Palestrante: Allyson A Barrett
Instituição: Center for Dental Biomaterials, College of Dentistry, University of Florida
Titulo do Workshop: “Combining Art and Science for Visual Acuity and Dental Shade Matching”

Resumo do Workshop:
This session is designed to test colour vision acuity – both the ability to recognize and discriminate colours - using a standardized test and objective exercises with restorative dental materials. The idea is to give the dentist the knowledge they need for shade evaluation in the clinic on a daily, ongoing basis since the eye remains the reliable, clinical tool of choice. Colour recognition and therefore, shade matching ability, can be enhanced and improved. You must first have objective knowledge of your own individual ability and some understanding of the subjectivity in colour perception. In years of colour science research within Dental Biomaterials at the University of Florida we have developed particular exercises which have been presented at both AADR and IADR conferences. Understanding effects of visual phenomena, the three-dimensional colour system that provides the basis for instrumental colour determination, and features of intra-oral instrumental shade analysis are part of this session. You will have a reasonably accurate idea of your own colour vision (quantitative score) and learn the difference between colour vision acuity and colour discrimination ability. Visual colour perception ability can be learned and improved!

- Objective Visual Acuity Exercises:
  - Isochromatic Plates (for the red-green colour axis vision);
  - Discrimination Pairs (Dental ceramic discs fabricated specifically for a wide range of colour differences, Delta E values, allow determination of one’s colour discrimination ability).

- Organizational effects of Shade guide selections
- Visual Perception Images (designed to “teach the eye” discriminatory nuances)

Biografia resumida:
Interest in colour comes to Allyson A. Barrett through years of studying painting with recognized artists from different countries. Going from Arts to Dental Sciences, her early work was with LL Hench in Bioglass and, then for many years, with KJ Anusavice at the Center for Dental Biomaterials, College of Dentistry, University of Florida. Her ceramics research includes optical, thermal and mechanical property characterization. She teaches colour to the UF dental students, residents, continuing education for practicing clinicians, on cruise ships and to private professional organizations. She feels that the eye is still the primary clinical “tool” and that knowing one’s own visual acuity is paramount to aesthetic selections. Colour is an integral part of our daily lives!

Sugestão de leitura:

Influence of tab and disk design on shade matching of dental porcelain

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Statement of problem. Given the complexity of tooth color, the variations of shade within each tooth, and translucency, it is difficult to view only one small area and select a shade match for restorations.

Purpose. This study tested the effect of specimen design on porcelain shade matching, hypothesizing that flat disks would be matched to one another with more accuracy than tooth-shaped tabs to tabs.

Material and methods. All testing was conducted in a Macbeth SpectraLight booth with D65 illumination. Seventy-three senior dental students (25 women and 48 men; mean age, 27 years) were asked to match selected Vita porcelain disks and Vita shade tabs to like specimens. The design order, namely matching tabs or disks first, was alternated for each observer. The specimens were handed to the observer individually. No time limit for matching was imposed, although each observer was given explicit instructions related to the observation and handling of the specimens. Upon completion of the matching exercises, each student received his or her standardized test results and reviewed the matching results. The time for testing and review was approximately 20 minutes per observer. An analysis of variance, with gender and order as 2 factors that could affect matching scores, was performed (P < .05).

Results. The mean matching scores were 78.4% for disks and 73.6% for tabs (P = .119). Female observers matched 76.5% of the disks and 77.5% of the tabs, whereas male observers matched 79.4% of the disks and 71.6% of the tabs (P = .054). Matching disks before tabs yielded equivalent levels of shade matching (disks, 77.6%; tabs, 77.1%). When tabs were matched first, the scores were as follows: disks, 79.8%, and tabs, 67.3% (P = .010).

Conclusion. Within the limitations of this study, there was no significant difference in shade-matching accuracy between the 2 shapes, although the order of design matching resulted in a difference in shade-matching ability. When tabs were matched first and disks second, improved matching was evident on the second test. The reverse was not true; no learning was demonstrated when the tabs were matched after the disks. (J Prosthet Dent 2002;88:591-7.)

CLINICAL IMPLICATIONS

In this study the gender of the shade matcher had no significant relevance to dental shade selection ability, in contrast to previous reports in the dental literature. Color-blind individuals may be able to discriminate adequately for acceptable dental shade matching. All dental personnel may benefit from an objective knowledge of their own color-/shade-matching ability, particularly because proficiency in shade matching can be learned and developed through multiple objective exercises.

Color matching and shade matching are an essential aspect of restorative and esthetic dentistry and have been accentuated by the recent social emphasis, attached to esthetic dentistry. Although there have been developments in restorative dental materials and instrumentation over the years, intraoral shade matching has not changed significantly since the initial dental studies by Clark. 1 Intraoral shade matching is still dependent upon each clinician’s visual discrimination and matching abilities. An objective knowledge of one’s color vision is essential to optimize the esthetics of patients’ prostheses. Learning to match shades, characterize restorations, and alter shades is dependent on one’s ability to perceive and discriminate colors and differences. Color screening of dental professional personnel is not typically done in North American dental schools, even though it is a factor in daily restorative dentistry. The fact that it is possible to improve one’s color perception 2 emphasizes the need for color instruction in dental education.
The few studies of visual color testing published in the dental literature usually describe limited testing. Moscr et al\(^4\) screened 670 participants at the 1981 session of the American Dental Association. Testing for red-green deficiency only, they found that 9.9% of the dental professionals exhibited some color vision deficiency. Serious color vision deficiency was found in 2.8% of that dentally related population. Rawlinson\(^4\) found that 2 of 6 dental students with defective color vision were unable to see yellow or blue, a parameter relevant to dental shades that often goes untested. Many of the students were unaware of their visual limitations. Consequently, the findings supported the continued use of visual screening to identify, as well as to encourage, those with color vision deficits to seek professional treatment at an early opportunity. O’Keefe et al\(^8\) and Wasson and Schuman\(^8\) advocated color vision screening as well as improved color education for dentists and dental students. Addressing the primary elements of color, O’Keefe et al noted that shade matching is the weak link in esthetic dentistry. Wasson and Schuman advocated product development that may help in shade selection, as they found that 9.3% of 150 subjects screened for red-green color vision had defective color vision.

Because the tooth is not a homogeneous surface, shade matching is considered to be very difficult. Assessing color-matching ability with the use of natural teeth or ceramic shade tabs is also considered to be difficult, as there are distinct areas of varying color and translucency within a single tooth. Determining specifically which area an observer is viewing for shade-matching purposes is complicated. van der Burgt et al\(^7\) used a perforated shield to consistently expose only a limited section of the tooth for viewing. Two viewing methods were used, and a difference in interobserver agreement was found. The interobserver differences were somewhat greater than the intraobserver differences. The authors concluded that even under the same conditions, visual and instrumental color determinations are subject to large errors.

The eye is very discriminating, detecting inhomogeneities and variations on small surfaces. Instruments such as colorimeters and spectrophotometers are designed to measure color by integrating stimuli on a designated flat surface. These instruments then print 3 numerical coordinates from a 3-dimensional color space established by the Commission on Illumination.\(^8\) The instrumental apertures are usually 3 mm, 5 mm, or 8 mm in diameter. The smaller apertures (3 and 5 mm) generally result in color coordinate shifts due to “edge loss.”\(^9\) A colorimeter with a minimum aperture of 8 mm is considered to be more reliable in repeat measurements, whereas human beings are less consistent from observation to observation, even under the same viewing conditions. If the surface being “measured” has any surface or color irregularities or is composed of multiple colors, it will all be integrated within the aperture area, and only parameters for 1 specific color will be generated.

Clarke\(^10\) noted that data from such irregularities may result in mistaken color identification. Instruments are also subject to mechanical problems. Goodkind and Schwabacher\(^11\) found it necessary to eliminate data from 1 of 4 colorimeters used in an intraoral study because of instrumental problems. Consequently, instrumentation can be considered accurate and effective for measuring flat homogenous materials and for making fine color distinctions that may not necessarily be visually detectable.\(^12\) Teeth do not fit this description. However, the eye, which is an excellent detector, does observe/record nonhomogeneity. Okubo et al\(^13\) reported that a colorimeter was only 50% accurate in matching shade tabs, whereas the matching accuracy of human observers was 48%. No significant difference was found between the shade-matching accuracy of the colorimeter and human observers. Even with the ability of instruments to make some fine color distinctions, these findings demonstrate the need for development of perceptual color education in dentistry.

There is an important distinction between normal color vision and visual color discrimination. Color discrimination, which is the ability to detect differences among colors, may be independent of defective color vision, a condition in which one is unable to perceive, let alone identify, some colors. Farnsworth\(^14\) noted that some observers may demonstrate low discrimination ability without an imbalance of color perception. The converse is also possible: an individual may not be able to perceive colors (that is, may be color blind), yet that same individual may be able to distinguish differences.

Given the complexity of tooth color, the variations of shade within each tooth, and translucency, it is difficult to view only one small area and select a shade match for restorations. In an effort to determine the effect of the irregularities of a tooth on dental shade-matching accuracy, 2 different shapes or designs of dental porcelain were selected for matching exercises. Dental porcelain disks with a flat homogeneous surface and porcelain tooth-shaped replicas (shade tabs) simulating natural tooth variations were used. This study tested the hypothesis that observers would match the flat, homogeneously colored disks to one another more consistently than the polychromatic tooth-shaped shade tabs to tabs.

**MATERIAL AND METHODS**

The observers consisted of 73 senior dental students (25 women and 48 men) with a mean age of 27 years. Before the dental porcelain shade-matching exercises, each dental observer took 2 standardized tests to assess his or her chromatic perception relative to both the red-green color axis and the blue-yellow axis. The standard Pseudo-Isochromatic plate test (Richmond Products,
Boca Raton, Fla.), which screens only for defective red-green vision, was administered first, followed by the Saturated 15 Hue Test (Luneau Ophtalmologic, Pads, France). The latter is considered to be a more accurate test for even moderate color anomalies on both chromatic axes (red-green and blue-yellow). All scores were recorded for each individual and each test exercise. No observers or data were excluded as a result of the standardized scores.

The observers were asked to match the same shaped dental porcelains (disks and tabs) to one another, according to shade. The exercises were conducted in a light booth with standardized daylight (D65) illumination (Macbeth, Newburgh, N.Y.) against a neutral gray interior known as Munsell N-7. The booth was the sole light influence in the testing room. No time limit for matching was imposed, although each observer was given explicit instructions related to the observation and handling of the specimens. Observers were informed that prolonged viewing could result in foveal fatigue and that viewing the neutral gray surroundings could eliminate the deleterious effect.

Two different shapes of Vita dental porcelain (Vident, Brea, Calif.) were used for observer shade matching. Specimens included one set of flat porcelain disks (16 × 2 mm) and one set of tooth-shaped tabs. The disks were homogeneous, sintered according to the manufacturer’s instructions, and polished with 1-μm alumina abrasive. Considering possible batch variation, the disks for each shade were made from the same container of porcelain powder. The finished dishes were measured with a colorimeter (CR-300; Minolta, Ramsey, N.J.) to ensure acceptable ΔEs for matching pairs (ΔE = 1). The second design set comprised commercially produced, polychromatic, tooth-shaped shade tabs. The same 8 shades (A1, A2, A3, B2, B3, C1, C2, and D2) were repeated for both the disks and the tabs. The shades were arranged for matching as follows: A1, C1, B2, A2, A3, B3, C2, and D2. This shade arrangement did not represent a particular order of value or shade group. Half of the disks were placed in a row within the light booth. Observers were instructed not to move the disks in this arrangement. The specimen shape to be matched was handed to the observer individually, in random order. The observer was asked to select the closest possible match from the specimens within the booth.

The Vita tab shades were arranged in the same order as the disks. They were placed within the Vita Lumin tab holder (Vident, Brea, Calif.) by their stainless steel stems with 1 space between each tab. The same instructions associated with disk-to-disk matching were given for tab-to-tab matching. Observers were not allowed to rearrange the tabs, but they could place the Lumin set holder in their hand. The design configurations (either disks first or tabs first) were alternated with each observer. Upon completion of the matching exercises, each student received his or her standardized test results and reviewed the matching results. Shade/color comparisons were viewed as was applicable to each observer’s results so that color distinctions could be noted visually and characteristics discussed. The time for testing and review was approximately 20 minutes per observer.

An analysis of variance, with gender and order as 2 factors that could affect matching scores, was performed ($P<.05$). The interactions between gender and order were considered but proved to be insignificant.

**RESULTS**

Although the disks were correctly matched more frequently than the tabs, the difference did not reach statistical significance. The overall disk-matching score was better than the tab-matching score by 5%. The mean matching scores for the variables of gender, tabs, disks, and order of porcelain design matching (tab or disk first) are presented in Table I. Female observers demonstrated virtually the same matching ability among themselves with the disks and tabs, matching the tabs only 1% more accurately than the disks. Within the male observer group, disks were matched 8% more accurately than tabs. In a comparison by gender, men matched the disks 3% more frequently than women, whereas women matched the tabs with approximately 6% more accuracy. However, there was no significant difference between the genders in terms of matching ability ($P=.21$).

The comparison of disk selection before tab selection yielded equivalent levels of shade-matching accuracy in each exercise. However, when tab selections were the first exercise, improvement was evident on the second
shape-matching test (*P* = .01): the disks were matched 12.5% more accurately than the tabs. No learning was demonstrated when the tabs were selected after the disks. This order yielded virtually the same number of matches with disks and tabs (77.6% and 77.1%, respectively).

The results of the 2 standardized color tests indicated that there were 4 color-blind men among the observers. None of the dental observers were rejected as a result of standardized test scores, because these persons might represent the diversity of clinicians’ ability. Of the 4 color-blind observers, 2 were not aware of their color vision deficiencies before the screening. Table II lists the scores for the color-deficient observers. Note that 1 color-deficient observer was able to match all of the disks accurately, demonstrating that one can be color vision-deficient yet still be able to discriminate differences well. The same observer, however, was able to match only 37.5% of the shade tabs correctly.

Tables III and IV combine the selections for all observers. The highest percentages recorded represent correct matches. Table III shows 3 matches chosen at or above 20%; these represent errors in color/shade perception. Disk A3 was paired as a match with A2 by 29% of the observers (Fig. 1), C2 with B3 by 20% of the observers (Fig. 2), and D2 with C1 by 34% of the observers (Fig. 3). There were 15 other incorrect pairings with frequencies below 20%.

As shown in Table IV, the correct pairings for the tabs generally were associated with the highest percentages shown, although the matching values were not significantly different from the disk values. The correct matches ranged from 43% to 99%. Shade tabs A3 and B2 had the highest percentages of correct matches (92% and 99%, respectively). Shade tab A1 was inappropriately paired with C2 by 52% of the observers (Fig. 4), whereas only 43% assigned shade tab A1 to A1. Only 2 additional tab shades were incorrectly paired by more than 20% of the observers: 22% chose shade tab A2 as a match with A1 (Fig. 5) and 22% selected shade tab B3 as a match with B2 (Fig. 6). There were 30 other incorrect pairings below 20%, 24 of which were below 5% (Table IV). A greater number of correct disk matches occurred for shades A1, A2, and B3, whereas a greater number of correct tab matches occurred for shades A3, B2, C1, and D2.

The most frequently matched shades (Table V) differed for the disks and tabs, with the exception of shade C2, which was paired by 77% of the observers in both shapes. Shade A1, which is the highest in value, was accurately matched 100% of the time for the disk shape. However, the tooth-shaped shade tab A1 was paired accurately by only 43% of the observers.

Table III. Disk-matching selections of all 73 observers

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>B2</th>
<th>B3</th>
<th>C1</th>
<th>C2</th>
<th>D2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>A2</td>
<td>95.9%</td>
<td>1.4%</td>
<td>2.7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>A3</td>
<td>28.8%</td>
<td>61.6%</td>
<td>78.1%</td>
<td>8.2%</td>
<td>4.1%</td>
<td>1.4%</td>
<td>100%</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>B2</td>
<td>16.4%</td>
<td>1.4%</td>
<td></td>
<td>80.8%</td>
<td>2.7%</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>B3</td>
<td>9.6%</td>
<td>12.3%</td>
<td>20.5%</td>
<td>74%</td>
<td></td>
<td>4.1%</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>C1</td>
<td>1.4%</td>
<td>1.4%</td>
<td></td>
<td></td>
<td>76.8%</td>
<td>100%</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>C2</td>
<td>2.7%</td>
<td>1.4%</td>
<td></td>
<td></td>
<td></td>
<td>63%</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>D2</td>
<td>1.4%</td>
<td>1.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Correct selection percentages are underlined.

Table IV. Tab-matching selections of all 73 observers

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>B2</th>
<th>B3</th>
<th>C1</th>
<th>C2</th>
<th>D2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>42.5%</td>
<td>1.4%</td>
<td>1.4%</td>
<td>1.4%</td>
<td>1.4%</td>
<td>52.1%</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>A2</td>
<td>21.9%</td>
<td>72.6%</td>
<td>1.4%</td>
<td></td>
<td></td>
<td>1.4%</td>
<td>1.4%</td>
<td>1.4%</td>
<td>100%</td>
</tr>
<tr>
<td>A3</td>
<td>91.8%</td>
<td>1.4%</td>
<td>2.7%</td>
<td></td>
<td></td>
<td>2.7%</td>
<td>1.4%</td>
<td>1.4%</td>
<td>100%</td>
</tr>
<tr>
<td>B2</td>
<td>1.4%</td>
<td></td>
<td>98.6%</td>
<td></td>
<td>1.4%</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>B3</td>
<td>11%</td>
<td>21.9%</td>
<td>63%</td>
<td></td>
<td>1.4%</td>
<td>2.7%</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>C1</td>
<td>13.7%</td>
<td>4.1%</td>
<td>1.4%</td>
<td></td>
<td>76.7%</td>
<td>4.1%</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>C2</td>
<td>1.4%</td>
<td>6.8%</td>
<td>2.7%</td>
<td>2.7%</td>
<td>1.4%</td>
<td>76.7%</td>
<td>8.2%</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>D2</td>
<td>2.7%</td>
<td>11%</td>
<td>13.7%</td>
<td>1.4%</td>
<td></td>
<td>69.9%</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Correct selection percentages are underlined.
difference in shade-matching ability by gender. The men mismatched 10.9% of the tab selections, whereas the women mismatched 2.7%.

The rates of mismatches of only 1 or 2 selections out of 8 possibilities were 56.1% for disks and 42.5% overall.

Of the female observers, 20.5% missed 1 or 2 disks and 16.4% missed 1 or 2 tabs; for male observers, the same measurements were 35.5% and 25.9%, respectively.

The overall percentage of the observer population with no errors in shade matching was 20.5% for disks.
irregularities that affected the gloss (light reflection), whereas the tabs, like natural teeth, had surface irregularities that affected the gloss (light reflection on the surface). The varying zones of translucency in the tabs also may account for some of the misperceptions.

As reported in the dental literature, variability in shade matching may be affected by different factors such as lighting, surround, fatigue, and other distractions, as well as by the lack of color perception development. This study was executed under almost ideal conditions of 1 unchanging surrounding environment and 1 single, consistent illuminant. Even so, there were still notable inconsistencies in shade recognition and matching. The results for this dental study population dispel the popular conception that women are better than men at color matching. One may infer that the dental assistant (female or male) could have the same, though not necessarily better, shade-matching ability as the dentist with normal color vision. Anusavice16 reported no difference in matching ability relative to gender, age, or clinical experience with 116 observers. One may conclude that the dentally educated population is more discriminating visually than the population at large.

Objective knowledge of one’s color vision is an important factor in judging shade-matching ability. It is important to note that one color-blind observer was able to match all 8 disks perfectly, demonstrating the significance of discrimination ability. The clinical ramifications of this study are easily seen when one considers that 76% of the observers missed 2 or fewer disk selections, indicating that 24% of a potential patient population would receive mismatched restorations. Two or fewer mismatches of tooth-shaped tabs were recorded for 61% of the observers. This also may be construed to indicate that almost 40% of the patients seen by these dentists would receive mismatched restorations and that 40% of the dentists might not perceive the mismatches in those restorations.

Table V. Percent matches for each shade and shape

<table>
<thead>
<tr>
<th>Shade</th>
<th>Matches by shade and shape (%)</th>
<th>Disks</th>
<th>Tabs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>100.0*</td>
<td>42.5</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>95.9*</td>
<td>72.6</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>61.6</td>
<td>91.8*</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>78.1</td>
<td>98.6*</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>80.8*</td>
<td>63.0</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>74.0</td>
<td>76.7*</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>76.7*</td>
<td>76.7*</td>
<td></td>
</tr>
<tr>
<td>D2</td>
<td>63.0</td>
<td>69.9</td>
<td></td>
</tr>
</tbody>
</table>

*Most frequently matched shades.

and 19.1% for tabs. The female zero-error results were 5% for disks and 6.8% for tabs. The male zero-error results were 15% for disks and 12.3% for tabs.

DISCUSSION

No significant difference in shade-matching accuracy \( (P > .05) \) was found between the disk and tab specimens. Nevertheless, the results indicated that the order in which specimen designs were matched (disks or tabs first) influenced shade-matching ability for the subsequent exercise. Farnsworth14 found that improvement generally was demonstrated during a second test as a result of familiarity with the materials. In the present investigation, however, when tab matching followed disk matching, the rate of accuracy was virtually the same for the 2 shapes. Given that the flat disks were matched with greater accuracy (12.5%) than the shade tabs, some slight complexity in matching with a tooth-like specimen may be indicated.

Value (brightness) has been considered the most highly recognizable characteristic in dental shade matching.15 Shade tab A1, the second highest value in the Vita set and the highest value in the present study, was matched by 100% of the population when the shade was in disk form but by only 42% when the shade was in tab form. These results indicate that value may not necessarily be the most important (highly recognized) factor in matching. In fact, A1 was matched to C2 by 52% of the observers. These 2 shades were separated by 5 other shades in the viewing arrangement. Two other mismatched pairs were shade tab A2 with A1 and B3 with B2. Both pairs were misperceived by 22% of the observers. Although they constituted mismatches, both combinations were within the same shade group yet differed in value and saturation. As stated previously, the frequency of assignments differed for the disks and tabs, demonstrating the irregularities or variability of shade matching. The disks were homogeneous with a glossy finish, whereas the tabs, like natural teeth, had surface irregularities that affected the gloss (light reflection on the surface).
1. No significant significance was found in matching accuracy for polychromatic tooth-shaped tabs and homogeneous porcelain disks. One design was not more difficult to match than the other.

2. The order in which matching was performed (disks or tabs first) influenced shade-matching ability. The results suggest that proficiency in shade matching can be learned and developed through multiple objective exercises, as demonstrated when tabs were matched before disks.

3. Gender had no significant relevance to dental shade-matching ability.

4. Of the 4 color-blind observers, 2 were not aware of their color vision deficiencies before the standardized color vision screening exercises. All practitioners may benefit from an objective knowledge of their own color vision status.

REFERENCES


Purpose. This study examined the hypothesis that critical loads for radial cracking in crown-like layers vary with the square layer thickness (at ceramic thickness less than 1 mm).

Material and Methods. Crown-like ceramic layers were bonded to simulated dentin substrates using an epoxy adhesive. The 4 ceramics types used were: a porcelain (Mark II; Vita Zahnfabrik, Bad Sackingen, Germany); an infiltrated alumina (In-Ceram; Vita Zahnfabrik); a zirconia (Prozyr; Norton Advanced Ceramics, Colorado Springs, Colo.); and a glass-ceramic (Dicor; Dentsply International, York, Penn.). The bonded ceramic thicknesses ranged from 100 μm to 6 mm. Hertzian tests were completed on the layer specimens. Radial crack initiation and evolution were video recorded in situ during loading. Critical loads were recorded. Regression analyses were completed on the data and correlation coefficients were ascertained.

Results. An increase in resistance to radial cracking was demonstrated for zirconia relative to alumina and also for alumina relative to porcelain.

Conclusion. This investigation provided failure predictions in ceramic/substrate layers. Four types of ceramic materials were also ranked in terms of predicted clinical performance. 31 references.—DL Dixon

Materials design of ceramic-based layer structures for crowns
Visual and instrumental agreement in dental shade selection: Three distinct observer populations and shade matching protocols

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ABSTRACT

Objectives. This study tested the hypothesis that the agreement between observer visual dental shade matches and instrumental shade identification is higher using the Vita 3D-Master® (3D) shade guide than the Vita classical (VC) shade guide.

Methods. Three populations selected shade matches: non-dental observers (GP) matched shade tabs-to-tabs and dental students (DS) and dentists (DD) matched an in vivo natural right upper central incisor (RUCI). All observers (n = 600) used both shade guides (3D and VC) in two lighting conditions, cool white fluorescent lighting (CWF) and natural sunlight (NSL). The shade tabs and natural teeth were identified using an intra-oral spectrophotometer (Vita Easyshade™) to determine the instrumental agreement with the visual shade selection. The percent visual–instrumental shade agreement (PVIA) was analyzed statistically considering: observer population, shade guide set, and lighting condition.

Results. A “substantial” intra-examiner agreement (k = 0.76) was observed. The PVIA ranged from 12% (DS) for the 3D-NSL condition to 42% (DD) with the VC-CWF condition, which also resulted in the highest PVIA for GP (38.5%) and DS (35%). Results indicated that the GP with neither dental knowledge nor shade guide experience had a significantly higher PVIA using the VC rather than the 3D shade guide. Dentists demonstrated the highest PVIA (42%) for both lighting conditions and shade guides, thereby rejecting the study hypothesis.

Significance. A significantly higher visual–instrumental shade agreement was demonstrated by the clinically experienced dentists (DD), regardless of shade guides and lighting conditions.

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1. Introduction

Esthetic excellence is largely an art with primarily subjective interpretation and not enough has been done to effectively analyze and formulate it [1]. Included within restorative and esthetic dentistry is color, in the practice of shade matching. Today’s color science principles still originate with Newton in the 1600s and are still based on Munsell’s basic three-dimensional notation theory of the early 1900s [2].

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It is the subjectivity inherent in the shade matching process that people try to overcome [3]. Yet, in dental shade matching, the human eye is still the most popular clinical approach. A person with color normal vision can recall approximately 300 different colors and is able to discriminate 5–10 million different colors in side-by-side comparisons [4]. Even so, studies have reported that up to 80% of the patients express their dissatisfaction with perceptible shade differences [5]. It has been affirmed that in dental shade matching, the eye is the finest null detector, nonetheless, observers must be trained to optimize their color perception [6]. Shade matching is generally associated with homogeneously colored objects however, teeth vary in color and translucency. Consequently, they are thought to be more difficult to shade match. A study using 73 dentally trained observers reported no significant difference between matching accuracy for the homogeneous porcelain discs (78.4%) and the inhomogeneous shade tabs (73.6%) [7].

Given that the same color can be perceived differently among observers [8], it is feasible that instrumental shade identification may remove a certain subjectivity that arises from individual color perception. Addressing the issue of color vision disparities, Moser et al. [9] screened the red-green color vision of 670 participants at an ADA meeting where nearly 13% of dental professionals demonstrated irregular color vision, while 2.8% exhibited severe color vision irregularities.

However, it has been demonstrated that instruments also have limitations. One such study reported 50% instrumental accuracy and 48% visual accuracy in matching designated commercial tabs, with no statistically significant difference between the two methods [10]. Another study demonstrated inconsistent interexaminer reliability for instrumental shade identification among four clinicians with different levels of color instrument training; although, the instrumental results for canine were more reproducible compared to those of central incisors [11]. Nonetheless, many dental studies have reported that color-measuring instrumentation has facilitated and supported the clinician’s shade selection to match the surrounding dentition [3,11–16].

One such instrument is an “intra-oral spectrophotometer” (EasyshadeTM, Vita Zahnfabrik, Bad Säckingen, Germany) with specific modes to identify reference shades from two commercial dental shade guides: the Vita 3D-Master (3D) (Vita Zahnfabrik, Bad Säckingen, Germany) and the Vitapan Classical (VC) (Vita Zahnfabrik, Bad Säckingen, Germany). This combination of shade guides, instrumental development and calibration capability presents a very orderly, integrated system for testing. The Easyshade is reported to convert the received light from the targeted object into tristimulus parameters based on a D65 illuminant, while the unit itself uses a 20 W halogen bulb. The color-measurement area includes two separate measuring apertures, a 1-mm and a 3-mm diameter. The illuminating diameter is 5 mm.

Dozic et al. [17] reported that the intra-oral spectrophotometer, Easyshade, was the most reliable instrument in both in vitro and in vivo circumstances. However, the relationship of human visual observations to instrumental shade identifications for dental applications is still lacking. There are very few reports with a substantial number of visual observations in direct comparison with instrumental evaluations. Thus, based on limited observer matches in conjunction with instrumental evaluations, a wide range and overlap of shade matches and mismatches have been reported [6,18–20].

While color instrumentation and shade matching procedures have been widely addressed in dental literature, the most popularly used shade guides have not changed much through the last 50 years. The Vita Toothguide 3D-Master (3D) was developed with a systematic arrangement for a wide range of natural dentition shades [21]. The 3D shade guide is arranged in five discernible value levels with multiple chroma levels, as differentiated from the traditional Vitapan Classical (VC) grouping primarily by hue.

As is known, lighting is fundamental to color perception and significantly influences the quality of shade matching. Studies have reported that shade matching performed under different lighting is not necessarily consistent and furthermore, it is difficult to determine the effects of particular lighting on shade perception [22–24]. Consequently, controlled and standardized illumination is often suggested for observer and instrumental dental shade evaluation. Considering that the instrument used in the present study is based on a daylight (D65) illuminant and that most clinical shade matching occurs under cool white fluorescent lighting, both of those conditions were employed in this study. While these are not necessarily the most accurate illumination sources for shade matching, they are among the more popularly used. When possible, consideration should be given to such variables as the color rendering index (CRI).

This study analyzed the percent agreement between the human observer visual shade match selections and the corresponding instrumental shade identifications, that is the “percent of visual–instrumental agreement” (PVIA) among three populations with varying levels of dental experience, testing the hypothesis that the agreement of visual shade selections and the instrumental shade identification is higher with use of the 3D shade guide than with the VC shade guide.

2. Materials and methods

The study protocol was presented to and approved by the local Ethics in Research Committee prior to the experiment. All the individuals involved were invited to participate in dental shade matching exercises on a voluntary basis. Prior to shade matching participation, each individual was screened for color vision recognition ability by correctly identifying selected plates from the Ishihara Color Vision Test. The voluntary observers fell into one of three distinct categories predicated on their dental knowledge and dental shade experience: (1) general population (GP) with no dental shade experience, (2) first year dental students (DS) with no clinical shade experience, and (3) dentists (DD) with a range of years experience. The gender and age of the participants were recorded.

Shade tabs from two commercial dental shade guides (VC and 3D) were used for all of the experimental shade matching exercises. The shade matching protocols differed to some extent in their implementation, appropriate to the experience and classification of each observer population. The GP participants matched shade tab-to-tabs. The DS and DD groups conducted intra-oral shade matches. Only the DD had patient subjects. For intra-oral shade matching, subjects and
patients were upright with the mouth at the observer's eye level.

External visual influences such as lipstick were removed and a neutral gray patient bib obscured clothing colors. Upper and lower teeth were apart and the tongue retracted. The shade tab was positioned in the same plane as the tooth (right upper central incisor—RUCI) to be matched by DS and DD [25].

Following each observer's visual shade tab selection the corresponding shade tab or natural dentition was identified instrumentally using an intra-oral spectrophotometer (Vita Easyshade®, serial no. 405643). The stainless steel probe tip of the instrument was protected with a specified polyurethane shield (Vita Zahnfabrik) for contamination control. Calibration was performed throughout the study. The 'instrument use mode' was set on the appropriate identification mode, that is, to "shade tab" for identification of tab shade and to "tooth single" to identify the intra-oral tooth shade. In addition, the instrument was set to yield shades in the commercial nomenclature for both of the shade guides (VC and 3D) that were used throughout this study.

Shade matching selections were conducted in two different lighting environments: 'out-of-doors', natural sunlight (NSL) and 'in-doors' under cool white fluorescent (CWF) lighting. Throughout the course of the study, the natural sunlight exercises were conducted during the same daylight hours, in keeping with dental clinic hours. As commercial shade tabs were used, the shade nomenclature on the tab handle was masked to prevent influencing observers' selections. The experimental adaptations particular to each population's experience are clarified below.

### 2.1 General population (GP)

Participants were enlisted by inviting random passersby in the vicinity of the dental school to engage in dental shade matching exercises. No explanation of color science principles or of clinical shade matching procedures was given to the participants. GP (n = 200) were instructed individually to focus on the middle third of the shade tab when selecting the shade tab-to-tab matches. The middle third focus corresponded to the area targeted with the instrument. Each observer was asked to take one shade tab from a box containing eight shades (Table 2) and to select the matching tab from each of two shade guide sets (VC and 3D). All identifying shade nomenclature was masked to prevent influencing shade selections. After matching in each of the two lighting conditions (NSL and CWF), each GP observer shade selection was identified instrumentally and recorded as a visual—instrumental "agreement or non-agreement".

### 2.2 First year dental students (DS)

DS participants (n = 200) were divided into pairs to conduct the shade matching. Each DS selected, in vivo, a shade tab match for a natural right upper central incisor (RUCI) on their partner. All participating DS had unobscured, natural dentition (RUCI), meaning there were no brackets or restorations to interfere with the visual shade assessment or instrumental shade identification. DS were instructed to focus on the middle third of the tooth and the shade tab during matching, which corresponded with the placement of the instrumental probe. The visual shade selections made in CWF and NSL were identified as visual—instrumental "agreements or non-agreements" in accordance with the instrumental intra-oral shade identification of the designated RUCI.

### 2.3 Dentists (DD)

DD participants (n = 200) followed same protocol as the DS and selected, in vivo, a shade match for a patient's natural RUCI. As with the other observer populations, the DD were instructed to focus on the middle third of the RUCI being matched. The patient's RUCI was clear of restorations or oral appliances that might interfere with the visual and instrumental shade identification. After visual shade selection for the RUCI in CWF and NSL, intra-oral instrumental identification was conducted and recorded as visual—instrumental "agreement or non-agreement".

All the instrumental shade identifications were made three times for each shade tab and each natural tooth after each observer's shade selection. The shielded instrumental probe was consistently placed in the middle third of the tab or tooth to correspond to the observer viewing instructions. Any discrepancy in the instrumental multi-readings was resolved by performing an additional set of readings per the manufacturer's recommendation. One single consensus was recorded for each visual—instrumental determination.

The intra-examiner Kappa coefficient (k) was calculated as previously described [26]. Each observer shade selection and instrumental shade identification was recorded strictly as a visual—instrumental "agreement or non-agreement" based on the instrumental shade identification. The data was compiled and analyzed statistically using Pearson's chi square test (α = 0.05) considering the observer population, shade guide set, lighting condition and visual—instrumental shade agreement or non-agreement.

### 3. Results

A “substantial” intra-examiner agreement (k = 0.76) was observed [26]. This study involved a total of 600 observers who ranged from 19 to 50 years of age. There were 299 females and 301 males with distinctly different levels of knowledge and experience for dental shade matching (Table 1). Each observer made four shade match selections, using two shade guides (VC and 3D) in two lighting conditions (NSL and CWF) for a total of 2400 observer shade match selections. The percent visual–instrumental agreement (PVIA) for each shade guide—illuminant condition per population – was calculated (Table 1).

Approximately 7% of the individuals that volunteered to participate in this study were excluded prior to shade matching because they were unable to identify all the color test plates indicating possible color vision confusion. By gender, the exclusion was 10.4% males (35 of 336) and 2.3% females (7 of 306). Per population, the ineligible volunteers were: GP: 12 (6%), 2 females and 10 males; DS: 14 (7%), 2 females and 12 males; and DD: 16 (8%), 3 females and 13 males. These results are in agreement with previous reports [9,13,16].
The shade tabs used in this study were identified instrumentally confirming the shade tab identification prior to use. The instrumental identification indicated that there were eight equivalent shades in the two different shade guide sets (VC and 3D) (Table 2).

Using the specific shade guide mode for the instrument, shade tab identification was consistently in agreement with the tab nomenclature. This was verified by unmasking the tab nomenclature after each GP observer completed their shade selections.

The most consistent matching condition, with no statistical difference among the three observer groups, was for the VC shade guide under CWF lighting (Table 1).

Combining the matching results for both shade guides, the GP visual–instrumental agreement (PVIA) was significantly higher when observers selected shades under CWF lighting (31%), rather than under NSL (26.2%) (p < 0.05). When the GP shade tab selections under both lighting conditions were combined, the PVIA was significantly higher using the VC shade guide (35.2%), than for the 3D shade guide (22.0%) (p = 0.0001).

Combining the results of the two lighting conditions, the DS demonstrated significantly greater PVIA using VC (32.2%) than using 3D (17.5%) (p = 0.0001). The instrumental identification indicated that there were 26 3D shades rather than the familiar 16 VC shades and was based, in part, on the increased shade range selection for shade identification. Also on the basis that the 3D shade guide design presents a new viewing arrangement for value and chroma that is associated with instructions of use. However, it must be noted that the number of samples in the shade guide or their arrangement should have no effect on the instrumental functioning for shade identification.

The testing hypothesis throughout this study was that the visual–instrumental shade identification agreement (PVIA) would be higher using the 3D shade guide. This hypothesis was based, in part, on the increased shade range selection of 26 3D shades rather than the familiar 16 VC shades and also on the basis that the 3D shade guide design presents a new viewing arrangement for value and chroma that is associated with instructions of use. However, it must be noted that the number of samples in the shade guide or their arrangement should have no effect on the instrumental functioning for shade identification.

The results of this study demonstrated that a general population (GP) with neither dental knowledge nor shade guide experience had a higher PVIA when they used the VC shade guide, thus rejecting the hypothesis for this population. The same held true for the first year dental students (DS) in vivo...
matching selections, which demonstrated higher PVIA when they used the VC shade guide than the 3D. These two populations (GP and DS) had neither previous experience nor knowledge of the 3D shade guide instructions of use.

Dentists (DD) demonstrated the highest PVIA (42%) and relative consistency under both lighting conditions, which may indicate that the dentists were not influenced by a particular shade guide set, rejecting the study hypothesis for this population. A small number of the dentists (14%) reported previous awareness of the 3D shade guide. That may have been a contributing factor to the group demonstrating a statistically significant greater PVIA than the other two populations with the 3D shade guide. Also, it may be considered that familiarity with the shade matching process among dentists played a role among the populations.

Another consideration for visual–instrumental agreement is that the human eye sees the heterogeneous aspects of each tab or tooth, the variations in shade and translucency. An instrument amalgamates these characteristics yielding one, homogeneous shade. The instrumental shade identification is affected by the amount of light that is reflected back into the instrument from the surface being targeted. Consequently, positioning of the probe or mouthpiece is reported to be critical to the repeatability of the instrumental reading. For that reason, one trained operator (k = 0.76) performed the instrumental identification throughout the present study.

The better standard illuminant for color viewing is generally thought to be the natural daylight, however it changes over time, especially given the significant number of observer hours in this study. While two lighting environments were used, the cool white fluorescent lighting may have provided a more consistent illumination than the natural sunlight. This may have had some effect on the visual selections, and subsequently on the study results. This observation is in accordance with literature indicating that the consistency of artificial lighting may contribute to better shade-matching results than natural daylight [15,27].

Simply stated, the color differences from color-measuring devices are based on the light emitted and reflected back from the targeted object. As noted by Ishikawa-Nagai et al. [16], samples need to be well illuminated to avoid measurement errors. The instrument in this study has an illuminating area of 5 mm, incorporating each of the two smaller shade identification areas. However, an instrument is not affected by most surrounding visual influences as is the human eye. At present, shade matching usually employs different illuminants such as those used in this study: environmental lighting (CWF ∼4000 K and NSL ∼5000–6500 K), instrumental lighting (halogen, 3350 K) and the instrumental color calculations (D65, 6500 K). Therefore, it would be advantageous to use the same standardized lighting for both the instrumental illuminant and for visual perception shade-matching studies if the goal is comparing results from different studies. This study did use natural daylight, which is purported to correspond to the D65 used in instrumental calculations. The CWF used in this study is closer to the instrumental illuminant than the NSL. In addition, it should be noted that these study results demonstrated the consistent and reliable calibration of the Easyshade by the correct shade recognition of the tabs. This concurs with previous studies [17,26], and it was the reason for using this instrument as the gold standard in the present study.

This research involved a significant body of observers and a correspondingly large number of visual dental shade selections using the same dental shade tabs under two different lighting conditions as recommended in the ASTM D-1729-89 [28]. Although the emphasis of this study was on the agreement for the observer visual and the instrumental shade identification, it is an harmonious appearance that is most essential to successful dental restorations.

Although a significantly higher visual–instrumental shade agreement was demonstrated by the clinically experienced dentists (DD), it should be possible to achieve a higher percentage of successful matches than the approximately 50% reported in the dental literature [10,14,16], which are in accordance with the results of the present study. Therefore, the results of this study suggest that shade training and/or dental experience are an important component in shade matching. As stated by Sproull, concentrated effort on shade training can contribute to improve matching results [6].

Further study with an experienced population that is familiar with the shade guide systems may yield different and hopefully higher agreement results.

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