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ORIGINAL ARTICLE

Influence of background/surrounding area on accuracy of visual color matching

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Abstract
Introduction Visual shade selection is subjective and influenced by factors that might be operator-dependent or not. The objective was to evaluate influence of observer nonrelated factors (background/surrounding area, and light) and observer-related factors (gender and color competence) on shade-matching quality and to identify the most often mismatched shades in correlation with the background.
Methods Ten observers with average or superior color discrimination competence according to ISO TR 28642:2011 were asked to match 48 shade tabs of three VITA Classical shade guides, in a viewing booth under two light sources: D65 and D50. Gray, white, black, red, and light blue background/surrounding area simulated various clinical situations. The results were statistically analyzed using Kruskal-Wallis test and Mann-Whitney U test. Post hoc power analyses and sample size calculations were also conducted.
Results The matching scores ranged between 72.7 % (using blue background) and 85.9 % (using white and black backgrounds). There was a statistically significant difference between matching scores on the five backgrounds ($\chi^2(4)=12.67$, $p=0.01$). When neutral gray was used as reference, Mann-Whitney U value was statistically significant only for the blue background ($U=107.00$, $Z=-2.52$, $p=0.01$). The influence of gender and lighting condition was also assessed, no statistically significance being found, but in both cases, the effect size and the achieved power were small. However, color discrimination competence did influence the results ($p<0.01$). Background influenced shade matching results for tabs A3, B3, B4, and D4.
Conclusions Within the limitations of this study, it was concluded that

1. When it comes to the influence of the background/surround area on quality of color matching, no difference among achromatic backgrounds was recorded. Significantly worse results were recorded when the blue background was used.
2. Observers with superior color matching competence performed significantly better than the ones with average competence
3. The most frequently mismatched shade tabs were A3.5, B3, B4, and D4.

Keywords Color matching · Shade guide · Background

Clinical relevance To provide indications regarding the most recommended colors of the background and surrounding area during dental shade matching

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Introduction

Tooth shade selection in dentistry is a routine clinical procedure. It is performed for tooth colored direct and indirect restorations, and within monitoring tooth whitening efficacy. Achieving optimal color appearance and consequently esthetics can be a challenge due to the complexity of the optical properties of the dental structures [1–3].

The methods that are currently available for shade matching in dentistry are based on visual or instrumental methods (using spectrophotometers, colorimeters, and computer-imaging), or, mostly recommended, a combination of the two of techniques [4–7].

Visual color matching is performed by comparing the tooth and shade guide tabs, in order to determine the best match. The results, from determining a single tab to building a color map of the tooth, are used for color reproduction (direct restorations) or communication with dental laboratory (indirect restorations).

Visual shade selection is subjective, with color perception depending on interaction of light and complex dental surface and structure. As a result, the final decision on color selection is influenced by a multitude of factors both operator-dependent and nondependent.

Numerous studies, including in vitro and clinical research, have been performed, in order to assess the role of light source and shade guide on shade matching results [8–11]. In addition, factors related to gender [3], professional experience of the observers [3, 10, 12–14], or the role of certain types of discromatopsies on the dental color selection have been investigated [15–17].

Background is defined as the surface upon which samples are placed along with the environment extending for about 10° from the edge of the stimulus in all, or most directions. (ISO TR 28642/2011) [18]. In practice, the background is represented most often by the darkness of the oral cavity; nevertheless, there are situations when the shade selection is performed against the opposite dental arch, the lower lip, or the rubber-dam. The surround is defined as the field outside the background. In clinical situations, the surround can be considered the entire environment in which the stimuli are viewed [18]. The adjacent and opposite teeth, not only the gingiva, lips, and skin but also the rubber-dam, patients' clothes, and even the dental office environment—walls, ceiling, and floor—play the role of the surrounding area of the operatory field. Although the influence of background and surrounding area of the operatory field is generally considered important, there are no studies that determined and quantified their influence on color matching quality.

Light is an essential factor for color perception. Since the natural daylight is considered as the most recommended condition, the daylight (D) standard light sources are recommended for shade selection. The experience of the observer is usually expressed through years of practice. However, testing of observer's color matching competence, irrespective of their experience, was recommended by ISO TR 28642. Gender is an important factor in color selection as far as color-deficient individuals are concerned. Color deficiency is predominantly of genetic origin and affects approximately 8 % of men and 0.5 % of women) [10].

The aim of the study was to assess the influence of color of the background/surrounding area, light, gender, and color discrimination competence on shade matching quality and to analyze the frequency of color mismatches by shade tab. Consequently, the null hypotheses were as follows:

1. Color of the background/surrounding area did not influence shade matching quality.
2. Light, gender, and color discrimination competence did not influence shade matching quality.
3. Shade matching quality was not shade tab-dependent.

Material and methods

Observers A group of fourteen observers were tested for their color discrimination competence using PseudoIsochromatic Plate (PIP) Color Vision Test and dental color discrimination competence test [18, 19].

At the end of the calibration, only ten observers (7 women, 3 men) who exhibited average or superior dental color discrimination competence were further included in the experiment (matched samples ranged between 75 and 100 %). A total of four female and two male observers exhibited superior, while the others exhibited average color competence. The study was approved by the Ethical committee of the University of Medicine and Pharmacy Iuliu Hatieganu, Cluj-Napoca, Romania, and each observer signed an informed consent.

PseudoIsochromatic Plate (PIP) Color Vision Test is a test for red-green deficiencies in color perception. The version with 24 samples was displayed on a computer screen, in a dark room. The observers were seated at a distance of 60 cm from the computer, with a 0° viewing angle to the center of the monitor. After assessing each plate for 2 s, they had to indicate the symbol formed by the dots into the displayed circle (number or continuous line between two dots); if no symbol was perceived, the observers were asked to indicate "no sign" [19].

For dental color discrimination competence test, we have used the specifications recommended in the ISO TR 28642: The observers were asked to match two sets of 16 tabs from two VITA Classical shade guides (VITA Zahnfabrik, Bad Säckingen, Germany). For one set of tabs, the original markings on tab holders were visible, while for the other set, they were covered and marked with numbers from 1 to 16. Color of the middle third of each tab was measured using a dental spectrophotometer (VITA Easyshade Advance, VITA, Bad Säckingen, Germany). Visual comparisons have been made in a dark room, under the D65 illuminant of a viewing booth (JUST LED Color Viewing Light, JUST Normlicht, Weilheim/Teck, Germany), at a distance of 30 cm, using 0°/45° optical geometry. The tabs were removed from joint tab holders, placed on the neutral gray background of the viewing booth, and mixed. No time limit was set for the process (Fig. 1a, b).

The percentage of correct matching was calculated. According to the ISO TR 28642/2011, observers who proved at

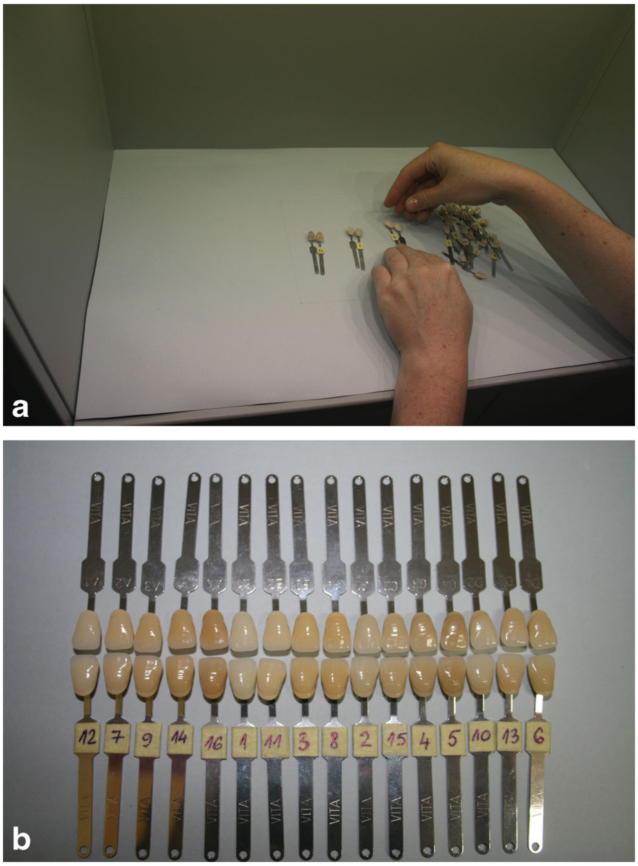

Fig. 1 The set-up for calibration tests. **a** Gray background. **b** Matching two sets of VITA classical shade guide tabs

least 75 % of correct matches were considered average-competent, whereas subjects who managed at least 85 % correct matches were assigned as superior competent in color discrimination [18].

Study design Observers were asked to match 3 sets of 16 tabs from three VITA Classical shade guides. Each of the 48 tabs was previously subjected to instrumental measurements, with a dental spectrophotometer (VITA Easyshade Advance, VITA, Bad Sackingen, Germany, "shade tab" mode). Original tab designations of two shade guides were covered and replaced by numbers ranging from 1 to 32. Original tab designations of the third shade guide remained uncovered—two corresponding tabs from the covered group supposed to be matched to corresponding uncovered tab. Color matching was performed in a viewing booth (JUST LED Color Viewing Light, JUST Normlicht, Weilheim/Teck, Germany). Visual color matching was performed using the 0/45° optical geometry, the distance of 35 cm, and using D65 (light source I) and D50 (light source II). Light source D65 and D50 represent illuminants having relative spectral power distributions as phases of daylight with correlated color temperature of approximately 6500 and 5000 K, respectively.

Different colors of background/surrounding area were selected in order to simulate various clinical situations (Fig. 2a, b).

- Gray (considered as neutral and most frequently recommended)
- White (simulates color of opposite teeth)
- Black (simulates color selection against a contraster)
- Red (imitates the lips and oral mucosa)
- Light blue (simulates the rubber dam)

Ten color matching sessions were performed by each observer (five backgrounds, two light sources). Means and standard deviations were determined for each background and under each of the two light sources. The differences between the gray background and the other four background colors were analyzed.

The percentage of correct matches for each of 16 VITA Classical shade tabs has been calculated. The Shapiro-Wilk test was used to determine the relevance of normal

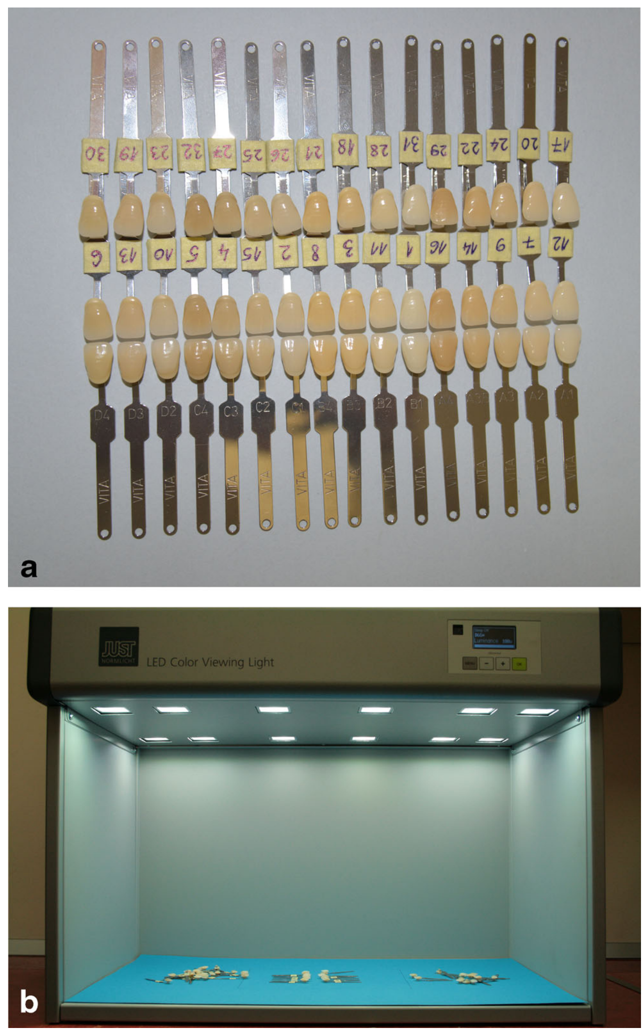

Fig. 2 Experiment set-up. **a** Matching three sets of VITA classical shade guide tabs. **b** One example of experimental background used (*blue*)

distribution. Differences between color matching scores on five different backgrounds were analyzed using the Kruskal-Wallis test. A series of Mann-Whitney *U* tests were conducted to compare the backgrounds. The α level was adjusted using the Bonferroni method (corrected $\alpha=0.0125$). Influence of light, gender, and observers' ability on color selection across each background was assessed using the Mann-Whitney *U* test ($\alpha=0.05$). Chi square tests were performed to determine whether all shade tabs were similarly matched across each background. The Spearman's correlation coefficient was computed to determine possible correlation between color matching results for different of tabs, backgrounds, or the light source. Post hoc power analyses and sample size calculations were conducted using the software package GPower (GPower v.3.1.9.2., Kiel, Germany), for each of the study hypotheses.

Results

According to the calibration test recommended by ISO TR 28642, six observers were assigned as superior–competent, and four observers proved average competence in color selection.

Median and interquartile ranges of matching scores across each background, under the two lighting conditions, are presented in Table 1.

Overall, the highest scores were obtained over white and black (85.9 %), followed by gray background (84.4 %), while the lowest scores were found on the blue background (72.7 %).

There was a statistically significant difference between matching scores on the five backgrounds ($\chi^2(4)=12.572$, $p=0.014$), where (4) denotes degrees of freedom. However, shade matching scores on gray background under D65 light source were not statistically different from the results of color competence test that was done performed against gray background.

When neutral gray background was used as reference and compared to the blue background, Mann-Whitney *U* value revealed statistically significant difference ($U=107.000$, $Z=-2.52$, $p=0.011$).

However, for white, black, and red backgrounds, no significant difference was found ($p>0.05$). The post hoc power analyses conducted showed that the achieved power for the gray-white comparison was 0.016 for an effect size of 0.09, the achieved power for gray-black comparison was 0.018 for an effect size of 0.123, and the achieved power for gray-red comparison was 0.319 for an effect size of 0.685.

Sample size calculations using the abovementioned effect sizes, $\alpha=0.0125$, and power of 0.80 showed that the minimum number of observations per group needed to find an effect is 2407 for the gray-white comparison, 1547 for gray-black comparison, and 52 for the gray-red comparison.

No significant difference was found when the influence of gender or the influence of lighting conditions was assessed ($p>0.05$). But again, we failed to reject the null hypotheses that gender or lighting conditions does not influence shade matching (the achieved power for gender was 0.09 for an effect size of 0.133, and the achieved power for lighting condition was 0.05 for an effect size of 0.007). Since the observed effect size was negligible, the number of necessary

Table 1 Median and interquartile ranges (IQR) of matching scores (%) against five colors of background, under illuminants D65 and D50

		Background color									
		Gray		White		Black		Red		Blue	
Subject	Calibration	D65	D50	D65	D50	D65	D50	D65	D50	D65	D50
I	81.3	53.1	84.4	43.75	46.9	56.3	53.1	78.1	50.0	65.6	37.5
II	100.0	93.8	87.5	100	93.8	93.8	81.3	87.5	100.0	81.3	81.3
III	87.5	93.8	93.75	100	93.8	87.5	87.5	84.4	84.4	75.0	68.8
IV	87.5	100.0	100.0	100.0	93.8	87.5	93.8	78.1	78.1	53.1	65.6
V	87.5	75.0	81.3	78.1	78.1	75.0	87.5	50.0	62.5	59.4	81.3
VI	100.0	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	84.4	84.4
VII	100.0	87.5	87.5	87.5	87.5	87.5	78.1	81.3	81.3	87.5	84.4
VIII	81.25	71.9	75	81.3	68.8	93.8	93.8	68.8	56.3	87.5	46.9
IX	81.25	62.5	46.9	62.5	68.8	62.5	59.4	34.4	50.0	56.25	43.8
X	75.0	78.1	81.3	71.9	87.5	81.3	81.3	65.6	75.0	37.5	84.4
Median	87.5	82.8	85.9	84.4	87.5	87.5	84.4	78.1	76.56	70.3	75
IQR	15.6	19.5	6.3	23.4	21.1	10.9	8.6	17.2	25.8	26.6	32.0
		84.4		85.9		85.9		77.3		72.7	
		14.1		22.7		10.2		23.4		28.9	

observations to achieve a power of 0.8 would be 305,364 observations per group for assessing the influence of lighting condition, and 926 observations per group for assessing the influence of gender (Table 2).

The color discrimination competence influenced color matching results. The overall shade matching scores of subjects with superior color discrimination competence were significantly better compared to subjects with average color discrimination competence ($p<0.01$). However, significantly different results among the two groups of subjects have been found only for gray, white, and red backgrounds. No statistically significant difference was found for black and blue backgrounds (Table 2).

The mismatching rates by shade tab are presented in Table 3. No difference was found between the results obtained on the five backgrounds, with the exception of tabs A3.5 ($\chi^2=14.5$, $p=0.006$), B3 ($\chi^2=15.4$, $p=0.004$), B4 ($\chi^2=20.1$, $p<0.001$), and D4 ($\chi^2=11.42$, $p=0.022$).

For the abovementioned tabs, a weak negative correlation between the matching score and the background has been recorded (Table 4). No correlation of color matching results was found between individual shade tabs and the light source ($p>0.05$).

Discussion

Visual methods of color selection are the most frequently used in dental practice [20–25], although the results are subjected to errors of multiple origins [4, 12, 26, 27].

In clinical situations, the background is either oral cavity or additional tools used in dental practice (contraster, rubber-dam). It was stated that the translucency of the incisal edge makes tooth color background-dependent [28–30]. Shade tabs used in our experiment were less translucent in the incisal area in comparison to natural teeth. Still, the differences in color matching results against different backgrounds could have been to certain extent originated from this factor.

The surrounding areas are adjacent and opposite teeth, oral mucosa, lips, and facial skin; patient bib and other colors in viewing field are also part of a surrounding area [26]. Neutral light gray has been recommended in the literature as the most appropriate for background and/or surrounding area [12, 31].

In our study, the matching scores for neutral gray, white, black, and red were not statistically different; however, the achieved power and the effect size were very small.

Among all, blue that generated the lowest scores proved to be significantly different by the gray reference. Therefore, the first null hypothesis was rejected only for the blue background.

Background selection The neutral gray is frequently recommended for color matching in dentistry. However, black contrasters are frequently used for professional pictures in dentistry, including the ones with the purpose of communicating on color and appearance for indirect restorations. The white and red backgrounds were selected to simulate the adjacent teeth and the oral mucosa and lips. It can be argued that the teeth, the oral mucosa, and the lips are characterized by a wide range of shades and the selected backgrounds cannot be

Table 2 Differences in the precision of the color selection in respect to the illuminant, gender, and color discrimination competence against five backgrounds

Variable	Background color	Mann-Whitney *U*	Wilcoxon W	*Z*	Asymp. sig. (two-tailed)	Exact sig. [2× (one-tailed sig.)]
Light source	Gray	46.000	101.000	−0.305	0.760	0.796
	White	47.500	102.500	−0.191	0.848	0.853
	Black	47.000	102.000	−0.233	0.816	0.853
	Red	49.000	104.000	−0.076	0.939	0.971
	Blue	47.500	102.500	−0.190	0.849	0.853
Gender	Gray	36.000	141.000	−0.500	0.617	0.659
	White	38.500	143.500	−0.292	0.770	0.779
	Black	40.500	145.500	−0.127	0.899	0.904
	Red	41.000	62.000	−0.083	0.934	0.968
	Blue	34.500	55.500	−0.623	0.534	0.547
Color Discrimination Competence	Gray	5.000	41.000	−3.352	0.001[a]	<0.001[a]
	White	6.000	42.000	−3.278	0.001[a]	<0.001[a]
	Black	27.000	63.000	−1.665	0.096	0.115
	Red	11.000	47.000	−2.870	0.004[a]	0.003[a]
	Blue	24.500	60.500	−1.825	0.068	0.069

[a] Statistically significant difference

Table 3 Overall mismatch rates of each tab of VITA classical shade guide (%)

	Shade tabs															
Shade tab	A1	A2	A3	A3.5	A4	B1	B2	B3	B4	C1	C2	C3	C4	D2	D3	D4
Mismatch rate (%)	6	34	21.5	52	1	4.5	16	50	42.5	16	26.5	13	0.5	40	23.5	25.5

representative for the clinical conditions. The same is true for using only used light blue background to simulate the rubber-dam color, as a wide range of rubber-dam shades is available.

The blue background generated the lowest percent of correct matches. Blue is the complementary color for the yellowish dental surface and therefore creates a simultaneous color contrast. Based on our findings, color selection against a blue rubber-dam should be avoided.

The findings on influence of years in practice on shade matching quality are controversial [3, 12, 32–34]. Although all of the observers in our study had previous experience in restorative dentistry, their color discrimination competence was a primary factor in observer selection. Overall, a significant difference between the observers of superior and average competence was recorded; when these differences were analyzed by background, it was shown that only gray, white, and red background generated significant differences in color matching results.

Light is one of the most important factors in color selection. The natural daylight is suggested for visual color selection [4, 35]. However, daylight constantly changes, with a correlated color temperature ratio that could exceed 1:20 throughout the day. Using artificial daylight overcomes this limitation and color-corrected illuminant (D50, D55, D65, D75) with the color rendering index (CRI) of 90 or greater was found to be superior compared to the natural daylight in dental color matching [1, 10]. No statistically significant difference was found between standard illuminants used in this study (D50 and D65). But still, we failed to reject the null hypothesis, since the achieved power was very small. The observed effect size was insignificant, and thus a very large number of observations would be needed for an achieved power of 0.8.

The presumption that gender is correlated with the ability in color selection is mostly due to the differences in color deficiency [3, 10]. Still, it is a traditional belief and was also reported that females are better color matchers that males when only color normal observers were compared [3].

Mann-Whitney *U* test was used for analyzing the data. This is a nonparametric test that can be safely used for assessing differences between samples of unequal sizes. In our study, we have used only three males and seven females for assessing the influence of gender upon shade-matching. However, they each performed 10 shade-matching test, and the total number of observations was compared. Post hoc power analyses showed that this number was insufficient and the effect size was too small; therefore, we did not find enough evidence to suggest that the null hypothesis is false at the 95 % confidence level. Though, the results of this study were in accordance with findings that there is no gender-based difference in color matching for color normal observers [1, 10, 16, 36–38]. Color discrimination competence did influence color matching results.

VITA Classical shade guide was used in this study as it is still considered as "the golden standard" in spite of its limitations [21, 39]. Additional rationale for selection of VITA Classical over VITA 3D Master that has been proven a better shade guide [22, 40, 41] was a smaller number of tabs in the former product (16 vs. 29). The time needed to match 29 tabs in a single session would likely have reduced the number of correct answers due to eye fatigue. Some darker and more chromatic VITA Classical tabs (A3.5, B3, B4) exhibited the highest percentage of mismatch. These results were background-dependent. The third null hypothesis was rejected since significant differences in color matching results were recorded for different tabs.

Table 4 Spearman correlation coefficients for A3.5, B3, B4, and D4 shade tabs against five backgrounds

Shade tabs	Spearman correlation coefficient	*p* value
A3.5	−0.219	0.002
B3	−0.212	0.003
B4	−0.257	<0.001
D4	−0.203	0.004

Conclusion

Under the limitation of this study protocol, it was concluded that

1. Color of the background/surrounding area influenced color matching results: The results recorded against the blue background were statistically different (worse) compared to other backgrounds. White and black generated the best results, followed by gray and red.
2. Observers with superior color matching competence achieved better color matching results compared to ones with the average color discrimination competence.

3. Darker and more chromatic tabs of VITA Classical shade guide (A3.5, B3, B4, and D4) were more often mismatched, situation influenced by the background color.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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