Evaluating Tooth Color Matching Ability of Dental Students


Abstract: Visual shade matching has remained a skill acquired through clinical experience. The purpose of this study was to evaluate the shade matching ability of dental students as they progress through their education. Sixty-five students, representing four levels of experience by year enrolled in dental school, participated in this study. Students were given a preclinical shade tab matching task. They were also asked to choose the best shade match for a natural tooth in each of three patients. The natural tooth shade matching task was designed to have simple, moderate, and complex cases to match. The frequency of correct answers was compared across samples across the four levels of fundamental tab match ability and clinical experience. On average, 51 percent of the students were able to match the correct shade tab in the matching task in a bench setting. For the natural tooth color matching task, 49.2 percent of the students selected the clinically acceptable color matched shade tabs (ΔE*≤2.69). Although there was no statistically significant difference across the levels of fundamental ability and experience, rates of correct answers for natural tooth color matching progressively improved for the complex case from year 1 to year 4. This study reveals that, for complex cases, education and knowledge of color science combined with clinical experience improve students’ ability for color matching in a clinical setting.

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Accurate shade matching in dentistry has become essential to an optimal dental restoration and successful clinical practice. With the creation of and increasing popularity of esthetic restorative materials, appearance “very strongly” influences about 42 percent of patients in their decision to obtain treatment, while 50 percent of remakes for esthetic restorations are the result of failure to match shades accurately.1,2 This leads to unnecessary additional patient visits, dentist anguish, staff frustration, and lab remake fees. Color matching in dentistry can be performed using visual and/or instrument-based methods. While color matching instruments such as colorimeters and spectrophotometers are objective, they are not widely used in dental practice yet. Visual shade matching performed with use of shade guides remains the mainstay of tooth color determination. Correct shade choice is limited by knowledge of color science, clinical experience, time constraints, and patient cooperation.

Visual color selection for dentistry is dependent on many factors, and variation in any of them can lead to an altered color perception.3-10 Tooth color consists of stratiform layers of enamel and dentin that absorb, reflect, transmit, or refract incident light, thereby producing the quality of color.7 Various light sources each produce a distinct spectrum of color leading to metamerism.8-10 Commercial shade guides do not represent the full spectrum of natural tooth color in the population, which contributes to difficulty in selecting a shade match. When natural teeth were compared to Vita Shade Guides, 15 percent did not match any shade tab, 35 percent appeared brighter than shade tabs, and 51 percent had more red.11 These problems are further compounded by use-related deterioration of shade tabs by abrasive sterilizing agents, handling, and storage.7 Variations in visual shade selection, protocol, technique, and interpretation also lead to inconsistencies.11 To effectively overcome the challenges associated with accurate shade selection, an understanding of both the art and science of color is essential.

Color has been described as a three-dimensional phenomenon, consisting of hue (color), value (brightness), and chroma (saturation).8,13,14 No single tooth is of uniform color. All teeth are aggregates of
Many individuals also have some form of color vision deficiency or color vision confusion. Individuals with a red-green deficiency showed lower color vision scores in the yellow regions of visible light spectrum, which is most relevant to dentistry. The genetic type of color vision confusion is commonly referred to as “color blindness,” affecting approximately 8 percent of men and up to 2 percent of women in the general population. Eight to 14 percent of dental personnel have been found to be color deficient. Acquired color vision confusion can be caused by various factors such as age, medical conditions, medications, and emotional shifts, which can result in papillary diameter changes, etc. Thus, it is important that any individual who is responsible for dental shade selection be screened for color vision deficiency using tests such as Neitz color vision test.

Experts have emphasized the need for training in vision physiology and color science in dental education. A survey of 112 dental schools around the world in 1967 found that only twenty-three had some formal color education in their curricula. Comprehensive color training continues to be lacking in the dental school curriculum. The most recent survey of dental school curricula performed by the American Dental Association’s Survey Center found that an average dental student spends only 4.8 percent of his or her entire dental education on learning about esthetic dentistry. Of this, 1.7 percent of the education is in the form of didactic instruction, and 3.1 percent is made up of laboratory instruction, dental school-based patient care experience, and community-based patient care or externship experience. Details about the educational components such as color science, shade selection technique and protocol, etc. are not available.

Dental schools do not teach the fundamentals of color science. The dental student and most clinicians generally are not familiar with visual color analysis and are perhaps often unable to adequately describe coloration to the dental laboratory technician. When clinicians are unable to discuss hue, chroma, and value with the technician, they are unable to supply the information necessary to create an esthetic restoration that harmonizes with the patient’s remaining natural teeth. Dental students have the most difficulty determining the correct hue group of unmarked shade tabs. Incorrect responses tend to remain in the same value and chroma range but are selected in a different hue group. These problems lead to a reported 89 percent of patients with anterior metal-ceramic restorations who are aware of color differences relative to their adjacent natural teeth.

The purpose of this study was to evaluate the shade matching ability of dental students at various levels of their education and clinical experience.

### Materials and Methods

Upon approval from the Institutional Review Board at Harvard Medical School, students from all four class years at Harvard School of Dental Medicine were enrolled in the study. The Neitz test of color vision was used as an exclusion criterion for participation in the study. Each student was presented with two tasks.

The first task—shade tab matching in a bench setting—was designed to reflect the fundamental shade matching ability of the students. Each student was provided with a new Vitapan Classical shade guide (Vita Zahnfabrik, Bad Sackingen, Germany) and three target shade tabs from different hue groups sample A (A1), sample B (B4), and sample C (D4) with the shade identification numbers covered. The students’ task was to correctly match the sample shade tab with its counterpart from the shade guide. Their responses were collected on a survey form and were recorded for statistical analysis.

The second task—natural tooth color matching in a clinical setting—was designed to assess the shade matching ability of participants in a dental clinical setting. The participants were asked to find a Vita Shade match for a natural central incisor of three patients (A, B, C). To minimize confusion, each patient also had a paper diagram indicating the part of the tooth for which the shade was to be determined (Figure 1). Patient A had a relatively monotone tooth color and was categorized as a “simple case.” Patient B had polychromatic tooth color with gradation from incisal to cervical on the facial surface and was categorized as a “moderate case.” Patient C had severe tooth color gradations and a horizontal line of hypocalcification on the facial surface and was categorized as a “complex case.” The students’ responses were collected on a survey form and were recorded for statistical analysis.

Conditions of each viewing session were standardized as much as possible. The task was performed.
Spectrophotometric measurements and color analysis were performed using a dental spectrophotometer system (MSC-2000 and Crystaleye software, Olympus, Japan). Color measurements were performed by obtaining CIE L*<sub>target tooth</sub>-L*<sub>shade guide</sub>, a*<sub>target tooth</sub>-a*<sub>shade guide</sub>, and b*<sub>target tooth</sub>-b*<sub>shade guide</sub> color coordinates for the tooth area. The database of a dental spectrophotometer Crystaleye (Olympus, Japan) was utilized to obtain the CIEL*a*b* color readings of shade tab. The color difference ∆E* between the natural tooth and shade guide tabs were calculated using the following equation:

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\Delta E^* = \sqrt{(L_{target \ tooth} - L_{shade \ guide})^2 + (a_{target \ tooth} - a_{shade \ guide})^2 + (b_{target \ tooth} - b_{shade \ guide})^2}
\]

The color difference ∆E* is an index to express a magnitude of difference between two objects. In dentistry, several in vivo studies have been performed to determine the clinical threshold of ∆E* for color evaluation. In this study, for the data analysis, the shade tab matches with a ∆E*≤2.69 were categorized as clinically acceptable/correct color matches. The frequency of clinically acceptable/correct answers was calculated, and these data were compared across each of the four class years and four categories of color matching ability using one-way ANOVA and Fisher’s multiple comparison test.

**Results**

After exclusion with the Neitz color vision test, seventy-six students participated in the study. Of these, data from sixty-five students (85.5 percent) were available for both parts of the study after attrition due to scheduling and other administrative constraints. Responses from seventeen students in year 1 (seven male, ten female), nineteen in year 2 (thirteen male, six female), fifteen in year 3 (ten male, five female), and fourteen in year 4 (nine male, five female) were included in the analysis. In total, twenty-six female and thirty-nine male students were involved.

For task 1 (shade tab matching in a bench setting), 51 percent of the responses were correct. When assessing across class years, 39.2 percent of the responses were correct for year 1, 64.9 percent for year 2, 55.5 percent for year 3, and 59.5 percent for year 4. When assessing across the three samples, 55 percent of the responses were correct for sample A, 47 percent for sample B, and 51 percent for sample C. No statistically significant difference was found in the rate of correct matches among samples A, B, or
C or among class years. The percentage of students who correctly matched all of the three shade tabs was 18.4 percent=Excellent; 40.0 percent matched two tabs correctly=Good; 27.7 percent matched one tab=Fair; and 13.9 percent were unable to correctly match any of the shade tabs=Poor (Table 1).

For task 2 (shade matching for natural tooth), the clinically acceptable/correct shades for patient A (simple case) were determined to be A1 and B1; for patient B (moderate case) were B2 and A2; and for patient C (complex case) were A2, D3, and A3 (Table 2). Forty-nine percent of the participants selected the acceptable/correct shades for all three patients: 80 percent for the simple case, 45 percent for the moderate case, and only 23 percent for the complex case. The data that were analyzed across the three patients showed a statistically significant difference in the rate of correct responses among the three patients (p<0.01) (Table 3). Additionally, Fisher’s reliability test showed that there was a

| Table 1. Percentage of students categorized in four color matching ability levels (n=65) |
|-----------------------------------------------|---------------|| Excellent (3 matches) | Good (2 matches) | Fair (1 match) | Poor (no matches) |
| % of students providing responses | 18.4% | 40.0% | 27.7% | 13.9% |

| Table 2. Shades determined to be correct responses for each case of task 2 (ΔE*≤2.69) |
|-----------------------------------------------|---------------|| Patient A (simple case) | Patient B (moderate case) | Patient C (complex case) |
| A1: ΔE*=1.01 | B2: ΔE*=1.11 | A2: ΔE*=1.21 |
| B1: ΔE*=1.63 | A2: ΔE*=1.42 | D3: ΔE*=1.77 |
| – | – | A3: ΔE*=2.09 |
statistically significant difference in the number of correct responses between patient A (simple case) and patient B (moderate case) \((p<0.05)\) as well as between patient A (simple case) and patient C (complex case) \((p<0.01)\).

When the results of task 2 were further assessed in correlation to the levels of fundamental color matching ability, no particular trend of acceptable/correct answers for all three patients was evident (Figure 3). Additionally, there was no statistically significant difference between class years in the students’ ability to choose the clinically acceptable/correct shade. However, there was a trend towards better performance in shade matching with the increasing class year for patient C (Figure 4). Female students had a better performance than male students in all three cases; however, there was no statistically significant difference between the groups (Figure 5).

### Discussion

Among all the various factors that influence ideal reproduction of tooth color, education in color science and clinical experience play a significant role in the visual color shade matching ability of a clinician. The color sciences curriculum is taught in an interdisciplinary fashion at Harvard School of Dental Medicine in the form of lectures and in the context of problem-based learning cases. The Restorative Department provides lectures on shade matching techniques and protocol when discussing

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**Table 3. ANOVA table and Fisher’s PLSD for percentage of correct answer in three clinical cases**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degree of Freedom</th>
<th>Mean Square</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor level</td>
<td>5716.378</td>
<td>2</td>
<td>2858.189</td>
<td>11.21676</td>
</tr>
<tr>
<td>Residuals</td>
<td>2293.327</td>
<td>9</td>
<td>254.8141</td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>8009.705</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Case 1 > Case 2 \((p<0.05)\); Case 1 > Case 3 \((p<0.01)\)

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**Figure 3. Comparison of percentage of correct/acceptable answers for the three patients at each level of fundamental color matching ability**
Figure 4. Comparison of percentage of correct/acceptable answers for the three patients in each of the class levels, showing a trend towards better performance with the increasing class year.

Figure 5. Comparison of percentages of correct/acceptable answers for the three patients in male and female groups, showing that females provided a higher percentage of correct/acceptable answers than males for all patients.
composite materials, porcelain, and removable, partial, and complete dentures. The application of this knowledge is reinforced in preclinical and clinical sessions, and skills are assessed as a component of students’ competency requirements. Students may also present and discuss color sciences when they present comprehensive treatment cases in the third and fourth years.

This study was a preliminary step in assessing the current status of the clinical color matching ability of dental students at various levels of their knowledge and clinical experience and sheds some light on how significant this influence may be. Dental students are an appropriate population to test shade matching abilities because they are generally young adults in same age group, have little or no experience in shade selection, and are likely to have fewer systemic conditions that affect color perception. The Neitz test of color vision was used to exclude those who might have genetic color vision deficiency from participating in the study. Participants from both genders were required to pass the color vision test. This also helped us to solve the issue of aptitude discrepancy between genders. Seventy-six students (95 percent) out of the total of eighty passed the test. The four who did not pass the Neitz test were informed of their results and advised to train and seek the help of their auxiliary staff for shade selection in their practice.

Students from all four class levels were selected on the basis of the following assumptions. Students of Year 1 performed the shade matching task based on the individual’s visual perception, with no formal knowledge of color selection and no clinical experience. Students of Year 2 represented the group that had some knowledge of dentistry and color selection; however, they did not have any patient contact or clinical experience. Students of Year 3 had basic lectures in dentistry and prosthodontics and had received some patient contact in a clinical setting. Year 4 students represented the group that possessed the most clinical experience and knowledge of prosthodontics. By the end of Year 4, the students had delivered twenty units of fixed partial denture prosthetics to patients. They also had an advanced education lecture series in prosthodontics and color selection in dentistry. The study was conducted in April to capture the students at the end of their dental school year. Therefore, they are ideal representations of students in each year/level of their education.

For the shade tab task, there was no significant difference between class years on students’ ability to shade match. The shade tab matching task does not depend on dental knowledge, and the results are a representation of the participant’s fundamental color matching ability. Therefore, the similarity in the overall performance of participants in each class year is not surprising. It is a well-known phenomenon that the color of the same shade tab from different shade guides for a system can have differences. In this study, the shade tab matches are the identical shade tabs in the complete shade guide. The match was confirmed with a dental spectrophotometer, and the color difference ΔE* value between each target tab and corresponding tab in a complete shade guide system was less than 0.5—a color difference that is imperceptible. Only 18.4 percent of the participants were able to correctly match all three shade tabs. There are at least two possible reasons for such a high error rate. This kind of color test was a first experience for most of the participants, and the translucent nature of porcelain separates this task of matching tabs from any other color matching task. Moreover, color gradation from incisal to cervical areas of the shade tab complicates the matching process.

For the natural tooth color matching task, the conditions are further complicated. Spectrophotometer and color analysis software were used to determine the correct response for the patient tooth color. There are many studies on perceptibility and visual acceptability thresholds. However, results vary widely depending on individual methodology. One study by Johnston and Kao used a colorimeter with a fitted metal mouthpiece and measured intraoral color differences between composite resin veneers and adjacent, contralateral, or opposing teeth that were natural or restored. Only 18.4 percent of the participants were able to correctly match all three shade tabs. There are at least two possible reasons for such a high error rate. This kind of color test was a first experience for most of the participants, and the translucent nature of porcelain separates this task of matching tabs from any other color matching task. Moreover, color gradation from incisal to cervical areas of the shade tab complicates the matching process.

This study utilized maxillary complete denture teeth and concluded that 50 percent of the dentist observers could perceive a color difference at ΔE* of 2.6 (perceptibility threshold) and would remake the restoration at ΔE* of 5.6 (acceptability threshold). The latest study that evaluated the clinical efficacy of a dental spectrophotometer found that the aver-
age ΔE* value of a clinically acceptable ceramic restoration (n=32) was 2.69. Since there is no gold standard ΔE* threshold for clinical shade match, in this study ΔE*≤2.69 was considered as the clinically acceptable/correct color match.

Overall, acceptable/correct answers decreased as complexity of case increased. Even with a small size of study population, there was a statistically significant difference in the number of correct responses between patients A, B, and C (Table 3 and Figure 3). This indicates that the sample patient selection as a representation of complexity level was adequate. Although there was no particular trend observed for fundamental color matching ability, better performance was observed as class level progressed for the complex case. It is possible that the participants depended only on their intrinsic shade matching skills for the shade matching task and first two cases (simple and moderate cases), while the complex case required the students to tap into their knowledge and experience of color selection to identify a proper match.

These results support the efficacy of clinical experience and professional knowledge for clinical shade matching in moderate to complex cases. Thus, educational outcomes need to include a commitment to lifelong learning with emphasis on dental materials, technology, and technique-enhancements for optimal results for all patients, whether simple, moderate, or complex cases. It is unknown whether the next patient who walks into the practice of a new graduate is going to present with a simple, moderate, or complex cases. It is possible that the participants depended only on their intrinsic shade matching skills for the shade matching task and first two cases (simple and moderate cases), while the complex case required the students to tap into their knowledge and experience of color selection to identify a proper match.

Conclusion

Although the color matching ability of dental students is strongly dependent on individual perceptual ability, clinical experience and knowledge of color science in dentistry can lead to better performance in a clinical setting, especially with complex color matching.

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REFERENCES