for fitting against tooth	1	0

Numbers in table body are actual number of responses.

being matched, both these variables significantly ($p < 0.01$) affected match outcome, irrespective of the guide used, with the upper left central incisor attracting a higher proportion ($n = 403$, 64.5%) of correct matches than any other test tooth. Crown preparations were matched correctly more frequently than veneer preparations. In relation to subject occupation, this only significantly affected the outcomes of matches using the Vita Classical guide according to both hue and

value ($p < 0.05$). In these cases the proportion of correct/near matches was highest for dental technicians (for hue: dental technicians = 62.6%, dentists = 53.2%; for value: dental technicians = 53.9%, dentists = 45.3%).

A number of participants expressed a guide preference. Table 7 summarises this data. A Chi-square test demonstrated no statistically significant difference ($p > 0.05$) in the distribution of preferences of the technicians and dentists.

Table 8 summarises these comments. It is clear that although the IPS guide attracted most comments, an overall preference for a particular guide was unclear.

DISCUSSION

This investigation employed the FM-100 Hue test to assess in a standardised, controlled way the colour discrimination abilities of the subjects. All such testing, in addition to teeth colour matching, was conducted using colour-corrected light to facilitate accurate colour matching, for it is reported that failure to use such lighting results in variation of match.¹⁸⁻²¹ The FM-100 Hue test is a highly useful diagnostic test to indicate the presence of colour vision defects.²² It has been applied for more than 40 years in industry to evaluate and rank colour acuity.²³ In dental research it has been adopted to exclude colour vision deficient observers^{17,24,25} from investigations. It has been reported to correlate well with shade matching abilities in dentistry,¹² though to date no one has correlated individual shade matching ability in respect of natural teeth. In the work reported here the criteria used to select the expert shade takers, and the methods whereby they reached a consensus view, have been adopted by others.^{1,11,26}

In the present work, performance in the FM-100 Hue test did not affect tooth shade matching performance. This could have arisen because the FM-100 Hue test covers the full 3D Munsell colour space, of which teeth occupy only a limited part. Although others have found a strong correlation between performance in the FM-100 Hue test and performance in Vita-Vita matching,¹² this work was not clinically realistic for it did not involve natural teeth with all the complexities this brings. The finding of the present study should, however, be taken with caution for there were only seven participants who scored low in the FM-100 Hue test.

The extracted teeth that were selected for inclusion in this study represented a range of clinically relevant preparations and tooth shades upon which to carry out this work. It should be noted that a number of heavily restored teeth were included, for such teeth, in the clinical situation, are an indication for the provision of crowns and veneers.^{27,28} In such studies it is the norm to take shades to enable the fabrication of

the final restoration. In this study, however, this was not the case for the IPS guide is specifically designed to record the shades of the underlying preparations so that they can be copied in the laboratory as a die, to ensure the aesthetics of the final restoration are not compromised by the shine through of the underlying tooth substance.^{2,3}

A key finding of this study was that many participants did not record shade on all occasions in the same way. This was both an interesting and a complicating factor. This lack of consistency in shade taking method may potentially contribute to miscommunication between dentist and dental technician. It also complicated this study's subsequent statistical analysis which out of necessity was largely confined to an analysis of trends, by Chi-square testing, in shade matching performance as influenced by various factors. A more rigorous analysis, to exclude the effects of confounding factors, proved not to be possible due to the non-linear distribution of the available shades of the guides in colour space and the many inter- and intra-subject variations displayed in shade taking practice.

In the present study the shade guide used was found to statistically affect the outcome of the match even though no single guide was preferred clearly by the participants. This has been reported previously by other workers^{7,29} when evaluating other shade guide systems. In the present study the chances of obtaining a match were highest when the IPS guide was used. At present no other studies on this guide, against which to compare this finding, are reported in the dental literature. In relation, however, to the Vita Classical guide, value was found to give the best chance of a close match (value 24.3% versus 15.9% for hue). This parameter, in an *in vitro* study that examined the subjects' ability to match the tab shades of a Vita Classical guide, has been shown by others²¹ to be a more perceivable feature than hue. It is acknowledged that in the present study, the percentage of correct matches (31.6%) is lower than that reported by Jarad *et al.*³⁰ (43%) in a similar experimental simulated clinical environment when matching shade tabs to each other rather than teeth. Such an approach is, however, likely to have given better results for it is easier to

match identical shade tabs to each other than teeth.³¹

In the present study the IPS guide was found to have higher reproducibility than the Vita Classical guide. As previously stated, the literature to date contains no studies on the IPS guide. The level of reproducibility of same shade matching for the Vita Classical guide in this study was 33.4%. This agrees with previously reported levels of agreement in *in vivo* tooth colour assessment studies conducted among general dental practitioners (35%)¹⁵ and by three examiners (36.7%).²⁶ Matching using the IPS guide achieved a 68.1% level of reproducibility among the mixed range of skills of the study subjects. This level is similar to that achieved by specialist prosthodontists using a systematic shade guide (Vitapan 3D Master) in *in vivo* matching.¹⁵ Perhaps the high level of reproducibility achieved for the IPS guide is due to the relatively limited number of shade tabs and the fact that these exhibit no gradation. No references, however, support this hypothesis. As previously discussed, this finding should be considered bearing in mind that both the shade guides have limitations of accuracy and reproducibility.^{5,7,8,29} Another factor that may have contributed to the success rates is the level of shade coverage of the guides, for neither guide covered the full range of the test teeth. The Vita Classical guide may have reflected better the shade of non-discoloured teeth, whereas the IPS guide covered, to a degree, some of these as well as being closer in shade to the discoloured teeth. Such an observation was born out by the recorded comments of the participants, many of whom said that upon certain teeth the guides gave no coverage. Previous work by others⁹⁻¹¹ has reported that the Vita Classical guide has deficiencies in some areas of natural tooth shades.

In relation to the effect of gender upon shade taking ability, the present study demonstrated no significant effect. The literature on this point is at variance, with some reporting that gender has no effect^{19,21,32} and others finding that females are significantly better than males at shade matching.¹³

Age in the present study did not affect outcome of shade matching. This finding is further supported by the lack of correlation between the subjects' FM-100 Hue test

error scores (Table 3) and their age. The range of participants' ages in the present study was 23 to 62 years (mean = 39.7, SD = 11.5). Within the literature it has been said that older observers show less purity in colour discrimination than the young.¹⁴ Ageing is also correlated with blue-yellow confusions³³ and it has been postulated that this may be as a result of the natural discolouration of the cornea and lens of the eye that occurs with age.³⁴ This is considered by Chu *et al.*³⁴ to be an incremental process that commences at 30 years of age and takes its effect after 50. For this reason, 40 years was empirically selected to divide the subjects into groups to test for any effect of age upon shade matching ability. Notwithstanding this, it is interesting to note that in the present study those above 40 years achieved slightly better selection of the actual shades than those that were younger. It is possible also that if such anatomical and physiological changes were found in the eye, these may only affect colour discrimination ability but not colour matching. According to Donahue *et al.*²⁵ after 55 years of age there is deterioration in fine colour discrimination and this therefore gives limited support to this theory.

In relation to the IPS guide, only one participant had used this before. It was therefore perhaps not surprising to find that the years of clinical/technical experience had no effect on matching outcome arising using this guide. In the case of the Vita Classical guide, the present findings, that experience affected significantly the shade matching outcomes made using this guide, agree with those of some^{15,16} but not with those of others.^{19,21} An explanation for this is not immediately obvious but may reflect the choice of the subject population in these studies. Despite the role of experience with the Vita Classical guide in influencing outcome, no clear trend relating years of experience and successful shade matching was identifiable.

This study demonstrated no significant effect of occupation upon the shade matching outcome arising from the use of the IPS guide. In relation to the Vita Classical guide, the technicians gave a significantly higher proportion of correct matches (dentists 29.1% and technicians 37.8%). Previous work relating to the Vitapan 3D Master, using tab to tab

matching, demonstrated no difference in the performance of dentists and technicians.³¹ This is clearly at odds with the present finding and is perhaps due to the fact that in Dundee Dental Hospital and School it is routine practice for the technicians to record the shade rather than the dentists. As no such effect was evident for the use of the IPS guide, which was new to all but one of the participants, it can perhaps be inferred that greater experience in the use of a guide optimises the chances of success. Following on from this it is perhaps the years of use of a guide that are a better measure of degree of experience than the years qualified.

Given the complexities of natural tooth structure it was no surprise to find that the tooth being matched significantly affected the outcome of matching. Others too have reported that different teeth present varying difficulties of matching.³⁵ This is compounded further by preparation of these teeth, for the quantity and quality of the residual tooth structure is known to affect the colour of both the tooth and its final restoration.^{3,36} In the present study it is thought that a higher proportion of crown preparations were correctly matched because the relatively destructive tooth preparation involved, compared to that of a veneer preparation, exposed more of the dentine and in so doing eliminated the double layer effect on the colour of tooth structure.³⁷ This was not the case with the veneer preparations because some enamel remained. In addition, the crown preparation removed the difficulty of matching the incisal edge.

CONCLUSIONS

It is concluded that within the limitations of this study:

1. The FM-100 Hue test, due to its wide coverage of colour space, is not a good predictor of dental shade matching performance
2. Age and gender did not affect tooth colour matching performance
3. Success with the Vita Classical

guide was experience- and occupation-dependent

4. Both guides performed well in the areas of shade they covered, with the Vita Classical guide matching well shades of natural unstained teeth and the IPS guide matching more closely stained/discoloured preparations
5. Despite the limitations of both shade guides, the IPS guide was more reproducible and accurate in matching the shade of prepared teeth.

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