



## Evaluation of blending effect of composites related to restoration size<sup>☆</sup>

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### KEYWORDS

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Translucency;  
Color matching;  
Dental material

**Summary Objective:** It has been clinically observed that color differences between teeth and some restorations are smaller than if they are viewed in isolation. The objective was to evaluate in vitro the influence of restoration size, initial color difference and translucency on blending effect (BE) of resin composites. **Methods:** Specimens were made of two composites (2CS,  $n=5$ ). The outer ring ( $D=10$  mm, 2-mm thick) was made of Palfique Estelite (PE, C2 shade), while the inner composites ( $D=2$ -, 4-, and 6-mm, 2-mm thick) were PE and Esthet-X (EX, A2 and B2 shades of both materials). Single-composite specimens (1CS) of all five shades ( $D=10$  mm, 2-mm thick,  $n=5$ , batch) were made as well. Visual color assessments were done by six observers using a 1-5 scale. The BE were calculated as a difference in visual scores between corresponding 2CS and 1CS. 1CS were additionally evaluated using a spectrophotometer ( $D55, 10^\circ$ ). Intra- and inter-observer agreements were tested.

**Results:** The blending effect for comparisons of PE/A2 for 2-, 4- and 6-mm inner composite was 2.7, 1.7, and 1.7, respectively. Lower values were recorded for PE/B2 (1.7, 1.2, and 1.1), EX/A2 (0.3), 0.0, and 0.1) and EX/B2 (-0.2, -0.1, and -0.1). The correlation coefficient ( $r$ ) among BE for 2-, 4-, and 6-mm inner composite (2CS) and  $\Delta E^*$  among batch shades and PE/C2 (1CS) were 0.98, 0.95, and 0.97, respectively.

**Significance:** Discovering and quantifying mechanisms of color shift of dental materials towards color of surrounding teeth may improve the esthetics of restorations and simplify shade matching.

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## Introduction

It is observed clinically that certain dental materials take on the color appearance of surrounding hard dental tissues after placement, thus improving esthetics [1,2]. This optical phenomenon is frequently described as 'chameleon effect' in manufacturers' characterizations of esthetic properties of various dental ceramics and resin composites. Searching the Internet, one might easily conclude that the 'chameleon effect' of dental materials is well known and well understood by both dental manufacturers and dental professionals.

The term, 'chameleon effect,' although known in psychology [3], is not used in color science. It is more appropriate to name this process as blending effect (BE). The related color science terms are color induction, color assimilation, and Von Bezold color blending effect, or Von Bezold spreading effect [4-10].

There are no published reports on the quantification of blending effect in dentistry, using either visual or instrumental methods. One paper reported that a resin composite had a BE of 2.5 CIELAB units and that most resin composite restorations produced undetectable color matching if the CIELAB color difference  $\Delta E^* < 2$  between the restoration and the surrounding tooth tissues [1]. No description of materials and methods used to obtain this was provided. Therefore, mechanisms, tests, methods, units and scales of measurement, standards and acceptable/unacceptable values for both visual and instrumental evaluation of BE of dental materials should be developed. Some of these issues are addressed in this paper.

Discovering mechanisms of shifting color of dental materials towards color of surrounding

dental tissues may improve the esthetics of restorations and simplify shade matching through reduction of number of shade tabs in dental color standards. It seems that the blending effect is a very complex phenomenon and that there are many factors that might influence its magnitude and direction as far as esthetic dental materials are concerned. The purpose of this study was to evaluate the influence of restoration size on blending, initial color difference and translucency of resin composites on the blending effect of resin composites.

## Materials and methods

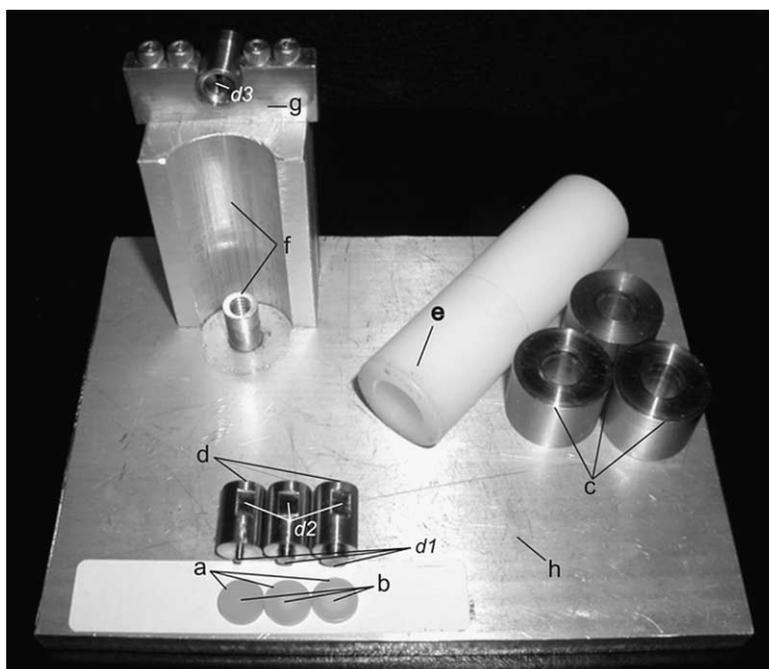
**Overview.** Five shades of commercial resin composites were studied (Table 1). Specimens that consisted of two-composite (2CS,  $n=5$ ) and single-composite (1CS,  $n=5$ ), disk-shaped specimens were made. Specimens and tools used for their production are shown in Fig. 1. The scheme of the specimens is shown in Fig. 2, together with the illustration of blending effect. The lighter of the 1CS specimens (the upper row) was used as the inner composite in 2CS (the lower row) and shifted towards the darker composite—the smaller the diameter of the inner composite the greater the shift. The outer rings mimicked hard dental tissue with different cavity sizes. Visual color assessments were done by six observers using a 1-5 scale. The BE was calculated as a difference in visual scores between corresponding 2CS and 1CS. 1CS were additionally evaluated using a spectrophotometer and correlation among these values and BE was

**Table 1** Product, manufacturer, code, composite type (CT), particle size, filler content, monomer, shade, lot, and polymerization time (PT) of resin composites tested.

Product	Manufacturer	Code	CT	Particle size	Filler content		Monomer	Shade	Lot	PT (s) <sup>a</sup>
					% wt	% vol				
Palfique	Tokuyama	PE	Microhybrid	0.2 $\mu\text{m}$	82	71	Bis-GMA/ TEGDMA	A2	E611	30
Estelite	Dental (Tokyo, Japan)							B2	W66832	30
								C2	W3292	30
Esthet-X	Dentsply/Caulk (Milford, DE)	EX	Microhybrid	0.6-0.8 $\mu\text{m}$	77	60	Bis-GMA/ Bis-EMA/ TEGDMA	A2	021004	20
								B2	020628	20

Abbreviations: Bis-GMA, bisphenol A diglycidyl ether dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-EMA, bisphenol A polyethylene glycol diether dimethacrylate.

<sup>a</sup> There was one polymerization cycle for 1CS and two polymerization cycles for 2CS (once per shade); specimens were always covered with a Mylar strip during polymerization.

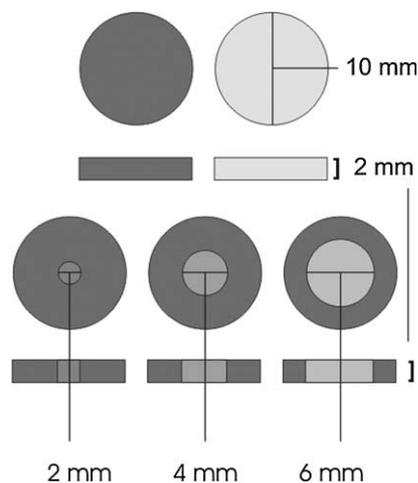


**Figure 1** Custom-made molds and tools and specimens made of two composites: (a) 2CS, outer composite; (b) 2CS, inner composite; (c) stainless steel mold, outer component; (d) stainless steel mold, inner component (d1, cylindrical extension; d2, notches; d3, screw); (e) plunger; (f) plunger guide; (g) inner component holder; (h) platform.

evaluated. Intra- and inter-observer agreements were tested.

The 2CS consisted of an outer and inner composite. The outer composite was ring-shaped, with an outer diameter (OD) of 10 mm, 2-mm thick and an inner diameter (ID) of 2-, 4-, or 6-mm, 2-mm thick for the inner composite. Specimens were made using custom-designed, stainless-steel molds and tools mounted on the metal platform. Molds consisted of outer and inner components. The outer component was a ring (25-mm in height, OD=24 mm, ID=10 mm). The inner component was a cylinder (23 mm in height,  $D=10$  mm) with two parallel side notches. A cylindrical extension was on the top middle area of the inner mold component (2-mm in height,  $D=2, 4,$  or 6 mm). It was possible to lower this extension using a screw at the bottom of the inner component. When the inner and outer components were put together, they formed a mold for the composite ring (outer composite). Composite was then incrementally applied, covered with a Mylar strip ( $D=14$  mm), and pressed to the thickness of the mold using a glass microscope slide. The curing tip (11 mm in diameter) of a polymerization lamp (Demetron 501, Demetron/Kerr, Danbury, CT USA) was held against the microscope slide centered over the specimen, and the specimen was polymerized in accordance with manufacturer's recommendations (Table 1). The lamp output was measured

periodically during the experiment using the internal radiometer. The energy of the polymerization light was 660-760 mW/cm<sup>2</sup>. After polymerization, composite rings were removed from the mold in two phases. In phase 1, the inner mold component, together with the specimen, was separated from the outer component by a plunger after placing the mold onto a custom plunger



**Figure 2** Scheme of the specimens and the illustration of blending effect: the lighter of 1CS specimens (the upper row) was used as the inner composite in 2CS (the lower row) and it shifted towards the darker composite—the smaller the diameter of the inner composite the greater the shift.

guide. In phase 2, the composite ring was separated from the inner mold component. It was done by placing the inner mold component onto a holder at the top of the plunger guide. The holder prevented rotation of the inner component (notches fitted into the holder) while turning a screw to lower the cylindrical extension. The inner composite was then applied and polymerized between two microscope glass/Mylar sets.

The outer ring was made solely of Palfique Estelite (PE) C2 shade (standard), while the inner composites were PE and Esthet-X (EX), A2 and B2 shades (batch shades). Composites of identical shade designations were chosen to enable an equal starting point in the evaluation of BE. The combination of PE/C2/4-mm inner composite and PE/C2 outer composite was made for calibration and quality control of color assessments. Single-composite disk-shaped specimens of all 5 shades ( $D=10$  mm, 2 mm thick) were made using polytetrafluoroethylene molds placed between two glass slide/Mylar strip sets.

All specimens were finished for 30 s in order to remove the shiny surface created with the Mylar. Finishing was done wet on 600-grit silicon carbide disks (lot # 586, 14.5- $\mu$ m particle size, Buehler, Lake Bluff, IL USA) in a dual-platen 20-cm table-top grinder-polisher (Ecomet 6, Buehler, Lake Bluff, IL USA), with a speed of 120 rpm and mild hand pressure. Then, specimens were dry-polished by the same operator using a polishing system (PoGo, lot # 021112, Dentsply/Caulk, Milford, DE USA) and a low-speed handpiece (Midwest Dental Products, Des Plaines, IL USA) at 4000-5000 rpm. Each specimen was randomly marked at the back using a 16-fluted carbide bur (Axis Dental, Irving, TX USA). Specimens were then stored at 37 °C and 100% relative humidity for one week.

Visual color assessments were made by six observers: four dentists (three general dentists and a prosthodontist) and two scientists. There was one female (general dentist) and five male observers. No observer was color deficient, and were tested using the Ishihara's Test for Color Blindness.<sup>1</sup> All observers were educated in color science, trained in shade matching by mastering a color training program and associated exercises [11], and calibrated (a consensus of what should be graded as 1, 2, 3, 4, or 5 was determined before the individual assessments).

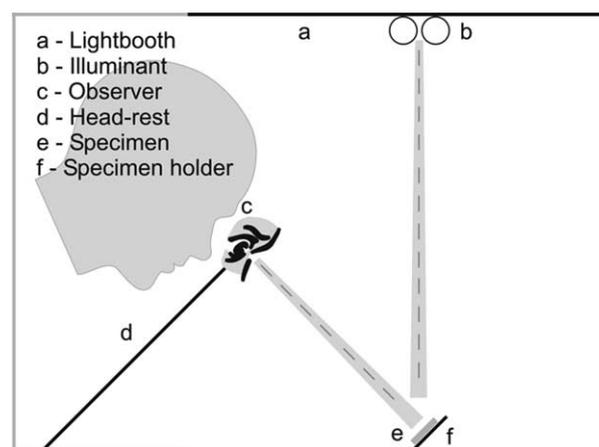
A lightbooth (Judge II, GretagMacbeth, New Windsor, NY USA), having a neutral Munsell N7

gray walls and floor, was used for color assessments (Fig. 3). The light source used for the visual assessments was an approximation to the D50 illuminant. External (overhead) lights were turned off during assessments. A custom-made neutral-gray specimen holder was placed on the floor of the lightbooth, providing a 45° angle between specimens and illuminant. Observers placed their heads on the dentist head holder described in a previous paper [12], but for this purpose mounted at 45° compared to the lightbooth floor, parallel to evaluated specimen surfaces. Therefore, a 45°/normal illuminant/viewing geometry was provided. Illuminance was measured periodically during the experiment using a meter for flash and ambient light (Gossen Color-Pro 3F, Bogen Photo, Ramsey, NJ USA). Measured values ranged from 960 to 1020 lx. Specimens were observed at a distance of 25 cm. A visual angle of subtense ( $2\theta$ ) was calculated using the following equation [13]:

$$2\theta = 2 \arctan(r/d) \quad (1)$$

where  $r$  is the radius of a specimen and  $d$  is the distance from the observer. For the described experimental conditions,  $2\theta=2.3^\circ$  for OD .f 10 mm.

After a period of adaptation by observing the walls of the lightbooth [14], observers compared the color of dry specimens: one 2CS or two 1CS at a time. The single-composite specimens were in edge-contact during color assessments. Results were expressed numerically using the 1-5 scale. Scores were as follows: 1—mismatch/totally unacceptable, 2—poor match/hardly acceptable, 3—good match/acceptable, 4—close match/small difference, and 5—exact match/no difference in color. Results were recorded into a spreadsheet (Microsoft Excel 2000, Microsoft, Redmond, WA



**Figure 3** Scheme of the settings for visual color assessments: (a) lightbooth; (b) illuminant; (c) observer; (d) head-rest; (e) specimen; (f) specimen holder.

<sup>1</sup> Ishihara S. Ishihara's tests for colour blindness. London: Hodder Arnold; 1998.

USA). BE was calculated as a difference in mean score (mean-category values) for a 2CS and corresponding 1CS pair.

The use of the Mean-Category Method implicitly assumes that the scores form an interval scale; i.e. that the perceptual difference between a score of 1 and 2, for example, is the same as the perceptual difference between a score of 2 and 3. The computation, and comparison, of difference values (BE) also implicitly assumes that the values form an interval scale. Since it is not reasonable to assume such linearity, visual scores were further processed using the Categorical-Judgment Method [15]. For each condition the proportional cumulative frequency scores were calculated and converted to Z scores using the inverse of the equation for the standard normal cumulative distribution. The Z scores represent an interval scale and  $BE_Z$  was calculated as a difference in Z score for a 2CS and corresponding 1CS pair.

Color and translucency parameters of 1CS were additionally evaluated using a spectrophotometer (Color-Eye 7000, GretagMacbeth LLC, New Windsor, NY USA) set to CIE D55 standard illuminant, 10° observer (CIE 1964 Supplementary Standard Observer), specular component included (SCI), and very small area view (VSAV) aperture ( $3 \times 8 \text{ mm}^2$ ). Spectral reflectance values in the visible range were recorded in increments of 10 nm and converted to CIELAB values. Prior to measuring, the spectrophotometer was calibrated according to a standard procedure using a black light trap and a white calibration tile, both provided by the manufacturer. Accurate positioning of the specimen in relation to spectrophotometer aperture was enabled by way of a custom aluminum jig [16]. Determination of color parameters was performed against white and black calibration tiles [17]. Software (ProPalette 5.0, GretagMacbeth address) parameters allowed the data to be presented as the average of a series of three measurements. The total color difference ( $\Delta E^*$ ) was calculated as follows [11]:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (2)$$

where  $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$  were the differences in CIELAB coordinates between the two specimens. Color differences ( $\Delta E^*$ ) of 1,  $\leq 2$ , and  $\geq 3.7$  were considered to correspond to a just perceivable color difference [18], a clinically acceptable difference [19], and a poor match [20], respectively.

Translucency parameter (TP) was calculated as a color difference between CIELAB values obtained for the same specimen against black and white backings [21].

Means and standard deviations for visual ratings for 2CS and 1CS for each observer and all observers together as well as CIELAB color coordinates of 1CS were calculated. BE and  $\Delta E^*$  for each resin composite, both compared to PE/C2 were calculated. Linear regression (Statview, SAS Institute, Cary, NC USA) was used to determine correlation coefficients ( $r$ ) among visual assessments as well as among visual assessments and color difference metrics. The inter-observer agreement was calculated as the mean value of the highest percentage of observers that graded specimens of each shade/inner diameter combination identically. The intra-observer agreement was calculated as the mean value of the highest percentage of identical scores for each group of five specimens of the same shade by a specific observer.

## Results

Visual scores and Z scores for comparisons of single-composite specimens and specimens made of two composites as well as respective BE and  $BE_Z$  values are listed in Table 2. The mean scores by observer ranged from 1.1 to 1.8 for 1CS and was 1.3 (s.d. 0.6) for all observers together. Corresponding mean scores for 2CS ranged from 2.2 to 2.6 and were 2.4 (s.d. 1.4) for all observers together. A linear regression of the mean-category values against the Z scores was carried out and the correlation coefficient  $r$  was 0.99.

Differences in  $L^*$ ,  $a^*$ , and  $b^*$  values as well as total color difference ( $\Delta E^*$ ) among each of four batch shades and PE/C2 are listed in Table 3, together with TP for the batch shades.

Based on restoration size,  $r$ -values among BE and  $\Delta E^*$  for 1CS (four batch shades vs. standard) were 0.98, 0.95, and 0.97 for 2-, 4-, and 6-mm inner composites, respectively. When all BE values were compared to all  $\Delta E^*$  values,  $r$  was 0.92. The value of BE increased with a decrease in color difference.

Comparison of BE and TP for four batch shades (1CS) brought  $r$ -values of 0.92, 0.89, and 0.88 for 2-, 4-, and 6-mm inner composites, respectively. When all BE values were compared to all TP values,  $r$  was 0.85. The value of BE increased with the increase of specimen translucency.

Correlation coefficient ( $r$ ) for mean 1CS and 2CS scores among pairs of observers was 0.96 (s.d. 0.04) and 0.98 (s.d. 0.02), respectively. The inter-observer agreement was 83% (s.d. 15%) for 1CS and 75% (s.d. 14%) for 2CS, while the intra-observer agreement was even higher: 88% (s.d. 18%) for 1CS and 81% (s.d. 17%) for 2CS.

**Table 2** Mean (s.d.) visual scores (VS) and mean categorical-judgment scores (Z)\* of single-composite specimens (1CS), specimens made of two composites (2CS) with different diameter of inner composite, and corresponding blending effect (BE and BE<sub>Z</sub>, 2CS minus 1CS).

Code/shade	1CS		2CS			BE	BE <sub>Z</sub>
	VS	Z	ID (mm)	VS	Z		
PE/A2	2.0 (0.6)	0.3	2	4.7 (0.4)	5.6	2.7	5.3
			4	3.7 (0.5)	3.5	1.7	3.2
			6	3.7 (0.5)	3.0	1.7	2.7
PE/B2	1.0 (0.2)	−1.2	2	2.7 (0.6)	2.0	1.7	3.2
			4	2.2 (0.6)	0.5	1.2	1.7
			6	2.1 (0.6)	0.4	1.1	1.6
PE/C2			4	4.8 (0.4)	5.6		
EX/A2	1.1 (0.3)	−1.1	2	1.4 (0.5)	−0.8	0.3	0.3
			4	1.1 (0.3)	−1.1	0.0	0.0
			6	1.2 (0.4)	−0.9	0.1	0.2
EX/B2	1.2 (0.4)	−0.9	2	1.0 (0.0)	−1.8	−0.2	−0.8
			4	1.1 (0.3)	−1.1	−0.1	−0.2
			6	1.1 (0.3)	−1.0	−0.1	−0.1

\*The 95% confidence interval for the Z scores was  $\pm 0.25$ .

## Discussion

The highest value of BE and BE<sub>Z</sub> was recorded for PE/A2 and it decreased from 2- to 6-mm inner composite (see Table 2). The next highest value of BE was observed for PE/B2, with the same trend related to size of inner composite. The highest size-related difference in BE for these two shades was recorded between 2- and 4-mm inner composite. A low value of BE was observed for EX/A2/2 mm, while all other values for EX were close or below zero. This result, however, does not mean that EX does not exhibit the blending effect. As presented in Table 3,  $\Delta E^*$  between batch shades and standard was the lowest for PE/A2, followed by PE/B2, EX/A2, and EX/B2, respectively, which corresponds to the decrease in BE values. It is quite possible, e.g. that  $\Delta E^*$  between the EX/B2/2 mm and PE/C2 combination decreased from 10 to 5. It would be a very pronounced BE, yet a  $\Delta E^* = 5$  would likely be scored as mismatch in the described experimental conditions. In situations like this, BE cannot be properly evaluated using the visual method. The accurate answer on magnitude and direction of color changes associated with BE can be obtained

only instrumentally and this topic requires further research.

The Categorical-Judgment Method was carried out in order to investigate the linearity of the ratings because this is a more robust analysis than the Mean-Category Method. Although the linearity of the ratings and BE scores was not assumed, the strong correlation observed between the mean-category values and the Z scores shows that the computation of mean-category values was valid and that differences between mean-category values can be used to represent the blending effect. Nevertheless, the Categorical-Judgment Method (BE<sub>Z</sub>) showed differences between conditions where the Mean-Category Method (BE) did not and allowed computation of the 95% confidence interval.

The *r*-values among BE values and  $\Delta E^*$  values among batch shades and the standard, showed strong correlation, indicating a great probability of calculation of one parameter based on the known value of another one. Linear regression analysis showed the direction of change of evaluated parameters. The same result is true for the relationship between BE and TP. These results were in accordance with the expectations that

**Table 3**  $\Delta L^*$ ,  $\Delta a^*$ ,  $\Delta b^*$ , and  $\Delta E^*$  values (s.d.) as compared to PE/C2 (all recorded for single-composite specimens and against white backing) and translucency parameter (TP) of the shades listed in the first column.

Code/Shade	$\Delta L^*$	$\Delta a^*$	$\Delta b^*$	$\Delta E^*$	TP
PE/A2	4.1 (1.1)	−0.5 (0.1)	−1.1 (0.5)	4.4 (0.7)	8.7 (0.7)
PE/B2	7.0 (0.4)	−1.4 (0.1)	2.8 (0.6)	7.6 (0.6)	7.9 (0.6)
EX/A2	7.5 (0.5)	−0.6 (0.1)	−6.4 (0.4)	9.9 (0.4)	7.6 (0.6)
EX/B2	8.3 (0.7)	−1.8 (0.1)	5.3 (0.8)	10.0 (0.3)	6.2 (0.9)

batch shades that were very different from the standard in 1CS, did not match it after placement as inner composite in 2CS, while shades of different translucency exhibited different BE values.

The mean score for PE/C2/4 mm inner- with PE/C2 outer 2CS combination confirmed quality and consistency of the evaluations. Given the inter- and intra-observer differences in color perception [11, 22], inter-observer agreement exceeded all expectations. These findings are quite different from the report where the highest agreement among observers was 39% for a single shade, while the same shades were chosen in only 22% in the repeated trials [23].

That the surrounding color can influence the color appearance of a color stimulus is well known to the vision science community. The surrounding area can have either an assimilation or contrast effect; that is, it can make the color of the stimulus more or less like that of its surroundings. The mechanisms of such contrast effects are not entirely understood, but visual adaptation, spatial processing and opponent processing are thought to be involved. Visual adaptation is a process by which the state of the visual system is modified by previous and present exposure to stimuli that may have various luminances, spectral distributions and angular subtenses [24]. In addition to the process of adaptation, the responses of the visual system at different spatial locations in the visual field are compared with each other.

Simultaneous color contrast often occurs when large areas of color are placed adjacent to each other. Due to simultaneous color contrast, colors shift towards the complementary color of the surroundings [6].

The blending effect is the opposite of simultaneous color contrast [5-10]. This effect, also known as assimilation, is a perceptual phenomenon that tends to occur for small areas of color where colors are perceived to be closer than if they were viewed separately. Although it cannot be reliably predicted whether contrast or assimilation will occur and factors other than the size of the specimen and surround are known to be important [25], specimen size does seem to be an influential factor. This additionally explains the decrease in BE values observed for evaluated restoration sizes with the visual angle of subtense for 2-, 4-, and 6-mm inner composites of 0.5°, 0.9°, and 1.4°, respectively.

Finally, continuous staring (lasting for at least 30 s) at an object reduces eye sensitivity to the object color and can provoke the complementary afterimage until color balance is restored. Afterimages are a consequence of localized adaptation of photoreceptors in parts of the retina exposed to

the stimulus. Similarly to contrast and assimilation effects, monochromatic or color afterimages are possible, depending on whether achromatic or colored areas are observed.

These considerations on blending effect apply to the relationship between teeth and esthetic materials, but this relationship is even more complicated since not only surface interactions are involved. In addition, human teeth are small, multi-layered, polychromatic, translucent, and curved. When a resin composite is placed as a restoration, diffused light penetrates from the surrounding hard dental tissues and may provoke change of the restoration's color. In cases when BE occurs, the color difference between tooth and restoration decreases as compared to the difference when the same objects are viewed in isolation [1]. As opposed to polymerization-, aging- and staining-dependent changes in color of resin composite, this color shift is welcomed. A similar mechanism exists for some dental ceramic restorations.

There are different factors that determine or interact with scattering and absorption coefficients of hard dental tissues and restorative materials, such as translucency, particle size and distribution, shade, surface roughness, gloss, metamerism, restoration size, double-layer effect, and optical properties of surrounding tissues [26-30]. Each of these factors can be discussed and evaluated in future experiments. Translucency depends on particle size with a smaller particle size resulting in a higher translucency and a higher BE (see Table 1 for particle sizes and other properties of the materials tested). When all other parameters are equal, lighter shades should be more translucent than the darker ones. Polishing provokes a decrease in surface roughness and an increase in gloss [31], which should lead to an increase in BE. With regard to restoration size, a decrease in color pattern size (surface of restoration) and its thickness should lead to an increase in BE, the former one being partially proved in this study. When both absorption and scattering are involved, it presents complex-subtractive color mixing [13]. The Kubelka-Munk theory [32,33] is the most frequently used method for evaluation of complex-subtractive color mixing of dental tissues and materials whether single-layers or multiple-layers are observed [34-36].

In order to minimize the variables associated with polychromatism and the curved shape of natural teeth, and because of the absence of relevant data, the model presented in this study was chosen for an initial evaluation of BE in dentistry. Since this is just the beginning of the study the blending effect in dentistry, there are no other findings with which to compare. Some other geometries, representing an

interaction between blending and layering (such as in the class I restorations), might be particularly interesting to evaluate. Concerns associated with particular optical properties and initial color differences among dental materials have been addressed earlier in the text. However, these issues are not easy to solve: although materials of the same shade designation were chosen for this study in order to provide consistency, this could not solve the color standardization problem: color difference between A2 shades of two manufacturers was 6.3, while  $\Delta E^*$  between B2 shades was 8.1. It might be useful to develop scales to quantify blending potential, test materials and provide practising dentists with this information. The blending effect of dental materials in their intended environment (teeth and other relevant tissues), whether in vitro or in vivo, using both visual and instrumental color measuring techniques, will certainly present a challenge in further research.

## Conclusions

Within the limitations of this study, the following conclusions were drawn.

The increase in color matching score for specimens made of two composites compared with the same two shades in separate specimens confirmed the existence of blending effect with some composites. The blending effect increased with a decrease in restoration size, decrease of color difference, and increase in translucency.

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## References

- [1] Hall NR, Kafalias MC. Composite colour matching: the development and evaluation of a restorative colour matching system. *Aust Prosthodont J* 1991;5:47-52.
- [2] Swift EJ, Hammel SA, Lund PS. Colorimetric evaluation of Vita shade resin composites. *Int J Prosthodont* 1994;7:356-61.
- [3] Chartrand TL, Bargh JA. The chameleon effect: the perception-behavior link and social interaction. *J Pers Soc Psychol* 1999;76:893-910.
- [4] Pridmore RW. Bezold-Brücke effect exists in related and unrelated colors and resembles the Abney effect. *Col Res Appl* 2004;29:241-6.
- [5] Shinoda H, Ikeda M. Color assimilation on grating affected by its apparent stripe width. *Col Res Appl* 2004;29:187-95.
- [6] McCamy CS. Colors of some small figures on colored grounds. *Col Res Appl* 2003;28:242-50.
- [7] Fach C, Sharpe LT. Assimilative hue shifts in color gratings depend on bar width. *Percept Psychophys* 1986;40-46:412-8.
- [8] Hurvich LM. *Color vision*. Boston: Sinauer Associates; 1981.
- [9] Walker JT. Brightness enhancement and the Talbot level of stationary gratings. *Percept Psychophys* 1978;23-4:256-9.
- [10] Helson H. Studies of anomalous contrast and assimilation. *J Opt Soc Am* 1963;53:179-84.
- [11] Paravina RD, Powers JM. *Esthetic color training in dentistry*. St. Louis: Elsevier-Mosby; 2004.
- [12] Paravina RD. Evaluation of a newly developed visual shade-matching apparatus. *Int J Prosthodont* 2002;15:528-34.
- [13] Berns RS. *Billmeyer and Saltzman's principles of color technology*. New York: Wiley; 2000.
- [14] Fairchild MD, Reniff L. Time-course of chromatic adaptation for color-appearance judgments. *J Opt Soc Am* 1995;12:824-33.
- [15] Bartleson CJ. Measuring differences. In: Bartleson CJ, Grum F, editors. *Optical radiation measurements*. Orlando: Academic Press; 1984.
- [16] Paravina RD, Ontiveros JC, Powers JM. Curing-dependent changes in color and translucency parameter of composite bleach shades. *J Esthet Restor Dent* 2002;14:158-66.
- [17] Paravina RD, Ontiveros JC, Powers JM. Accelerated aging effects on color of composite bleaching shades. *J Esthet Restor Dent* 2004;16:117-27.
- [18] Kuehni FG, Marcus RT. An experiment in visual scaling of small color differences. *Color Res Appl* 1979;4:83-91.
- [19] O'Brien WJ, Groh CL, Boenke KM. A new, small color difference equation for dental shades. *J Dent Res* 1990;69:1762-4.
- [20] Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. *J Dent Res* 1989;68:819-22.
- [21] Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. *Int J Prosthodont* 1995;8:79-86.
- [22] Kuehni RG, Ramanath R. Comparing observers. *Col Res Appl* 2004;29:183-6.
- [23] Barna GJ, Taylor JW, King GE, Pelleu GB. The influence of selected light intensities on color perception within the color range of natural teeth. *J Prosthet Dent* 1981;46:450-3.
- [24] ISO 9241-8:1997: Ergonomic requirements for office work with visual display terminals (VDTs)—Part 8: Requirements for displayed colours. Geneva: International organization for standardization; 1997
- [25] Westland S. *Models of colour perception and colour appearance Colour in food: improving quality*. Cambridge: Woodhead Publishing; 2002.
- [26] Zijp JR, ten Bosch JJ, Groenhuys RA. HeNe-laser light scattering by human dental enamel. *J Dent Res* 1995;74:1891-8.
- [27] Vaarkamp J, ten Bosch JJ, Verdonschot EH. Light propagation through teeth containing simulated caries lesions. *Phys Med Biol* 1995;40:1375-87.
- [28] Davis BK, Johnston WM, Saba RF. Kubelka-Munk reflectance theory applied to porcelain veneer systems using a colorimeter. *Int J Prosthodont* 1994;7:227-33.
- [29] Campbell PM, Johnston WM, O'Brien WJ. Light scattering and gloss of an experimental quartz-filled composite. *J Dent Res* 1986;65:892-4.
- [30] O'Brien WJ. Double layer effect and other optical phenomena related to esthetics. *Dent Clin North Am* 1985;29:667-72.

- [31] Paravina RD, Roeder L, Lu H, Vogel K, Powers J. Effect of finishing and polishing procedures on surface roughness, gloss and color of composites. *Am J Dent* 2004;**17**: 262-6.
- [32] Kubelka P. New contributions to the optics of intensely light-scattering materials. Part I. *J Opt Soc Am* 1948;**8**: 448-57.
- [33] Kubelka P. New contributions to the optics of intensely light-scattering materials. Part II. *Nonhomogenous layers*. *J Opt Soc Am* 1954;**44**:330-55.
- [34] Miyagawa Y, Powers JM. Prediction of color of an esthetic restorative material. *J Dent Res* 1983;**62**:581-4.
- [35] Ishikawa-Nagai S, Sawafuji F, Tsuchitoi H, Sato RR, Ishibashi K. Using a computer color-matching system in color reproduction of porcelain restorations. Part 2: Color reproduction of stratiform-layered porcelain samples. *Int J Prosthodont* 1993;**6**:522-7.
- [36] Ragain JC, Johnston WM. Accuracy of Kubelka-Munk reflectance theory applied to human dentin and enamel. *J Dent Res* 2001;**80**:449-52.