Tooth Shade-Matching Ability Between Groups of Students with Different Color Knowledge

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Purpose: The aim of this study was to evaluate the effect of gender and knowledge of color in dentistry on the visual shade-matching ability of dental students with no experience in shade matching and without identification skills. ***Materials and Methods:*** A total of 32 color-normal participants, 16 female (F) and 16 male (M), completed all phases of the experiment. The control group did not listen to a 60-minute lecture (FNL = females that did not listen; MNL = males that did not listen); the other group listened to a lecture about color in dentistry (FL = females that listened; ML= males that listened). The Toothguide Training Box (TTB) (VITA Zahnfabrik) was used. The final exam consisted of a total of 15 lightness–chroma–hue tasks. The correct selection of lightness (L*), chroma (C*), and hue (h*) was observed, as was the computed shade-matching score, $\Sigma\Delta E^*_{ab}$, for each participant. Mann-Whitney *U* test was used for statistical analysis of the data ($\alpha = .05$) (SPSS 22.0 for Windows [IBM]). ***Results:*** Gender was found to play an important role in shade matching. The FL group selected L* better (L* = 12.11) in comparison with the MNL group (L* = 11.00), which is not significantly different ($P = .19$). The FL group selected L* better in comparison with the ML group (L* = 10.57), which is not significantly different ($P = .10$). The FNL group selected C* statistically significantly better (C* = 9.86) than did the ML group (C* = 8.57) ($P = .016$). The shade-matching score, $\Sigma\Delta E^*_{ab}$, for group FL ($\Sigma\Delta E^*_{ab} = 22.50$) and group ML ($\Sigma\Delta E^*_{ab} = 31.79$) was marginally statistically significant ($P = .06$). ***Conclusion:*** A 60-minute lecture from the field of color in dentistry has a minimal impact on tooth-shade matching, whereas gender plays an important role. *Int J Prosthodont 2016;29:487–492. doi: 10.11607/ijp.4712*

Shade matching is an essential aspect of restorative and esthetic dentistry. All the energy and work put into treatment planning, accurate teeth preparation, impression taking, and the exact anatomical shape of the teeth is worthless if, at the end of the treatment, the patient is not satisfied with the color of the teeth. Shade matching can be carried out chairside or in the laboratory, and visual and/or instrumental methods can be used. Both possibilities have advantages and disadvantages. The factors that influence shade matching are more important for the visual method, whereas the instrumental method is more objective and rapidly obtained and can be quantified.[1]

Different color-measuring instruments can be used for the instrumental method, such as spectrophotometers, colorimeters, spectroradiometers, digital cameras, and spectral imaging.[2,3] These instruments show values of the color space and the nearest color standard in the selected shade guide.

Although developments have been made in restorative dental materials and instrumentation over the years, shade matching has not changed significantly. Visual shade matching still depends on the individual clinician's visual discrimination and matching abilities. Therefore, an objective knowledge of one's color vision is essential to optimize the esthetics of a patient's prostheses. Learning to match and alter shades and characterize restorations depends on the ability to perceive and discriminate colors and differences.

The visual method is known as *shade matching* and is performed using dental shade guides. A tooth or restoration is compared with color standards, usually in a tooth-shape form, made of ceramics, acrylic, or composite. The color standards (ie, shade tabs) are organized in groups. These groups are divided on the basis of a primary difference in the lightness (VITA 3D-Master, VITA 3D-Master Linearguide) or in the hue (VITAPAN Classical, VITAPAN Lumin Vacuum,

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Chromascope, Primodent V). The right sequence in shade matching must be known for each shade guide. With the VITA 3D-Master (3D), shade matching is carried out in three steps. The first involves matching the correct lightness group; the second, the correct chroma; and in the last a more red or more yellow hue may be chosen. The right sequence of steps derives from a knowledge of the color space and its values. There are five levels of lightness in 3D (tab groups: 1 for lightest to 5 for darkest) with tabs in each group of approximately the same lightness; five chroma levels (1 for least chromatic to 3 for most chromatic in each group, except in value group 1, which has two chroma levels, and group 5, which has three chroma levels); and three hue variations (L for more yellow, M for medium, and R for more red, for the value groups 2, 3, and 4; groups 1 and 5 have only M hue).[4]

Visual shade matching is subjective. It is affected by eye fatigue, age, clinical experience, color deficiencies, judgment, mood, and emotional shifts and illusions.[5,6] This range of parameters results in varied and unpredictable differences in color evaluation and matching among clinicians.[7] It also depends on the lighting conditions, the color of the walls, and the clothes worn by the patient and the staff. Gender plays an important role in shade matching, with females achieving significantly better shade-matching results than males.[3] Some other studies do not agree with this,[6,8] and some state that age and clinical experience are not important in the process of visual shade matching.[9–12] Others say that experience in shade matching plays an important role.[3,13–15] An improvement in color perception requires color instruction in dental education. Goodkind and Loupe pointed to a deficiency in color education that leaves students with incomplete knowledge.[16]

The purpose of this study was to evaluate the effect of gender and knowledge of color in dentistry on the visual shade-matching ability of dental students with no experience in shade matching and no identification skills.

Materials and Methods

The study was performed after obtaining the approval of the Institutional Review Board. The color vision of the participants was evaluated using Ishihara tests. No participants were found to have deficient color vision. A total of 32 color-normal participants completed all phases of the experiment. Of these, 16 were female (F) and 16 were male (M) dental students, with an age range of 21 to 27 years, all with no experience in shade matching and with no identification skills. Participants were divided by draw. One group of students, the control (n = 16, MNL = 9, FNL = 7), did not listen to a 60-minute lecture about color in dentistry; the other group (n = 16, ML = 7, FL = 9) listened to the lecture. The lecture gave the participants knowledge about the sensibility of the cones and rods to the visible spectrum of light, the factors that influence visual shade matching, and the development of color spaces, especially CIE L*a*b* and CIE L*C*h*, and its values (the information on color dimensions). It explained the value ΔE^*_{ab}; the position in the color space of the teeth and its shape; the different methods of shade matching (visual and instrumental); the arrangement of different shade guides; and how to use the VITA 3D-Master shade guide, the importance of the sequence in choosing first the lightness (L*), then the chroma (C*, or intensity), then the hue (h*). Finally, the lecture gave instructions for the Toothguide Training Box (TTB), which was developed by Jakstat[17] (University of Leipzig) in collaboration with VITA Zahnfabrik.

The instructions on the TTB were given to all participants prior to the color training and the final exam on the TTB. The TTB includes 26 shade tabs of the VITA Toothguide 3D-Master (VITA Zahnfabrik) (no group 0). The lighting was standardized. Color-corrected light (Dialite Color) with a color-correlated temperature of 5,500 K, 1,500 lux at a distance of approximately 10 cm, and a color-rendering index (CRI) of 92 was used. The students did not have to deal with the anatomy of the teeth and patients' expectations, because they compared the tab with another tab and not with a tooth. A neutral light gray framed the shade tabs that were being matched, which is in accordance with previous studies.[11] The study was conducted in a dark room with the ceiling lights turned off. In this way, the influence of the surrounding colors was reduced.

The exercises were designed to simulate the three-step shade-matching procedure recommended for 3D: step 1 was lightness selection, step 2 was chroma selection, and step 3 was hue selection. The first set of TTB exercises was related to lightness selection (selection of the appropriate 3D group, from 1 to 5), and eight correct matches were needed to pass this step and proceed to step 2. In step 2, each exercise had two substeps: initial lightness selection and subsequent chroma selection (selection of the appropriate 3D chroma level, from 1 to 3 [1 for the least chromatic, 3 for the most chromatic in each group, except in lightness group 1, which has two chroma levels; lightness group 5 has three, lightness groups 2, 3 and 4 each have five chroma levels]). Seven correctly solved lightness-chroma tasks were required to pass this step and proceed to step 3. Step 3 involved three substeps: initial lightness and chroma selection and subsequent hue selection (selection of the appropriate 3D hue variations [L for more yellow, M for medium, and R for more red for lightness groups 2, 3, and 4; groups 1 and 5 have only M hue]). Seven correct lightness–chroma–hue selections were required to pass this step and proceed to the final exam. The final exam consisted of a total of 15 lightness–chroma–hue tasks. The final TTB exam was used to test all the participants. These shade-matching results were recorded on a laptop computer connected to the TTB and processed. The color difference (ΔE^*_{ab}) between the task tab and the selected tab was computed as follows:

$$\Delta E^*_{ab} = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2}$$

where ΔL^*, Δa^*, and Δb^* denote the differences in lightness, chroma, and hue coordinates, respectively.

The L*, a*, and b* values of all 26 shade tabs were obtained from measuring three completely new shade guides with a spectrophotometer (VITA Easyshade Advance). Each tab was measured three times under color-corrected light (Dialite Color) with a color-correlated temperature of 5,500 K, 1,500 lux, and 92 CRI. The average of all nine measurements was taken as the L*, a*, and b* values of each of the 26 shade tabs. The correct L*, C*, and h* selections were counted. The higher L*, C*, and h* scores correspond to better shade-matching results and vice versa. For a set of 15 exact matches, this score would be 15. The means and standard deviations were calculated. The shade-matching score, $\Sigma\Delta E^*_{ab}$, for each participant was computed as the sum of the color differences between all the task tabs and the selected tabs. The lower $\Sigma\Delta E^*_{ab}$ scores corresponded to better shade-matching results and vice versa. For a set of 15 exact matches, this score would be 0. The means and standard deviations were calculated. Mann-Whitney *U* test was used for statistical analysis of the data ($\alpha = .05$). The data analysis was performed using SPSS 22.0 for Windows (IBM).

Results

The L*, a*, and b* values of all 26 shade tabs are listed in Table 1 (three shade guides, three measurements each, an average of nine measurements). The FL group better selected L* (L* = 12.11) in comparison with MNL (L* = 11.00), which is not significantly different ($P = .19$). The FL group better selected L* in comparison with group ML (L* = 10.57), which is not significantly different ($P = .10$). The FNL group selected C* statistically significantly better (C* = 9.86) in comparison with ML (C* = 8.57) ($P < .05$, $P = .016$; Tables 2 and 3). The shade-matching score, $\Sigma\Delta E^*_{ab}$, for group FL ($\Sigma\Delta E^*_{ab} = 22.50$) and group ML ($\Sigma\Delta E^*_{ab} = 31.79$) was marginally statistically significant ($P = .06$) (Table 2, Fig 1). The correct L*, C*, and h* selections and the shade-matching score, $\Sigma\Delta E^*_{ab}$, of the final exam for all groups are listed in Table 2.

Table 1 L*, a*, and b* Values of the 26 Shade Tabs from the VITA 3D-Master Measured with the VITA Easyshade Advance Spectrophotometer

	L*	a*	b*
1M1	85.06	–1.91	11.43
1M2	85.46	–1.86	17.59
2M1	81.24	–0.76	12.96
2L1.5	80.97	–1.48	16.21
2L2.5	81.22	–1.26	21.61
2M2	81.58	–0.38	18.33
2R1.5	80.94	–0.06	15.34
2R2.5	80.68	0.09	21.2
2M3	81.21	–0.44	24.04
3M1	75.77	0.26	13.94
3L1.5	74.29	–0.1	17.88
3L2.5	75.26	0.52	23.77
3M2	76.79	1.07	21.07
3R1.5	75.01	1.17	16.06
3R2.5	75.21	1.63	22.84
3M3	76.69	1.38	26.32
4M1	70.62	1.57	15.34
4L1.5	71.2	1.27	19.64
4L2.5	70.91	2.1	25.7
4M2	71.57	2.48	21.97
4R1.5	71.22	2.83	18.93
4R2.5	70.99	3.46	24.7
4M3	71.47	3.24	29.3
5M1	65.99	2.52	16.87
5M2	67.16	4.2	24.56
5M3	68.06	5.54	33.3

Table 2 L*, C*, h*, and $\Sigma\Delta E^*_{ab}$ for the Final Exam

	Group	n	Mean	SD	Correct selection (%)
L*	ML	7	10.57	1.90	70.46
	MNL	9	11.00	1.50	73.33
	FL	9	12.11	1.83	80.73
	FNL	7	11.57	1.72	77.13
C*	ML	7	8.57	0.98	57.13
	MNL	9	8.11	2.42	54.06
	FL	9	9.22	1.48	61.47
	FNL	7	9.86	0.38	65.73
h*	ML	7	9.29	1.98	61.93
	MNL	9	8.78	1.79	58.53
	FL	9	9.67	2.24	64.47
	FNL	7	10.14	1.86	67.60
$\Sigma\Delta E^*_{ab}$	ML	7	31.79	11.72	
	MNL	9	30.82	9.82	
	FL	9	22.50	12.00	
	FNL	7	24.70	12.03	

ML = males who listened to the lecture; MNL = males who did not listen to the lecture; FL = females who listened to the lecture; FNL = females who did not listen to the lecture; L* = correct lightness selection; C* = correct chroma selection; h* = correct hue selection.

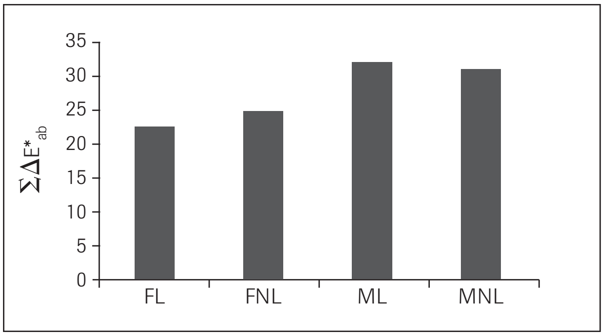

Fig 1 $\Sigma\Delta E^*_{ab}$ for the final exam. FL = females who listened to the lecture; FNL = females who did not listen to the lecture; ML = males who listened to the lecture; MNL = males who did not listen to the lecture.

Table 3 Test Statistics for ML and FNL[a]

Test	C
Mann-Whitney *U*	8.000
Wilcoxon W	36.000
Z	−2.400
Asymp sig (2-tailed)	.016
Exact sig [2*(1-tailed sig)]	.038[b]

[a]Grouping variable: gender.
[b]Not corrected for ties.

Discussion

Visual shade matching is subjective. It is affected by many factors, such as eye fatigue, age, clinical experience,[13,18] degree of color-vision deficiencies of the individual choosing the shade,[19] judgment, mood, emotions,[20] and illusions. It can also be affected by the viewing conditions (presence or absence of a light-correcting source),[6] type of lighting,[21] chronic diseases, and certain medications.[19] To improve shade matching, some practitioners use a Shademat Visual+,[22] which is commercially unavailable. Gender was found to play an important role in shade matching in the present study: females achieved better results in terms of lightness, chroma, and hue selection. The FNL group achieved even better results in comparison with ML and MNL (Table 2). The FNL group selected C* statistically significantly better ($C^* = 9.86$) than ML ($C^* = 8.57$) ($P < .05$, $P = .016$; Tables 2 and 3). The FL group selected L* better than did ML ($L^* = 10.57$), which was not significantly different ($P = .10$). Females also achieved better shade-matching results than males in both the group who listened to the lecture (FL: $\Sigma\Delta E^*_{ab} = 22.50$; ML: $\Sigma\Delta E^*_{ab} = 31.79$; $P = .06$), which was marginally statistically significant, and the group who did not listen (FNL: $\Sigma\Delta E^*_{ab} = 24.70$; MNL: $\Sigma\Delta E^*_{ab} = 30.82$; $P = .37$) (Fig 1), which is in accordance with other studies.[3,11,23] One possible reason is genetic. Neitz and Jacobs[24] postulate a polymorphism at the locus on the X chromosome that specifies the red-sensitive photopigment of the retina. They stated there should be homozygous women who resemble each of the male hemizygous types; but a third class of women will be heterozygous at the locus. Later it was discovered that there is a spectral shift toward red of about 6 nm in either the M (green cones) or the L (red cones) pigment.[25] The polymorphism at this site could produce two types of L pigments and two types of M pigments in the color-normal population. Mollon[26] stated that the human species is basically trichromatic. If women are heterozygous for one of the photopigments, they are in fact tetrachromatic, which may give them an extra dimension of color discrimination and an added advantage in the ability to discriminate color. Other studies have found that gender does not play an important role in shade matching.[6,8,10,22,27–30]

Conventional shade matching with shade guides depends on the education and training of the clinician performing the shade matching, the quality of the shade guide used, the quality of shade-matching method, and the conditions.[31]

In 1988, Goodkind and Loupe[16] found that DDS/DMD-level and graduate-level programs gave significantly more attention to four measures (giving a special color course, teaching a color-ordering system, employing a color engineer, and sponsoring color research) than did the programs in the 1968 survey by Sproull.[32] Recently, there has been a substantial increase in the percentage of programs with courses on color or color in dentistry, but the number of hours devoted to the teaching of color decreased compared with the results of the 1988 survey by Goodkind and Loupe.[16,33]

Color has been described by Munsell as a three-dimensional phenomenon consisting of hue, lightness, and chroma.[34] Hue distinguishes one color family from another; lightness is the scale of white to black/gray; chroma corresponds to the saturation of the perceived color. The 3D shade guide uses Munsell's terminology, and the shade matching is carried out in three steps. This guide uses the accepted color-perception concepts of lightness, chroma, and hue. The 3D shade guide has improved conventional shade matching. It was chosen for this study because its color distribution is more ordered than the color distributions of other traditional shade guides[35] and it has resulted in a higher color match in studies comparing it with the VITAPAN Classical shade guide.[36–38] It enables significantly closer matches compared with the VITA Lumin shade guide.[39] In comparison with the VITA Lumin or Chromascop (Ivoclar Vivadent) shade guide systems, the 3D shade guide resulted in the lowest rate of coverage errors.[40]

There are three VITA 3D-Master shade guides: Toothguide, Linearguide, and Bleachedguide. The training box contains the Toothguide shade guide. The method is highly logical, but it can be challenging for the dental professional with little experience in shade matching or little knowledge about the physical background of the system.[31] In this study, the participants made mistakes in each step of the shade selection. The shade matching was demanding for them, which is in accordance with Chu et al.[31]

Eye sensitivity to lightness, chroma, and hue differences is uneven.[41] The order that best matches the capabilities of the human eye is lightness, chroma, and hue, which corresponds to the importance of the three color elements in obtaining an accurate shade match.[42,43] Barna et al[11] stated that males have greater sensibility for lightness selection and that there are no differences in the chroma selection. Chroma was determined more easily than lightness and hue by groups of dentists and dental technician students during the training with TTB in another study.[44] In a study by Llena et al,[14] the highest percentage of correct answers during training with TTB was obtained for lightness. Lightness group 5 obtained the greatest percentage of correct answers. Hue presented the greatest identification difficulties, with a percentage of correct answers of 62.23 ± 9.65.[14] In a study by Winkler et al,[30] students had the greatest difficulty determining the correct hue group for the shade tab. Incorrect responses tended to remain in the same lightness and chroma range, but were in a different hue group. In a study by Schropp,[45] the observers matched the correct lightness of the test tab in 44% of the simulated clinical situations. Better results were obtained on a computer screen (55%) and with computer software (90%). In the present study, the correct selection of the lightness ranged from 70.46% (ML) to 80.73% (FL), the correct selection of the chroma ranged from 54.06% (MNL) to 65.73% (FNL), and the correct selection of hue ranged from 58.53% (MNL) to 67.60% (FNL) (Table 2). All groups selected the lightness better in comparison with the chroma and the hue, which is in accordance with other studies.[33,43,46,47]

In the human retina, there are 120 million rods that are susceptible to lightness, in comparison with 6 million cones that are susceptible to color. The human eye is capable of perceiving variations in the L* axis more clearly than in the a* and b* axes, as the quantity of cells responsible for vision in black and white is much higher than that of the cells responsible for color vision. Therefore, lightness seems to be more important to color perception than chroma or hue.[33,43,46,47] The 3D shade guide is organized in accordance with this. The first step in shade matching is the selection of the appropriate lightness group. Any mistake in this step contributes to a larger overall mistake, ΔE^*_{ab}. Such eye sensitivity means that a mistake in the lightness selection is more detectable by observers in comparison with a mistake in the chroma or hue. This was found to be true in a study by Milleding et al[48] that evaluated the clinical performance of Procera Titanium crown system in general practice. The divergence from an excellent color rating was mainly the result of mismatch in lightness. Any loss of lightness is fundamental for color stability and clinical success.[46] In the present study, the students who listened to the lecture knew the importance of the right selection of the lightness group, but only the results for the FL group (L*= 12.11; 80.73% of correct selections) can confirm that they perform better than FNL (L* = 11.57; 77.13%), which was not statistically significant (P = .45) (Table 2). The results for the lightness selection by the males are not in accordance with Miller,[49] who stated that knowledge of the basic principles of color is also important for shade selection. Another possible reason for mismatches is that some tooth colors are more difficult to match than others.[50] The human eye cannot perceive lightness, chroma, and hue separately. It is hard to understand or justify the attitude that the shade-matching procedure with 3D shade guide should be performed dimension by dimension.[51] The different eye sensitivity to chroma and hue is the reason the new color-difference equation CIEDE2000 or ΔE_{00}, based on CIE L*a*b*, was developed. It introduced lightness, chroma, and hue weighting functions, parametric factors, and an interactive term between chroma and hue differences.[52]

The shortcoming of this study is that a 60-minute lecture on the topics as listed in the Materials and Methods section seems to be insufficient to discriminate between two different groups. It would be better to give a lecture and literature on the topic of color to participants and to give an exam on knowledge of color in dentistry to both groups. If the exam results of the control group were significantly worse, it would be appropriate to test both groups on TTB and verify whether knowledge affects shade matching.

Conclusions

Determining the shade of a tooth demands clinical skills and experience.[13,18] A 60-minute lecture from the field of color in dentistry has a minimal impact on shade matching; however, gender plays an important role. The females achieved better results in terms of lightness, chroma, and hue selection and shade-matching score.

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