Color appearance is an important parameter for patient acceptance of dental restorations. The esthetic demands of patients and dental professionals have additionally elevated the importance of accurate shade selection. Published studies cite several sources of shade matching errors, some controlled by the operator and others out of the operator’s control. These sources include shade matching conditions (starting from the lighting), methods and tools, shade guides, education and training, color deficiency, and numerous physiological and psychological factors (fatigue, nutrition, medications). Clinicians must pay attention to shade matching variables, such as an accurate and reproducible light sources and color education and training.

Shade matching should be performed using standardized ideal daylight conditions with a correlated color temperature range of 5000 K (D50) to 7500 K (D75). These color temperatures are sought because of their universal nature and broad spectrum of wavelengths. However, these conditions are rare in natural lighting. The color temperature of
daylight is always changing and can range from 1000 K to 20,000 K. This makes it difficult to rely on natural daylight to provide the “ideal” color temperature when the dental healthcare provider is selecting a shade for the restoration. Adding to this, research has demonstrated that natural light does not necessarily produce better results than color-corrected artificial light. Handheld lights designed specifically for color matching in dentistry are available and may be a better option than complete reliance on natural daylight or office lighting.

Education and training have been found to affect shade selection quality. Color matching, like many other aspects of dentistry, requires a fine skill and should be practiced regularly. There is a difference between experience and education and training in dental color matching. It has been reported that senior dental students are expected to be more successful because of their gradually increasing knowledge and clinical experience. Probably a combination of dental education and training produced better shade matching results. Traditionally, women are considered more able to select shades accurately than men can. However, a number of studies have identified no significant influence of sex on shade matching results.

The results of visual shade matching using color measuring devices must be evaluated as the reproducibility of instrumental shade matching has been reported to be much higher than that of standardized visual methods. Information on instrumental color differences also enables comparison with visual thresholds (perceptibility and acceptability threshold), which is important for the interpretation of the results of visual shade matching. Finally, colorimetric findings allow dental shade guides to be compared; selecting and using the shade guide with the smallest coverage error (corresponds to the best color match to natural teeth) is best.

The purpose of this study was to determine whether use handheld lights with or without a polarizing filter influenced shade matching results more than using a viewing booth and whether education and training influenced shade matching results. The null hypotheses were that shade matching results would not be influenced by the type of light or education and training.

**MATERIAL AND METHODS**

A total of 96 evaluators, third-year dental students of the University of Texas School of Dentistry at Houston, participated in the study. Committee for the Protection of Human Subjects and institutional review board approval were obtained. A professional viewing booth (Judge II; GretagMacbeth) was used as the control (Fig. 1). Two handheld devices for visual shade matching (color-matching lights) were used (Rite-Lite 2; AdDent; and SmileLite; Smile Line USA), each with and without a detachable polarizing filter (Fig. 2). Student evaluators were divided into 4 equal groups, each consisting of 25% of the class in alphabetical order. Color matching lights were randomized by groups via coin flip to group I, Rite-Lite 2 (without polarizing filter) (RL); group II, Rite-Lite 2 (with polarizing filter) (RLP); group III, SmileLite (without polarizing filter) (SL); and group IV, SmileLite (with polarizing filter) (SLP). According to manufacturer’s instructions, the evaluators were instructed to hold the SmileLite 10 cm away from the tooth on which they were performing the shade selection and 5 cm away when using the Rite-Lite 2. One of 4 shade tabs (task tabs): B1, A2, A3, and A4 (Vita classical; Vita Zahnfabrik) was positioned at the maxillary central incisor socket of a typodont with adjacent anterior teeth removed from the typodont. A gray background was used in all situations. The evaluators used another shade guide (Vita Linearguide 3D Master; Vita Zahnfabrik) to match the shade of each of the 4 task tabs. The order of shade selection is presented in Table 1. In the sessions before education and training, half of the evaluators performed the exercise using the viewing booth (VB) first and the handheld lights (HH) second, while the other half of the evaluators...

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**Clinical Implications**

The importance of color appearance in the esthetics of dental restorations highlights the need for accurate, high-quality shade matching. Comparison of results obtained with 2 different handheld shade-matching lights (with or without a polarizing filter) to a gold standard control strongly suggested the suitability of these handheld lights for clinical use. Furthermore, completion of an online color education and training program significantly improved shade matching quality.

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**Figure 1.** Evaluator performing shade matching in viewing booth using Vita Linearguide 3D-Master shade guide.

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**Table 1.** Means and standard errors of shade matching results for different light sources and education and training conditions.
performed the exercise in the reverse order. The evaluators had an opposite order of shade-matching lights in the sessions after education and training. Every student performed shade matching a total of 16 times; there were 4 shade matchings in each of four sessions, 8 before and 8 after education and training.

Education and training included a lecture on the basics of color in dentistry and clinical color matching. During the week after the lecture (and before continuing with the “after” part of the experiment), all evaluators completed Dental Color Matcher (www.scadent.org), an online education and training program for esthetic dentistry. The training program included color vision screening (normal versus deficient), a lecture with information on color in dentistry (light source parameters, metamerism, surrounding colors, time and length for shade selection, patient position, translucency/transparency, and other topics), a variety of color matching exercises, and a 12-question quiz at the end of the program. For numerical calculation in the experiment, an ordinal score was assigned to shade-matching performance based on color differences between the task tab and the chosen commercial shade guide tab. The CIELab differences in color ($\Delta E^{*}_{ab}$) were calculated as:

$$\Delta E^{*}_{ab} = \sqrt{\left(\Delta L^{*}\right)^2 + \left(\Delta a^{*}\right)^2 + \left(\Delta b^{*}\right)^2}.$$  

The smallest $\Delta E^{*}_{ab}$ value was assigned 10 points (best match), the second highest was assigned 9 points (second best match), and so on, until 1 point for the tenth best match. Selections of shades worse than the tenth best match were assigned 0 points.
Table 2. Mean (±SD) color differences between CIELab (ΔE*ab) and CIEDE2000 (ΔE00) for best match (10 points), second best match (9 points), and up to tenth best match (1 point)\(^a\)

<table>
<thead>
<tr>
<th>Points</th>
<th>ΔE*ab</th>
<th>ΔE00</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.4 (0.7)</td>
<td>1.2 (0.8)</td>
</tr>
<tr>
<td>9</td>
<td>2.6 (0.3)</td>
<td>1.8 (0.3)</td>
</tr>
<tr>
<td>8</td>
<td>3.3 (0.5)</td>
<td>2.3 (0.8)</td>
</tr>
<tr>
<td>7</td>
<td>3.6 (0.4)</td>
<td>2.2 (0.5)</td>
</tr>
<tr>
<td>6</td>
<td>4.7 (1.5)</td>
<td>3.4 (1.5)</td>
</tr>
<tr>
<td>5</td>
<td>4.8 (1.5)</td>
<td>3.1 (1.2)</td>
</tr>
<tr>
<td>4</td>
<td>5.4 (1.2)</td>
<td>3.5 (0.9)</td>
</tr>
<tr>
<td>3</td>
<td>5.5 (1.1)</td>
<td>4.1 (1.4)</td>
</tr>
<tr>
<td>2</td>
<td>6.4 (1.3)</td>
<td>4.5 (1.0)</td>
</tr>
<tr>
<td>1</td>
<td>6.9 (1.5)</td>
<td>4.9 (0.8)</td>
</tr>
</tbody>
</table>

\(^a\)CIEDE2000 differences were calculated based on CIELab order of matches.

In addition, color differences between the task tabs and matched tabs were calculated according to a more recent and advanced CIEDE2000 formula, as follows:\(^b\):

\[
\Delta E_{00}^{*}=\sqrt{\left(\frac{\Delta L'}{K_{L,SL}}\right)^2 + \left(\frac{\Delta C'}{K_{C,SC}}\right)^2 + \left(\frac{\Delta H'}{K_{H,SH}}\right)^2} + R_{I}\frac{\Delta C}{K_{C,SC}} + R_{H}\frac{\Delta H}{K_{H,SH}}
\]

Results were analyzed using SAS version 9.4 software (SAS for Windows (Microsoft)). Repeated measures analyses with linear mixed models were used to compare shade-matching performance scores across multiple student observations. Model residuals confirmed that the scores approximated a normal distribution. The main effects included in the first model were light (handheld and viewing booth), education and training (before and after), group, and shade tab (B1, A2, A3, and A4). Interaction terms were added to the model to test if any differences by repeated effects varied by group. Further models tested for the effect of sex, the interactions of sex with group, and the repeated effects.

To supplement descriptive and analytical statistics and provide clinically relevant perspective on the results, numeric color differences between task tabs as selected matches were interpreted through a 50:50% acceptability threshold of \(E_{00}=1.8\).20,21

**RESULTS**

Mean (±SD) color differences in CIELab (ΔE*ab) and CIEDE2000 (ΔE00) for best match (10 points), second best match (9 points), and up to tenth best match (1 point) are presented in Table 2. The correlation between color differences CIELab and CIEDE2000 was \(R=986\). The correlation between visual scores and color differences was \(R=.985\) for ΔE*ab and \(R=.982\) for ΔE00.

Estimated mean (±standard error [SE]) scores are presented in Table 3, and the model for predicting shade matching scores in Table 4. Estimated mean scores of shade matching results with handheld lights were 7.8 (0.1) and in the viewing booth 7.2 (0.1), with those of the handheld lights being significantly higher (\(P<.01\)). Differences between handheld lights and viewing booth scores did not vary significantly by group (\(P=.15\)).

The estimated mean scores of shade matching results for before and after shade matching (with education and training in between) were 7.2 (0.1) and 7.8 (0.1), respectively. The after score was found to be significantly higher (\(P<.01\)). The before and after education and training scores did not vary significantly by group (\(P=.41\)).

The combined effect of light and education and training improved the shade matching score by 1.2, from 6.8 in the before sessions using the viewing booth to 8.0 in the after sessions using handheld lights.

A 10% increase was recorded in the number of evaluators who selected 1 of 4 best matches using handheld lights versus a viewing booth, whereas an 11% increase was recorded for after education and training versus before (Table 5). Finally, there was a 21% increase in the number of evaluators who selected 1 of 4 best matches in after sessions using handheld lights than in before sessions using the viewing booth (Table 5).

No significant overall differences in shade matching results by sex were recorded (\(P=.98\)): women = 7.5 (0.1), men = 7.5 (0.1). Differences between viewing booth and handheld lights were not found to vary by sex (\(P=.06\)). Although differences between shade tab scores were
found to vary by group (P=.04), this interaction did not significantly vary by sex (P=.38).

**DISCUSSION**

The null hypotheses that the type of light and education and training would not influence the shade matching results were rejected; the null hypothesis regarding the influence of sex was not rejected. The objective of the study was to evaluate the effect that different light sources, polarization, education and training, and sex have on shade matching results. Several studies reported that clinicians were inconsistent in shade matching. Factors such as age, experience, eye fatigue, and physiological conditions like deficient color vision may lead to bias and inconsistencies. In this study, data were collected from third year predoctoral dental students. Dental students are an appropriate group for shade matching research as the majority are generally young, healthy adults without medical disorders that can affect their shade matching competency. Target tabs A2, A3, and A4 were selected because of their frequency in the population and their variety in lightness (medium-light, medium-dark, and dark). Finally, tab B1 was selected because it is a light shade and therefore the most desirable shade for patients.

Shade selection should be performed under ideal natural light conditions. These conditions are difficult to achieve. Previous research has shown that shade matching results are better with artificial color-corrected light than under natural light. Natural daylight was not used as the control because it is too variable and unreliable. In this study, handheld lights were found to be better than the control (a statically significant improvement of 7.8 compared with 7.2, respectively). One possible explanation for this is that the evaluators were focused solely and directly on the shade matching area observed through a small window of the handheld light. This could have reduced background distraction and increased focus on the shade-matching exercise. These are clinically favorable results (additionally, having a viewing booth in a clinical setting is not practical). The advantages of the evaluated handheld lights compared with other available shade-matching aids include their portability, user friendliness, and affordability. Further research might evaluate the influence of different lights and polarizing filters on the shade selection of natural teeth because the optical properties of enamel and dentin are different from those of the shade tabs.

Education and training on color matching plays an important role in shade matching accuracy. Previous studies have concluded that dental care professionals need to participate in hands-on courses, continuing education classes, and other training programs. Comparisons between the percentages of evaluators who chose 1 of the 4 best matches were performed, because the mean scores ranged from 7 to 8, which corresponded to the third and fourth best match, and because the majority of evaluators (63% to 74%) selected 1 of the 4 best matches. Data support previous findings that color matching results are improved by education and training. More research should be conducted in the area of retraining with standardized exercises, as merely shade matching on patients daily does not necessarily improve or maintain skills. Computer programs that engage the participant could also be a way of improving education for many dental healthcare providers.

This study supports previous research that reported that men and women overall scored the same when it comes to quality of color matching. Sex differences across the various shade tabs were similar among the 4 groups. The use of different handheld lights with and without polarizing filters did not affect the results by sex.

The greatest improvement in shade matching quality was recorded when light was combined with education and training. When these parameters were evaluated together, the average match with a handheld light after education was 8.0 compared with 6.8 seen with the viewing booth before education. The same is true for the percentage of evaluators who selected one of the best shade matches.

### Table 5. Percentage of participants who selected best shade match

<table>
<thead>
<tr>
<th>Points</th>
<th>VB</th>
<th>HH</th>
<th>B</th>
<th>A</th>
<th>B/VB</th>
<th>B/HH</th>
<th>A/VB</th>
<th>A/HH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>21.6</td>
<td>27.3</td>
<td>22.5</td>
<td>26.4</td>
<td>20.1</td>
<td>25.0</td>
<td>23.2</td>
<td>29.7</td>
</tr>
<tr>
<td>9</td>
<td>22.4</td>
<td>30.7</td>
<td>25.4</td>
<td>27.7</td>
<td>18.5</td>
<td>32.3</td>
<td>26.3</td>
<td>29.2</td>
</tr>
<tr>
<td>8</td>
<td>15.4</td>
<td>11.5</td>
<td>12.5</td>
<td>14.3</td>
<td>14.8</td>
<td>10.2</td>
<td>15.9</td>
<td>12.8</td>
</tr>
<tr>
<td>7</td>
<td>4.4</td>
<td>4.2</td>
<td>3.0</td>
<td>5.6</td>
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<td>2.6</td>
<td>5.5</td>
<td>5.7</td>
</tr>
<tr>
<td>6</td>
<td>7.9</td>
<td>6.1</td>
<td>7.3</td>
<td>6.8</td>
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<td>6.3</td>
<td>7.6</td>
<td>6.0</td>
</tr>
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<td>3.9</td>
<td>4.0</td>
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<td>3.6</td>
<td>3.9</td>
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<tr>
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<td>13.8</td>
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<tr>
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<td>7.3</td>
<td>3.4</td>
<td>2.9</td>
<td>2.3</td>
</tr>
<tr>
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<td>1.7</td>
<td>2.5</td>
<td>2.7</td>
<td>1.4</td>
<td>2.3</td>
<td>3.1</td>
<td>1.0</td>
<td>1.8</td>
</tr>
<tr>
<td>1</td>
<td>2.9</td>
<td>1.6</td>
<td>3.4</td>
<td>1.0</td>
<td>4.2</td>
<td>2.6</td>
<td>1.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

A, after education; A/HH, handheld results after education; A/VB, viewing booth results after education; B, before education; B/HH, handheld results before education; B/VB, viewing booth results before education; HH, handheld; VB, viewing booth.

---

**Table 4. Model for prediction of shade matching scores**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num DF</th>
<th>Den DF</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>1</td>
<td>1414</td>
<td>24.94</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Education and Training</td>
<td>1</td>
<td>1414</td>
<td>24.31</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>88</td>
<td>0.00</td>
<td>.99</td>
</tr>
<tr>
<td>Group</td>
<td>3</td>
<td>88</td>
<td>0.02</td>
<td>1.00</td>
</tr>
<tr>
<td>Target Tab</td>
<td>3</td>
<td>1414</td>
<td>4.02</td>
<td>.01</td>
</tr>
</tbody>
</table>

Den DF, denominator degrees of freedom; F, F value; Num DF, numerator degrees of freedom.
4 best matches (7-10 points), with a 21% improvement shown with the handheld light after education compared with the viewing booth before education. These data should motivate clinicians to incorporate color-corrected light sources into their practice, seek out proper education on how to match shades, and take an active role in applying their knowledge. With this proactive approach, clinicians can achieve more esthetic restorations and have fewer costly remakes that can require additional chairside time and affect patient satisfaction.

There is no exact match in clinical shade matching, and this scenario was simulated in the experimental design of this study. The term “coverage error” ($\Delta E_{COV}$) represents the mean of best matches between a set of natural teeth and the tabs of the evaluated shade guides. Studies of shade range coverage reported that the coverage error of all dental shade guides was greater than the 50:50% acceptability threshold of $\Delta E_{ab}^{*} = 2.7$,$^{20,21}$ the only exception being a study that reported an $\Delta E_{COV}$ of 2.7 for Vita 3D Master,$^{27}$ and that Vita 3D Master had the smallest $\Delta E_{COV}$ value of all shade guides, meaning that it matches the color of human teeth the best. This is why Vita Linearguide 3D-Master was selected as the shade matching tool in this study, in which the first and second best matches (10 and 9 points, respectively) were at or below this threshold in both CIELab and CIEDE2000. Only the best matches for task tabs A2 and A3 were lower than the CIELab perceptibility threshold of 1.2. This is a major difference from traditional colorimetric studies where $\Delta E_{ab}^{*}$ can approach or equal a score of 0.

This study tried to simulate a clinical procedure and determine shade matching success using terms understandable and meaningful to dental clinicians (best match, second best match, and so on.). An additional reason for this was that large differences among the corresponding matches were recorded in this study; for example, color differences for 4 best Vita 3D-Master matches to task tabs were 2.2, 0.6, 1.0, and 1.6. Many similar discrepancies were found in $\Delta E_{ab}^{*}$ values. Also, the sixth best match for one task tab had smaller $\Delta E_{ab}^{*}$ than the third best match for another task tab. In terms of clinical realities, shade matching was more “successful” in the latter case, as evaluators had only 2 better options in the given circumstances. Therefore, the usage of $\Delta E_{ab}^{*}$ values alone could have been misleading in this experiment. It was concluded that the most appropriate way of expressing the outcomes of this study was to use visual scores as the primary parameter. These scores were associated with numerical color differences, which enabled comparisons with other studies and interpretation with and through visual thresholds.

**CONCLUSIONS**

Within the limits of this in vitro study, the following conclusions were drawn:

1. Mean shade matching scores with handheld lights were significantly better than the results obtained using a viewing booth ($P<.01$). Polarizing filters did not influence the shade matching results.
2. Mean shade matching scores were significantly better after education and training ($P<.01$).
3. Light combined with education and training increased the quality of shade matching.

**REFERENCES**


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