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Metameric effect between natural teeth and the shade tabs of a shade guide

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The objective of this study was to evaluate metameric effects, that is, the dependence of the colours of teeth and shade tabs on the illuminant used. The colours of 49 teeth of 37 participants and of the corresponding shade tabs of the 3D-Master (VITA Zahnfabrik; colour match $\Delta E_{ab} < 2$) were measured using an intra-oral spectrophotometer (VITA Easyshade). Spectral reflectance data (from 400 to 700 nm) were recorded. Commission Internationale de l'Éclairage (CIE) L*a*b* values were calculated for D65 (reference daylight), A (incandescent light), and TL84 (store/office light) as reference illuminants. A modified metamerism index (Mod-M) and hue-angle ratios were calculated to express differences between tooth and tab colour relative to the difference observed under D65 illumination. The Mod-M for teeth and tabs was greater than unity (indicating a greater colour difference relative to D65) by 57.1% for A and by 49.3% for TL84. Hue-angle ratios of teeth and tabs using the test illuminants were different from those obtained using the standard illuminant D65. If teeth and shade tab matching is conducted using daylight illumination, the colour difference may not be the same under other lighting conditions, leading to perceptible, or even unacceptable, colour differences under these conditions.

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The colour of an object depends on the object itself, the observer, and the illumination (1). The spectral distribution of the light under which an object is viewed differs among illuminants. The light being reflected by, or transmitted through, the illuminated object depends on this distribution. For example, the colour of an object is often perceived as more red in incandescent light than in daylight or in fluorescent light with a high correlated colour temperature. Furthermore, an observer could have the perception of the same colour when comparing two objects with a specific illuminant, yet different colours when another illuminating light source is used. This phenomenon is known as metamerism (2).

In the daily lives of patients, many different light sources are present, for example daylight, incandescent light, or illuminants comparable with store or office light sources. Good colour matching of a dental restoration by a dentist under daylight conditions may not result in a match under other light conditions. This metameric effect between teeth and dental restorations could have a negative effect on dental aesthetics. Only when two objects have identical spectral reflectance curves (i.e. reflect or absorb the same percentage of light at each wavelength) will they always be the same colour under different illumination or observer conditions (3). Previous research has shown that the chromaticity of dental materials, for example composites and ceramics, and the shade tabs of shade guides, are affected when the illuminant is changed (4–7). The translucency of all ceramics is also significantly affected by the illuminant (8). *In vitro* studies of metameric effects between the colour/translucency of dental porcelain and repair composite, and between dentine and composites, concluded that changes in optical properties with different illuminants were different for the materials tested (9–11). Therefore, careful shade matching should be performed between dental materials and dental repair materials, and between dental materials and natural teeth; metamerism seems, however, to be of greater concern with regard to composites and ceramics or teeth and of less concern with regard to ceramics and teeth.

Colour is expressed in terms of Commission Internationale de l'Éclairage (CIE) L*a*b* values, which describe a position in three-dimensional (3D) colour space – L* represents lightness, and a* and b* represent red/green and yellow/blue chromaticity, respectively. The Euclidean distance between two locations in this 3D colour space, denoted ΔE^*_{ab}, can be interpreted as being proportional to the perceived colour difference (in the rest of this article the asterisk is omitted). If the colour of a sample A matches the colour of sample B perfectly under the reference daylight D65 (identical corresponding tristimulus values X, Y, and Z; $\Delta E_{ab} = 0$), ΔE_{ab} computed for the two samples under another illuminant would give the metameric index (12).

In the work-flow of colour reproduction from the patient's natural tooth colour to the finished dental restoration, selecting the most suitable shade tab from a shade guide, by comparison, is usually the first step. This should be performed under standardized daylight lamp conditions rather than by using, for example, window daylight (13, 14). However, a good match of tooth and shade tab under daylight illumination may not be a match under other illuminants. Previous *in vitro* research revealed a change of chromacity of natural teeth and ceramics with different illuminants. The objective of this study was therefore to evaluate the metameric effects between natural teeth and shade tabs. This should reveal whether shade matching with shade guides should be performed under different lighting conditions to increase the accuracy of the shade-matching process. To enhance the clinical significance of the findings, this should include a clinical setting and a matching of electronic tooth-colour measurement with visual colour determination. The null hypothesis stated that there were no metameric effects between teeth and tabs.

Material and methods

Measurement of the colour of natural teeth - A tooth-colour gamut was obtained by recruiting 66 preclinical dental students who gave informed consent to take part in the investigation. Maxillary right central incisors, right canines, and mandibular right first bicuspids that were unrestored, unfilled, and unaffected by dental disease were included (198 teeth). The contralateral tooth was used in the event of fillings or restorations being present in the maxillary right central incisor, right canine, or mandibular right first bicuspid. As far as possible, all measurements were made in an achromatic room painted in ~20% grey. Participants had to remove make-up if present and had to wear a grey cape to hide artificial colours. Tooth colour was measured using an intra-oral spectrophotometer (VITA Easyshade Compact, serial number H11604, software version 2HW; VITA Zahnfabrik, Bad Säckingen, Germany) (15). To standardize the illumination, a daylight lamp was used. The instrument used was, however, a contact-type spectrophotometer with its own light source and control measurements for background lighting conditions and therefore relatively independent of ambient lighting. An infection-control shield was used for every participant, and the instrument was calibrated for every participant. The probe tip was placed above the dentin core (which corresponds best to the middle third of the facial tooth surface) and one measurement was performed in the 'tooth mode'. The spectral reflectance was recorded at wavelengths from 400 to 700 nm, in steps of 10 nm, using an additional software package provided by the manufacturer which is not available in the commercial software package (SHADERITE2HW®; JJL Technologies LLC, N. Austin, TX, USA).

Colour measurement of the shade tabs – All shade tabs of a 3D-Master were measured using the Easyshade Compact in 'shade tab' mode over a grey background. The probe tip was placed 2 mm from the cervical edge of the tab and equidistant from the mesial and distal edges. The manufacturer confirmed that the performance of the 3D shade guide was within production colour-tolerance standards. According to the manufacturer, the shade tabs consist of different ceramics, but not the same ceramics used for restorations in dental laboratories.

Selection of fitting tooth/shade tab pairs – For this investigation, only pairs of teeth and tabs with a good colour match were used. CIE L*a*b* values for the D65 illuminant and the CIE 1931 standard observer were calculated from the measured spectral reflectance curves for teeth and 3D shade tabs using a software package that was developed by S.H. for this purpose. Pairs of teeth and tabs for which the colour difference was within a given tolerance were sought. The colour difference was calculated using the Euclidean distance formula for two colour samples:

$$\Delta E_{ab} = ((L1^* - L2^*) \times (L1^* - L2^*) + (a1^* - a2^*) \times (a1^* - a2^*) + (b1^* - b2^*) \times (b1^* - b2^*))^{1/2}$$

Different thresholds for perceptibility or acceptability have been described previously (16, 17); in this investigation a colour difference between the tooth and the tab that did not exceed $\Delta E_{ab} = 2$ was accepted (18). This match was achieved for 68 teeth. Previous research has described a discrepancy between colorimetric and/or spectrophotometric measurement of tooth colour and visual colour matching (19). Examiner-dependent failures in measurement and edge-loss effects could also both be present (20). Teeth with a match within the given limits were therefore visually checked by two experienced prosthodontic clinicians [one female (N.C.) and one male (A.J.H.)] with the same 3D-Master shade guide used for the tab measurements. The room where visual checking of matching was carried out was the same room as described above. A daylight lamp with diffuse light from two angled 5 W lamps [D55 (DIN 67505), 1500 Lux (distance about 25 cm)] was also used for assessment (Dialite Color, Eickhorst, Germany). The same regions of the shade tabs and the teeth, as described above, were matched. For assessment of metamerism the only teeth included out of the pool of 68 teeth were those rated as a good colour match by both examiners, which was a total of 49 teeth from 37 participants [mean age of participants, 23.0 yr; standard deviation (SD) 3.6; 62.2% women).

Assessment of the performance of the spectrophotometer used – Repeatability (short-term), reproducibility, inter-instrument reproducibility, and accuracy – were tested (21). Measurements were performed on the middle third of the facial surface of an extracted human central right incisor and on a '2M2' shade tab. To ensure the same measurement area, a composite mould was made for the tooth and the tab for positioning of the probe tip. Repeatability was tested with 20 measurements performed by one examiner for the tooth and the tab; reproducibility was tested with 20 measurements performed by each of two examiners for both the tooth and the tab; inter-instrument reproducibility was tested by performing 20 measurements each for the tooth and the tab with the instrument used and with a second instrument (VITA Easyshade Compact, serial number H012018, software version 2HW). The mean, the range, and the SD values of measured L*, a*, b*, ΔL*, Δa*, and Δb* (D65, CIE 1931 standard observer) are reported. Accuracy was tested by measuring the 3D shade guide fitting to the production colour-tolerance standards. All tabs were measured in the shade tab mode, as described above, and the shade tab determined by the instrument was observed.

Assessment of the metameric effect – To evaluate metamerism, L*a*b* values for the 49 teeth and the corresponding shade tabs were calculated from the measured spectral reflectance curves for illuminant A (incandescent light), for TL84 illuminant (store/office light), and for D65 as reference light (CIE 1931 standard observer). Because no pairs

Table 1

Assessment of the performance of the spectrophotometer used

Examiner	Device	Tooth/Tab (n = 20 each)	Mean L* (range; SD)	Mean a* (range; SD)	Mean b* (range; SD)
		Repeatability (short)			
A.J.H.	H11604	Tooth	87.99 (87.9/88.0; 0.03)	1.05 (1.0/1.1; 0.05)	31.01 (30.9/31.1; 0.08)
A.J.H.	H11604	Tab	77.42 (77.4/77.5; 0.04)	0.80 (0.7/0.9; 0.03)	18.27 (18.2/18.5; 0.07)

Examiner	Device	Tooth/Tab (n = 20 each)	Mean ΔL* (range; SD)	Mean Δa* (range; SD)	Mean Δb* (range; SD)
		Reproducibility and inter-instrument reproducibility			
A.J.H. and N.C.	H11604	Tooth	−0.13 (−0.2/−0.1; 0.04)	−0.06 (−0.1/0; 0.05)	−0.57 (−0.6/−0.5; 0.05)
A.J.H. and N.C.	H11604	Tab	−0.34 (−0.4/−0.2; 0.07)	−0.10 (−0.2/0.1; 0.05)	−0.04 (−0.1/0.2; 0.08)
A.J.H.	H11604 and H012018	Tooth	1.49 (1.4/1.5; 0.04)	−0.27 (−0.3/−0.2; 0.05)	0.01 (−0.1/0.1; 0.08)
A.J.H.	H11604 and H012018	Tab	−0.18 (−0.2/−0.1; 0.04)	−0.30 (−0.4/−0.2; 0.03)	−0.74 (−0.8/−0.5; 0.07)

SD, standard deviation.

exhibited a $\Delta E_{ab} = 0$ for reference D65, a modified metamerism index (Mod-M) had to be used (10–12), where Mod-M_A or TL84 gives a ratio relative to the standard illuminant D65. Mod-M_A was calculated by use of the formula:

$$\text{Mod} - M_A = \frac{\Delta E_{ab}\text{ between tooth and tab for illuminant A}}{\Delta E_{ab}\text{ between tooth and tab for illuminant D65}}$$

Calculation of Mod-M_{TL84} was analogous. A value of unity was indicative of no metameric effect. The ratio of hue-angles, h*, where h* = arctan(b*/a*), was also calculated with D65 as the reference standard for both A and TL84:

$$\text{hue-angle ratio} = \frac{h^*(\text{A/TL84 illuminant}) - h^*(\text{D65})\text{ for tooth}}{h^*(\text{A/TL84 illuminant}) - h^*(\text{D65})\text{ for tab}}$$

The level of significance between the L*, a*, and b* coordinates for the three different illuminants was assessed using one-way analysis of variance (ANOVA) and Tukey's post-hoc test. The level of probability for statistical significance was set to alpha = 0.05. All statistical analysis was performed using SPSS 16.0.1.

Results

Spectrophotometer performance

Table 1 shows the results for repeatability, reproducibility, and inter-instrument reproducibility. In the accuracy assessment the instrument detected 25 out of 26 shade tabs correctly (96.2%). The shade tab '4L2.5' was wrongly recognized – the shade '4M3' was displayed. This is equivalent to a ΔE_{ab} of approximately 2.25.

Colour change for the different illuminants

There was no statistically significant difference between lightness (L*) under different illuminants for either teeth or shade tab (Table 2, Fig. 1). However, chromaticity differed significantly. For the illuminants other than D65, the a* value was found to be more towards red; it was also more towards red for A than for TL84 ($P < 0.001$ in every assessment; Tukey's post-hoc test). The b* value was found to be more towards blue for teeth for TL84 as the illuminant compared with D65 ($P = 0.047$).

Colour difference between teeth and tabs

The mean ΔE_{ab} between the shade tab and the tooth was 1.52 (SD 0.38; range 0.35–1.98) for D65, 1.51 (SD 0.45; range 0.44–2.35) for A, and 1.48 (SD 0.49; range 0.30–2.60) for TL84. Eight pairs (16.3%) of teeth and tabs for A and seven pairs (14.3%) of teeth and tabs for TL84 had a $\Delta E_{ab} > 2$ and would thus not have fallen within the chosen colour difference limit of 2. The mean Mod-M_A was 1.03 [95% confidence interval (CI), 0.95/1.12] (Fig. 2) and ranged up to 2.06, meaning that the colour difference was 2.06 times higher for A than for D65. The percentage of pairs with a Mod-$M_A > 1$, meaning the presence of a greater colour difference compared with D65, was 57.1%. The mean Mod-M_{TL84} was 1.00 (95% CI, 0.91/1.09) (Fig. 2) and ranged up to 2.35. The percentage of pairs with a Mod-$M_{TL84} > 1$

Table 2

Mean L, a*, and b* values for the different illuminants, with one-way analysis of variance (ANOVA) level of significance between the groups*

	D65	TL84	A	*P*-value
Teeth				
L*	78.35 (3.28)	79.16 (3.21)	79.65 (3.14)	0.135
a*	0.64 (1.07)	2.82 (1.22)	6.27 (1.81)	< 0.001
b*	23.21 (4.71)	25.60 (5.14)	23.68 (4.96)	0.043
Shade tabs				
L*	77.07 (4.87)	77.99 (4.78)	78.43 (4.66)	0.859
a*	1.66 (1.38)1	3.08 (1.47)	6.41 (2.00)	< 0.001
b*	22.23 (5.56)	24.39 (6.04)	23.20 (5.84)	0.708

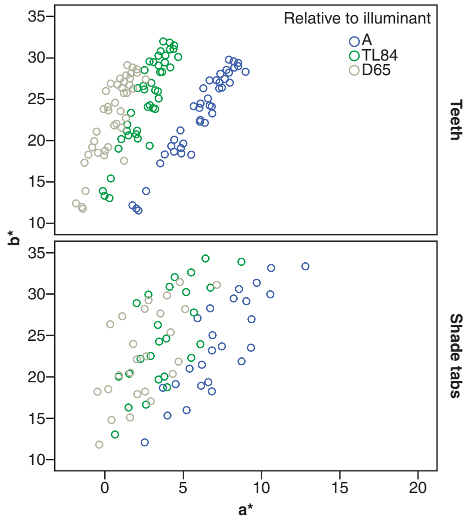

Fig. 1. Colour change for different illuminants, a*/b* plot.

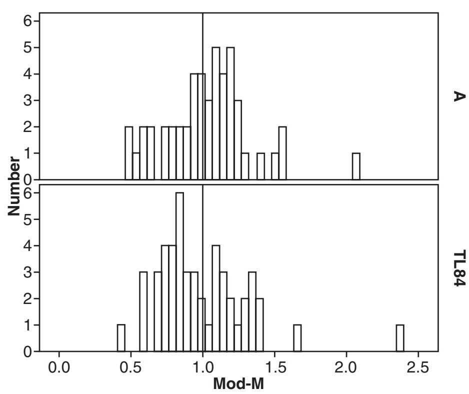

Fig. 2. The line represents a modified metamerism index (Mod-M) of unity, which is indicative of no metameric effect between the tab and the tooth relative to the standard illuminant D65. A smaller index is indicative of a small colour difference from that under D65 illumination; a higher index is indicative of a large colour difference.

was 42.9%. In our experiments we found that the closer the two spectral reflectance curves, with no crossing points, the fewer the number of metameric problems (Fig. 3).

The effect on h* of changing the illuminant can be seen in Table 3. The mean change in the hue-angle of the teeth was 1.98° more towards red than for the tabs for illuminant A in comparison with the standard illuminant D65. Consequently, the mean ratio of hue-angle changes for A was 1.17 (95% CI, 1.16/1.18; range: 1.08–1.25). A positive ratio means that the hue changes were in same direction, towards red, for teeth and tabs. A ratio above 1 means that the hue change was larger for teeth than for shade tabs (a mean of 1.17 times greater for teeth than for tabs). For TL84 the mean change of hue-angle for teeth was 1.72° more towards red than for tabs compared with the standard illuminant. The mean ratio of hue-angle changes was 1.54 (95% CI, 1.51/1.58; range: 1.28–1.91). The hue changes were therefore again in the same

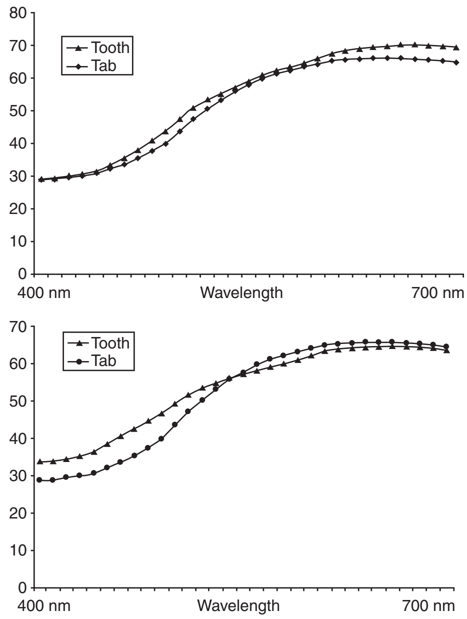

Fig. 3. The upper spectral reflectance curve shows a tooth and tab pair with a small metameric effect and no crossing point of the curves [ΔE_{ab} = 1.14 for D65, mean modified metamerism index (Mod-M) of 1.04]. The lower curve shows a pair with a larger metameric effect and a crossing point (ΔE_{ab} = 0.96 for D65, mean Mod-M of 1.61).

Table 3

Mean h, Δh*, and ΔΔh**

Relative to	Mean h* (SD), in °	Mean Δh* (SD) (Δh* = h* A/TL84–h* D65)	ΔΔh* (SD; range) ($\Delta\Delta h^*$ = Δh^* $teeth_{A/TL84}$–Δh^* $tabs_{A/TL84}$)
Teeth			
D65	88.9 (3.1)		
A	75.4 (2.0)	−13.5 (1.3)	
TL84	84.1 (2.2)	−4.9 (1.0)	
Shade tabs			
D65	87.3 (2.6)		
A	75.8 (1.9)	−11.5 (1.0)	
TL84	84.1 (2.1)	−3.2 (0.6)	
A			−1.98 (0.54; −0.97/−3.49)
TL84			−1.72 (0.56; −0.82/−3.49)

SD, standard deviation.

direction for teeth and tabs, but showed a larger hue change for the teeth than for the tabs.

Discussion

The research hypothesis had to be rejected. The Mod-M was usually different from 1, and the ratio of hue-angle changes for teeth and the corresponding shade tab for the test illuminants A and TL84, relative to the standard illuminant D65, were different.

The test illuminants were compared with D65, which is recommended as a standard illuminant (CIE) representing daylight conditions. For testing metameric effects relative to the standard illuminant, commonly occurring lighting conditions for the specific question should be chosen. Illuminant A was chosen because incandescent lighting is commonly encountered by our patients in their home, as is TL84 in their professional or general life, for example in offices or stores. No conclusions about other lighting conditions should be drawn from these results. The CIE standard metamerism index could not be used in this investigation because this would have needed identical tristimulus values for the pairs of teeth and tabs relative to D65, which was not the case. Instead, a modified index was used, Mod-M, with '1' being indicative of no colour change in comparison with D65 (11, 12). It was shown that both smaller (Mod-M < 1) and larger (Mod-M > 1) colour differences occurred for both A and TL84 compared with the reference. Smaller colour differences may be acceptable, however. For nearly half of the pairs the colour difference would be greater under illuminants other than D65. Analysis of hue-angle changes revealed that shade tabs and teeth changed their hue in the same direction. For A and TL84 illuminants the hue change was towards red relative to D65, both for teeth and tabs. The change in hue was, to some extent, systematically larger for the teeth, however. The mean extent of this larger change was approximately 2° (illuminant A). For comparison, this is, according to the manufacturer, approximately the difference in hue between two shade tabs on the 3D-Master with different hue (M to L or R shades). For varying shades of red a ΔE_{ab} of 1.1 was found to be an acceptable threshold, whereas a ΔE_{ab} of 2.1 was found to be acceptable for different shades of yellow (22). The clinical meaning of the size of the Mod-M, or the ratio of hue-angle changes, which would be unacceptable in dentistry could not be drawn from this analysis and is a matter for future research. Nevertheless, a metameric effect was found to be present and this should be borne in mind when shade matching under clinical conditions. Colours may match when chosen in daylight conditions but may not under other lighting conditions, leading to a perceptible, or even unacceptable, colour difference under the changed lighting conditions. As the colour stimulus emanating from an object depends on the illuminant and on the spectral reflectance of the object itself, the presence or absence of a metameric effect should be tested for every tooth and shade tab combination individually, because teeth differ in structure. Routine clinical use of a spectrophotometer and evaluation of spectral reflectance data do not seem practicable. One recommendation for clinical dentistry could be to have not only a daylight light source for shade matching, but also other lighting sources, for example illuminant A, to test metameric effects visually. Metamerism could then be predicted and another shade may be tested to achieve a better match under several lighting conditions.

An important limitation in the interpretation of the results is that the metamerism between teeth and shade tabs is different from the metamerism between teeth and dental restoration material. This is obvious for veneering ceramics of metal-based frameworks or composite materials. But, even if shade tabs may seem comparable with all-ceramic restorations in structure and optical characteristics, a comparable metameric effect might not be given. For the 3D shade guide investigated, the ceramics used for the shade tabs differ from those sold by VITA for dental restorations. Therefore, even if the selected shade tab showed no, or only small, metameric effects compared with the tooth, this is no guarantee that the finished restoration, especially, for example, one with a metal-based framework, will also match. Even the porcelain layer thickness and the type of alloy used will affect the colour of a restoration and, possibly, the metameric effects (23, 24).

Bearing the limitations in mind, this study found a metameric effect between natural teeth and shade tabs and consequently recommends matching between shade tabs and teeth using different lighting conditions. A topic for future research should be to determine whether, to enhance accuracy of shade matching, it would be better to manufacture shade guide shade tabs from the actual restorative material if that resulted in less metamerism than the material now used for the tabs.

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