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Visual evaluation of the color adjustment of single-shade and group shade resin composites in restorations with different cavity configurations

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ABSTRACT

Objective: To evaluate the influence of the tooth shade, type of resin composite and cavity configuration on the color adjustment of single-shade and group shade resin composites.
Methods: Class I and V cavities were prepared in artificial acrylic mandibular right molars with different shades - A1, A2, A3, A3.5 and A4. Three single-shade (OMN, UNI, CHA) and two group shade (FIL, HAR) resin composites were evaluated. Seventy-five observers, including dentists, dental students and laypersons (n = 25), participated in the study. A psychophysical experiment based on visual assessments of the color matching between each tooth and each restoration was ranked from 0 (excellent match) to 4 (huge mismatch), and mean frequencies (%) were calculated. Visual color differences among composite materials and tooth shades were statistically tested ($P < 0.05$).
Results: The results showed highest percentages of unacceptable color mismatches for class V compared to class I restorations, especially for more chromatic tooth shades (A3.5 and A4). The percentage of ratings of acceptability was higher for laypersons group. For class V, OMN presented significant difference only from UNI in tooth shades A1, A2, A3 and A4. However, for class I, OMN presented significant differences with CHA for A1, A2 and A4, and with HAR and FIL for A1.
Conclusions: Class I resin composite restorations exhibit superior color matching than Class V, with lighter and low chroma tooth shades demonstrating better color adjustment. The color matching of both cavity configurations is comparable for single and group shade resin composites.
Clinical significance: Cavity configuration and tooth shade may impact color matching of single and group shade resin composites. This study demonstrates superior color matching in class I configurations over class V for both single and group shade resin composites. Additionally, restorations placed in teeth with lighter shades exhibit more favorable color adjustment.

1. Introduction

The correct shade match between the tooth and the resin composite is an important factor in achieving satisfactory esthetic results in restorative dentistry [1]. To mimic dental tissues accurately, it is essential to carefully select the correct composite shade. However, currently, there is a lack of shade standardization across various commercial brands. Therefore, a thorough evaluation of the colorimetric behavior of each composite system is crucial for achieving clinical success [2].

Blending effect, color adjustment, or color assimilation are some of the terms used to describe the ability of a translucent resin composite to shift its color towards the surrounding structures when placed in a cavity [3–5]. This effect is believed to be caused by a color shift due to reflected light and the color of adjacent dental structures. However, the color shift is usually not sufficient to correct an incorrect shade selection.

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Therefore, new single-shade composites using a variety of technologies have been introduced to improve the blending effect without the need for multi-shades composites [6]. Among these new class of materials, Omnichroma (OM) (TokuyamCorporation, Tokyo, Japan) has been the most researched [7]. Although previous studies [8–10] have shown a better blending effect for single-shade composites, the color difference often exceeded the acceptability threshold [11].

While color evaluation can be conducted using either visual or instrumental methods, the visual method is the predominant approach used in dentistry. Although the visual method is subjective, the visual judgment on color match or mismatch is frequently the decisive factor in the overall acceptance by the patient. An advantage of single-shade composites is their enhanced color adjustment potential (CAP), which refers to the interaction between perceptual and physical components. As the perceptual component is subjective, it cannot be measured by any device, thus requiring visual evaluation. The visual color adjustment potential (CAP-V) [5] is a simple method to quantify the color adjustment in clinical practice. However, although this is an important physical concept, its correlation with visual analysis is poorly established [5]. Moreover, CAP-V involves the observation of single and dual specimens, comparison that are not possible to be observed when making the color match judgements clinically.

A recent study [12] evaluated visually the shade match of three composite materials (Omnichroma, Tetric EvoCeram and TPH Spectra ST) placed into occlusal preparations (class I restorations in molars) on acrylic teeth shades - A2, B1, B2, C2 and D3. Thirty dental professionals performed visual color assessments, ranking the shade matches as best match, intermediate match, or poorest match. The results showed that shade matching is material and shade dependent, and that the single and group shade composites presented reduced shade matching ability compared to multi-shade composites, which may limit their use in highly esthetic clinical situations. Abreu et al. [13] evaluated color matching of these composites in class III restorations using visual color analysis made by 6 dental PhD students. Multi-shade universal composites presented higher color matching than Omnichroma, yet no differences were found among the different tooth shades for all materials studied.[13] The differences in the experimental conditions of the two studies make it difficult to evaluate the influence of the experience of the observer (whether a dental professional, student, or layperson), the location of the restoration (anterior or posterior teeth), and the restoration configuration (class III or class I) on the visual evaluation of the blending effect of a single-shade resin composite.

Most studies designed to obtained visual assessment in dental color research use different types of observers, mainly comparing laypersons to dentists [14,15]. It seems that experience or training can both influence color perception in dentistry [16–18], although few studies did not find such differences [14,19]. Thus, it is important that studies on visual color assessment consider using different groups of observers.

Also, most studies that evaluate the blending effect and color matching of universal resin composites compare different commercial brands, tooth shades and cavity sizes in simulated class I restorations [3,10,12,20,21]. The overall results demonstrate a satisfactory behavior with improved color matching for lighter and less saturated shades [12,20] and in more conservative cavity preparations [3,21,22]. Restoration location and cavity configuration have different impacts on the esthetic of the smile. Restorations placed in anterior teeth, as well as in the buccal and interproximal tooth surfaces, are more easily visualized and tend to have a more pronounced impact on esthetics. Therefore, it is important to evaluate the influence of cavity design and location to better understand the behavior of these composites on more challenging esthetic scenarios, considering the visual perspective of observers with different experience and training. Thus, the aim of this study was to evaluate the influence of the tooth shade (A1, A2, A3, A3.5 and A4), the type of resin composite and cavity configuration (class I and class V) on the color adjustment of single-shade and group shade resin composites, testing the research hypotheses that:1) the type of resin composite 2) the tooth shade, and 3) the cavity configuration influences the color matching of resin composite simulated restorations.

2. Material and methods

2.1. Ethical issues

This study was approved by the Research Ethics Committee of the participating institution (CAAE 50211521.8.0000.5346, 4.957.749). All participants read and signed the informed consent form.

2.2. Sample preparation

Five resin composites with color adjustment potential were evaluated: Omnichroma, Vittra APS Unique, Charisma Diamond One (Single-shade), Filtek Universal and Harmonize (Group shade). The characteristics of the tested materials are presented in Table 1.

Class I and V cavities were prepared in artificial acrylic mandibular right molars with different shades - A1, A2, A3, A3.5 and A4 (P-Oclusal, São Paulo, Brazil), resulting in five (5) different shades for each cavity preparation and resin composite restoration. The study design, tested resin composites and cavity configurations are presented in Fig. 1.

Standardized class I and V cavities were prepared using a round-end tapered diamond bur #3131 (KG Sorensen, Cotia, São Paulo, Brazil) which was replaced every five preparations. Both preparations presented mesiodistal length of 8.0 mm and depth of 2.0 mm. The depth of the class I preparation was measured at the central groove of the occlusal surface, and the buccalingual width was 2.5 mm. The class V buccal cavities were prepared 1.0 mm coronal to the cement-enamel junction, presenting 2.5 mm of cervical-occlusal width.

After cavity preparation, to simulate the adhesive protocol and eliminate any potential interference from the adhesive color, an achromatic adhesive system Ambar APS (FGM, Joinville, Brazil) was applied to the cavity walls according with the instructions provided by the manufacture.

The resin composites were placed in a single increment, using the stamp technique in order to obtain uniform anatomy among the restorations [12]. The resin composites were light-cured following the recommendation of each manufacturer with a light-emitting diode (LED) device (Bluephase, Ivoclar Vivadent, Schaan, Liechtenstein) with 1000 mW/cm^2.

The operator was blinded to the tested resin composites and tooth color. The preparations and restorations were performed by two trained operators, one was responsible for the cavity preparations, while the other focused on performing all restorative procedures. Randomization of the preparation, restoration type, resin composite, tooth shade and visual evaluation order was carried out by an independent assistant who was not involved in the study.

2.3. Visual assessment

The visual assessment was carried out by 75 participants - 25 each of specialists in restorative dentistry or prosthodontics (n = 25); final-year dental school students (n = 25) and laypersons (n = 25). The number of subjects was based on a previous study [23] that recommends a minimum of 20 observers per category. The distribution of men and women in each category was equal. All participants were tested for color deficiency using the Ishihara test for color blindness and were under 60 years old.

All visual assessments were carried out in the same room with controlled lighting and temperature. All restorations were observed in a viewing cabinet (Color Viewing Light 4 BASIC, Just Normlicht) with light source simulating the spectral relative irradiance of CIE D65 standard illuminant to ensure consistent viewing conditions. Specimens were placed in the center of the viewing cabinet and fixed in the same position using gray modeling clay (Soft, Acrilex, São Bernardo do

Table 1
Composition and information regarding the resin composite systems tested in this study.

Material/ Manufacturer	Type/ Shade	Matrix	Filler type/ Particle size	Filler content	Batch no.
Omnichroma (OMNI) Tokuyama Dental, Tokyo, Japan	Supra-nano filled Single-shade	UDMA, TEGDMA	Spherical SiO_2ZrO2 Particle size - 260 nm	wt./vol. 79/ 68%	019E89
Filtek™ Universal (FIL) 3M ESPE, St. Paul - MN, USA	Nano-hybrid Group-shade A3	AUDMA, AFM, Diurethane-DMA, 1,12-dodecane-DMA	Non-agglomerated/non-aggregated 20 nm silica filler and 4 to 11 nm zirconia filler, aggregated zirconia/silica cluster	wt./vol. 77.2/57%	2002800203
Vittra APS Unique FGM, Joinville, Brazil (UNI)	Nano-hybrid Single-shade	UDMA, TEGDMA	Boron-aluminum-silicate glass, zirconia filler Particle size – 200nm	wt./vol. 72-82/ 52-60%	200121
Harmonize™ (HAR) Kerr Dental, Orange, CA, USA	Nano-hybrid Group-shade A3E	Bis-GMA, Bis-EMA, TEGDMA	Spherical SiO_2ZrO2 Barium glass Particle size - 5-400 nm	wt./vol. 81/ 64.5%	7900376
Charisma Diamond ONE (CHA) Kulzer GmbH, Hanau, Germany	Nano-hybrid Single-shade	UDMS, TC-DI-HEA, TEGDMA	Ba−Al−B−F−Si glass, PPF, SiO_2 Particle size - 5nm - 20μm	wt./vol. 81/ 64%	K010021

Abbreviations: bis-GMA = bisphenol A glycol dimethacrylate; Bis-EMA= Ethoxylatedbisphenol A dimethacrylate; PEGDMA=polyethyleneglycol dimethacrylate; TCD-DI-HEA = 2-propenoic acid; (octahydro-4,7-methano-1*H*-indene-5-diyl) bis(methyleneiminocarbonyloxy-2,1-ethanediyl) ester; TEGDMA = triethylene glycol dimethacrylate; UDMA = urethane dimethacrylate. PPF = pre-polymerized filler; SiO_2 = silicon oxide (silica); ZrO_2 = zirconium oxide; $BaO-Al_2O_3-SiO_2$ = barium aluminosilicate glass; $B_2O_3-F-Al_2O_3-SiO_2$ = boroaluminosilicate.

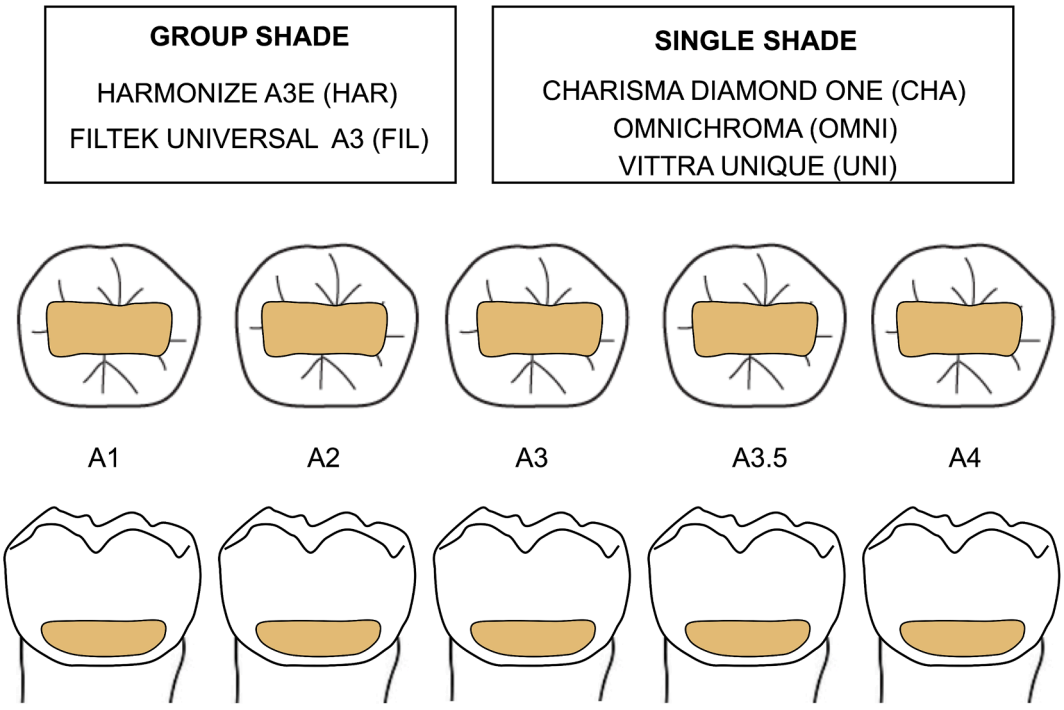

Fig. 1. Study flowchart with tested resin composites and cavity configurations.

Campo, São Paulo, Brazil) on a 45° tilted base, which corresponds to diffuse/0° illuminating/measuring geometry. External lighting was turned off during assessments. All observers were positioned in front of the viewing booth, approximately 60 cm from the specimens. The observers were instructed to find a comfortable focal distance and to maintain that same position for all evaluations. The maximum observation time was 30 seconds per specimen. The visual color difference between each tooth and restoration was ranked from 0 to 4, being 0 - Excellent match, 1 - Very good match, 2 - Not so good match (border zone mismatch), 3 - Obvious mismatch, 4 - Huge (pronounced) mismatch [10]. Depending on the mean value of the restorations visual color assessment for each group of the observers, different perceptibility levels were defined. A mean value <1 was rated as not perceptible; ≥1 and <2 as perceptible and acceptable color match, and mean visual color assessment ≥2 as unacceptable color mismatch.

Instructions regarding the evaluation time, position and possible responses were given to the participants before the visual evaluation. They were also previously informed that every tooth had received a

restoration and were instructed to consider the color match between the restoration and the surrounding tooth structures when grading each specimen. The evaluation order was randomized, leading to different tooth sequences for each observer. In order to prevent visual fatigue, rests periods were allowed between observations.

2.4. Statistical analysis

To analyze statistically the differences between the visual assessments for the different materials and tooth shades for class I and V restorations, the non-parametric Kruskal-Wallis one-way analysis of variance by ranks test was used to ($\alpha = 0.05$), since equal variances could not be assumed for all groups studied after performing Levene's test of homogeneity of variance. Mann-Whitney U test was used for contrasts between different materials and within the same tooth shade, and between different tooth shades and the same material. Bonferroni correction was applied according to the multiple comparison performed ($p < 0.001$). A standard statistical software package was used to perform the statistical analysis (SPSS Statistics 20.0.0, IBM Armonk, NY)

3. Results

Figs. 2 and 3 illustrate the mean frequency of visual assessment (%) rated as perceptible and acceptable and as unacceptable for class I and class V restorations, respectively, across all tooth shades. In general, for both cavity configurations and all resin composites, the most chromatic tooth shades (A3.5 and A4), exhibited the highest percentages of perceptible visual color differences. For the A4 tooth shade (Fig. 2), the percentage of observers who rated the class I restorations with perceptible color difference was: 79.8 % (OMN), 69.2 % (FIL), 59.9 % (UNI), 73.2 % (HAR) and 54.5 % (CHA). However, for the A2 tooth shade, the percentage of observers who rated the class I restorations with perceptible color difference was: 46.6 % (OMN), 31.9 % (FIL), 46.6 % (UNI), 55.9 % (HAR) and 16.0 % (CHA). Furthermore, the percentage of perceptible color difference was higher for class V compared to class I restorations for all resin composites, except for FIL in tooth shades A1 and A2, and for OMN in tooth shade A2 (Fig. 3).

Mostly, the results showed a highest percentages of unacceptable color mismatches for class V compared to class I restorations (Fig. 3), especially for more chromatic tooth shades (A3.5 and A4). For instance, the percentages of unacceptable class V restorations for tooth shade A3.5 were: 46.6 % (OMN), 46.6 % (FIL), 69.2 % (UNI), 57.2 % (HAR) and 16.0 % (CHA), but for class I restorations of the same tooth shade, were 2.7 % (OMN), 14.6 % (FIL),16.0 % (UNI), 12.0 % (HAR) and 1.3 % (CHA). All resin composites class V restorations placed in teeth with A3, A3.5 and A4 shades showed lower percentages of acceptability compared to class I, and only FIL and HAR, tooth shade A1, and OMN and HAR, tooth shade A2, showed a slightly smaller percentages of acceptability or tolerance for class V restorations compared to class I.

When the results of the group shade resin composites - FIL (A3) and HAR (A3E) - were analyzed separately from the single shade groups (OMNI, UNI, and CHA) the FIL restorations exhibited better color match results on A2 tooth shade for both cavity configurations. However, HAR showed the better color match results for Class I on tooth shade A3, and for both cavity configurations on tooth shade A1.

Tables 2 and 3 show the visual rating (0-4) for color differences in class I (Table 2) and class V (Table 3) restorations for each observer category. In this ranking: < 1 is considered a not perceptible (excellent match); ≥ 1 and < 2 is an acceptable match, and ≥ 2 is an unacceptable color mismatch. For both cavity configurations, laypersons rated the color differences with the lowest mean visual ratings, regardless of materials, and tooth shades. Taking into account the results of all the observers, the best matches were found for the CHA in tooth shade A2 (visual rating is 0.19) and OMN in tooth shade A1 (visual rating is 0.25) for Class I restorations.

Class V presented higher values of visual ratings for most of the materials and tooth shades for each observer category. These restorations showed unacceptable mismatches (ratings > 2) for tooth shades A3.5 and A4, except for CHA in tooth shade A3.5. In contrast, class I restorations showed mean visual rating values corresponding to acceptable matches (ratings ≤ 2) for all materials and tooth shades, according to layperson and student observer categories. Thus, considering all observer categories, the mean visual rating values indicate that all color matches were acceptable for class I restorations. However, for class V restorations color matches were acceptable only for tooth shades A1, A2 and A3 for all resin composites, except FIL in tooth shade A1.

The results of the statistical analysis of the visual rating color differences among tooth shades (A1, A2, A3, A3.5 and A4) values and,

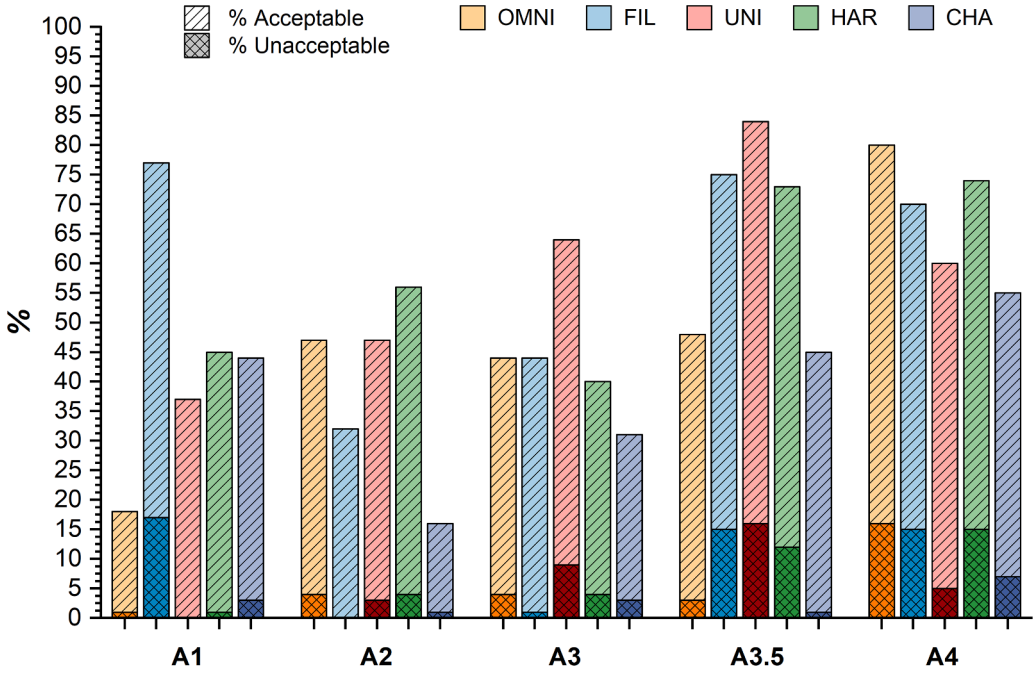

Fig. 2. Mean frequency of visual assessments (%) rated as perceptible and acceptable and as unacceptable for class I.

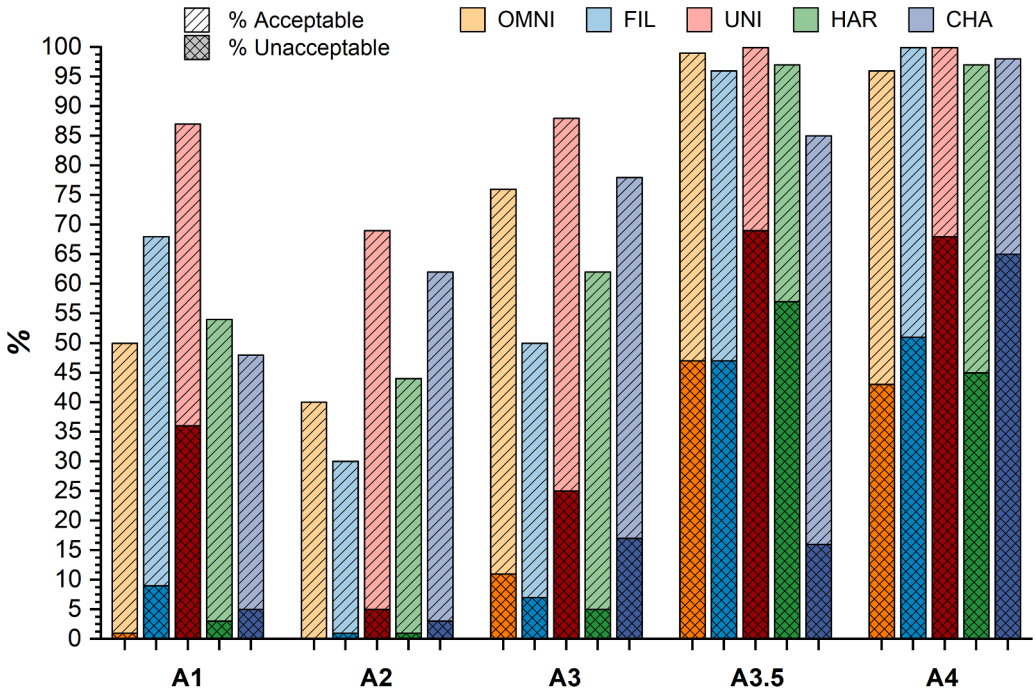

Fig. 3. Mean frequency of visual assessments (%) rated as perceptible and acceptable and as unacceptable for class V.

Table 2
Visual rating (0-4) for color differences in class I restorations for each observer category.

CLASS I		OMNI	FIL	UNI	HAR	CHA
LAYPERSON	**A1**	0.16^{Bb}	1.40^{Aab}	0.32^{Aa}	0.80	0.76
(n=25)	**A2**	0.48	0.28^{A}	0.32^{B}	0.60	0.20
	A3	0.20^{A}	0.92	0.52	0.64	0.28
	A3.5	0.44^{a}	1.16	1.52^{ABa}	0.76	0.68
	A4	1.12^{AB}	1.08	1.04	1.00	0.56
DENTAL STUDENT	**A1**	0.08^{EDd}	1.96^{ABabcd}	0.56^{Ab}	0.48^{BDc}	0.72^{a}
(n=25)	**A2**	0.76^{EAc}	0.48^{AC}	1.04^{b}	1.20^{a}	0.08^{Aabc}
	A3	0.72^{B}	0.40^{BDE}	1.16	0.52^{AC}	0.56
	A3.5	0.60^{Cabc}	1.72^{CDc}	1.56^{Aa}	1.52^{CDb}	0.76
	A4	1.80^{ABCD}	1.40^{E}	0.88	1.80^{AB}	0.84^{A}
DENTIST	**A1**	0.52^{Ab}	1.80^{Cab}	0.80^{B}	0.92^{A}	0.56^{a}
(n=25)	**A2**	1.00	0.88^{A}	0.88^{A}	1.28	0.28^{A}
	A3	1.16	0.72^{BCa}	1.72^{abc}	0.72^{BCb}	0.60^{c}
	A3.5	1.32	**2.28^{ABa}**	**2.20^{ABb}**	**2.04^{ABc}**	0.60^{abc}
	A4	**2.20^{A}**	1.52	1.48	1.88^{C}	1.44^{A}
ALL	**A1**	0.25^{DEFGad}	1.72^{ABabc}	0.56^{ADc}	0.73^{ABa}	0.68^{Bbd}
(n=75)	**A2**	0.75^{BFc}	0.55^{BDF}	0.75^{Cb}	1.03^{a}	0.19^{ABCabc}
	A3	0.69^{CG}	0.68^{ACE}	1.13^{Aa}	0.63^{CD}	0.48^{a}
	A3.5	0.79^{AEace}	1.72^{CDcd}	1.76^{ABCab}	1.44^{BDef}	0.68^{Cbdf}
	A4	1.71^{ABCDa}	1.33^{EF}	1.13^{BD}	1.56^{AC}	0.95^{Aa}

The same capital letter shows statistical difference among the shades for the same material ($p < 0.001$).
The same lowercase letter shows statistical difference among the materials for the same shade ($p < 0.001$).
Bold numbers indicate mean values considered as unacceptable color mismatches (≥2.00).

among all resin composites for each observer groups and all observers group for class I and class V are presented in Tables 2 and 3, respectively. For both cavity configurations, significant differences were found ($P < 0.001$) among the tooth shade A1 and tooth shades A3.5 and A4, except for CHA and FIL in class I considering the mean results reported by all observers. Also, no statistically significant differences were found between tooth shades A3.5 and A4, except for CHA in class V and, for OMN and UNI for class I.

For class I restorations, considering the results reported by all observers, for tooth shade A2 significant difference were found between OMN and CHA, in tooth shade A1, OMN presented no significant difference only from UNI, and for tooth shade A4 significant differences were found only between OMN and CHA.

For class V, OMN presented significant difference only from UNI in tooth shades A1, A2, A3 and A4; UNI showed significant differences with all resin composites in tooth shade A1 with FIL, OMN and HAR for tooth shades A2 and A3, considering the results reported by all observers. Other resin composites only showed statistically significant differences with CHA for some of the tooth shades.

4. Discussion

Achieving adequate color matching between restorations and natural teeth is essential for successful dental treatment, the present study was

Table 3
Visual rating (0-4) for color differences in class V restorations for each observer category.

CLASS V		OMNI	FIL	UNI	HAR	CHA
LAYPERSON	**A1**	0.40^{BE}	1.12^{AC}	1.24^{BE}	0.68^{BE}	0.36^{CD}
(n=25)	**A2**	0.12^{CF}	0.20^{AC}	0.56^{CF}	0.36^{CF}	0.52^{B}
	A3	0.96^{AD}	0.44^{D}	1.52^{AD}	0.72^{AD}	0.96^{A}
	A3.5	**2.36^{ABCc}**	**2.28^{BCD}**	**2.76^{DEFa}**	**2.48^{ABCb}**	**1.28^{Dabc}**
	A4	**2.16^{DEF}**	**2.32^{AB}**	**2.80^{ABC}**	**2.28^{DEF}**	**2.32^{ABC}**
DENTAL STUDENT	**A1**	1.24^{BEb}	1.36^{ADa}	**2.44^{Aabcd}**	0.88^{CFd}	0.96^{ABc}
(n=25)	**A2**	0.84^{CF}	0.48^{CFa}	1.40^{ADa}	0.92^{BE}	1.04^{CD}
	A3	1.64^{AD}	1.16^{BE}	1.96^{BC}	1.12^{AD}	**2.00^{BC}**
	A3.5	**2.88^{ABCc}**	**2.68^{DEF}**	**3.40^{ABa}**	**3.40^{ABCb}**	**2.04^{ADabc}**
	A4	**2.60^{DEF}**	**3.28^{ABC}**	**3.16^{CD}**	**2.88^{DEF}**	**3.20^{ABC}**
DENTIST	**A1**	0.80^{BEb}	1.08^{ADa}	**2.84^{Cabcd}**	0.72^{BEd}	0.80^{ABc}
(n=25)	**A2**	0.64^{CFa}	0.48^{CFc}	1.40^{ABCabc}	0.56^{CFb}	1.04^{C}
	A3	1.44^{ADa}	0.96^{BEb}	**2.36^{ABabc}**	0.96^{AEc}	1.88^{A}
	A3.5	**2.68^{DEF}**	**3.00^{ABCb}**	**3.32^{Ba}**	**3.08^{ABCc}**	1.84^{Babc}
	A4	**2.84^{ABC}**	**2.76^{DEF}**	**3.36^{A}**	**2.76^{DEF}**	**3.44^{ABC}**
ALL	**A1**	0.81^{BCb}	1.19^{ACa}	**2.17^{ACabcd}**	0.76^{BEc}	0.71^{CEd}
(n=75)	**A2**	0.53^{ADb}	0.39^{AEcd}	1.12^{BCabc}	0.61^{CFa}	0.87^{BDd}
	A3	1.35^{ACa}	0.85^{DBcd}	1.95^{BDabc}	0.93^{ADbe}	1.61^{BCde}
	A3.5	**2.64^{ABb}**	**2.65^{CDEa}**	**3.16^{ABab}**	**2.99^{ABCc}**	1.72^{ADEabc}
	A4	**2.53^{CDa}**	**2.79^{AB}**	**3.11^{CDa}**	**2.64^{DEF}**	**2.99^{ABC}**

The same capital letter shows statistical difference among the shades for the same material ($p < 0.001$).
The same lowercase letter shows statistical difference among the materials for the same shade ($p < 0.001$).
Bold numbers indicate mean values considered as unacceptable color mismatches ($\geq$2.00).

designed to provide answers to the color match between Class I and Class V composite restorations and the surrounding tooth through visual assessment of both single-shade and group shade resin composites. Given the significant impact of environmental conditions on dental restorations [24,25] and the experience or training of the observers [16–18] on the visual assessment, color evaluations were conducted on artificial acrylic mandibular right molars with different shades by three groups of observers (dentists, dental students and laypersons).

Single-shade resin composites are available in one universal shade and were developed to match all 16 VITA Classic shade tabs, thus providing a shade match for any tooth color represented by the VITA Classic shade guide [21]. Conversely, group shade resin composites are available in a limited range of shades, each designated for a recommended set of shade tabs [12]. The results of this study, obtained from the visual evaluation of the color matching indicate that the group shade composites exhibit a percentage of acceptability comparable to that of single shade resin composites across all observer categories and cavity configurations. Moreover, they even reached values close to 100 % of acceptability for lighter and less chromatic tooth shades (A1, A2 and A3) in both cavity configurations. Thus, the first tested hypothesis was rejected, indicating similar color shift towards the surrounding structures for both single and group shade resin composites.

As A3 is the shade option most frequently selected by dentists [23, 26] the visual assessments were carried out using artificial acrylic mandibular right molars featuring two shades with a higher chroma and two shades with a lower chroma than A3, along with shade A3 its self: A1, A2, A3, A3.5 and A4. The results of the present study showed significant mean visual rating differences only for A1 tooth shade with Class V restorations when compared to tooth shades A3.5 and A4, for both single and group shade materials and among all observer categories. Furthermore, in general, no statistically significant differences were found between A3.5 and A4 tooth shade for most of the resin composites. However, for the shades with low chroma, statistically significant visual rating differences were only found only in some comparisons among the tested resin composites.

In the current study, all mean ratings for class I restorations, reported by laypersons and students, were considered acceptable ($\leq$2), regardless of the resin composite and tooth shade. For the dentist observer category, class I restorations in tooth shade A3.5 received acceptable ratings for all resin composites except OMN and CHA and, only OMN presented mean ratings >2 for tooth shade A4. However, considering the mean rating values reported by all observers for class I restorations, no tooth shade or resin composite presented mean values in the range of unacceptable mismatches (>2), indicating acceptable results for all combinations tested. In contrast, for class V restorations color matches were acceptable only for tooth shades A1, A2 and A3 for the majority of the resin composites, regardless of the observers category.

The results obtained from the visual evaluation of color matching of class I and class V restorations were also presented as the mean frequency of visual assessment: considering the perceptibility and unacceptability reported by all observers, Figs. 2 and 3, respectively. The overall results demonstrate better shade matching for class I, with improved color matching results for lighter and less saturated shades for both cavity configurations. Thus, the second and third tested research hypothesis were accepted, indicating that the cavity configurations as well as the tooth shade can both influence color adjustment.

The results concerning the tooth shades are consistent with Barros et al. [20] and Iyer et al. [12], both studies concluded that surrounding shade can affect the color adjustment. However, the first study [20] evaluated the color adjustment potential though instrumental color assessments and was limited to low chroma tooth shades (A1, A2 and A3) and a single- shade resin composite (Vittra APS Unique). While, the second study [12] evaluated color matching of single, group and multi-shade resin composites through instrumental and visual assessments in both low and high chroma tooth shades (B1, B2, A2, C2 and D3), demonstrating a significant interaction between the tooth shades and the resin composites. In contrast, others authors [13], found no differences in visual ranking/scores for different tooth shades within the same resin composite groups or for different tooth shades for all composites. However, instrumental color measurements were performed using photographic analyses, and similar to Barros et al.[20], this study also assessed low chroma tooth shades.

A recent study [27] determined visual 50:50 % color difference acceptability thresholds (AT) for regions of dental color space with varying chroma: low, medium and high chroma. 50:50 % CIEDE2000 AT for dentistry were significantly different depending on the chromaticity of the samples, and the observers showed higher acceptability for more achromatic samples (low chroma value) than for more chromatic samples. This association between chroma levels and visual acceptability could justify the results concerning tooth shades in our study, where

more chromatic tooth shades (A3.5 and A4) received the highest mean visual ratings (>2) and displayed the highest percentage of visual unacceptability, particularly in class V restorations.

It has been reported that color difference of resin composites is shade-dependent, meaning the color matching of a single composite may vary according to the shade used [5]. The results from present study for class I and class V cavity configurations restored with the group shade resins (FIL (A3 and HAR (A3E)) showed the lowest visual ratings for A3 tooth shade (Tables 2 and 3) in comparison to the single shade composites, showing that group shade resin presented improved visual color matching than the single shade universal composite for this tooth color. This result, may be attributed to the use of A3 and A3E shades for both tested group shades resin composites [12]. In addition, this result is consistent with de Abreu et al. [13], who concluded, based on visual color assessments, that multi shade composites (A1-A3) achieved superior color matching compared to single shade (OMN) composites in class III restorations.

The experience of the observer is usually expressed through years of practice. However, testing of observers' color matching competence, irrespective of their experience, is recommended by ISO TR 28642 [28]. In the present study, the observers with superior color matching competence (dentist and dental students) were more rigorous in assessing visual color matching compared to laypersons. For instance, for class V restorations, 36 % of the mean ratings indicating color matching unacceptability (>2) were reported by laypersons, while the percentages were 40 % for dental students and 44 % for dentists. Consequently, the percentage of ratings indicating acceptability (≤2) was higher for laypersons compared to students and dentists. These findings are consistent with other studies that have evaluated color matching by different categories of observers [11,16,27].

The influence of cavity dimensions on the blending effect has been investigated, restorations that have smaller dimensions result in superior color matching with the tooth [3]. Additionally, the effect of cavity depth has been studied, revealing that deeper cavities and thicker restorations exhibit improved blending [22]. Beveling of the enamel margins also enhances blending by creating a gradual transition between the restoration and the tooth surface [21]. However, to the authors' knowledge, this is the first study to evaluate the influence of different cavity configurations on color matching of single and group shade resin composites. The findings demonstrate that color matching with different tooth shades is influenced by the cavity configuration. This result may be attributed to the anatomy characteristics of the buccal and occlusal surfaces. Surfaces that are more flat, such as the buccal, tend to reflect light in a specular manner, resulting in lighter and more luminous appearance, whereas irregular surfaces such as the occlusal tend to scatter light, creating a more favorable environment for shade matching [29,30].

The present study has several strengths, including a substantial number of observers (75) with varying levels of experience, training, and competence, categorized into three groups to provide a comprehensive perspective on color matching. All observers were tested for color discrimination using the Ishihara test, ensuring assessments by individuals with verified color discrimination abilities. Tooth-shaped specimens were fabricated from artificial teeth with standardized anatomy and shades. The cavity and restoration sizes, as well as depths/thicknesses, were kept consistent for both cavity configurations (class I and class V). The use of the stamp technique further standardized the restorations, eliminating potential bias related to anatomical variations.

However, the study also has inherent limitations typical of in vitro research. In the oral cavity, color matching can be influenced by multiple factors such as surrounding structures, including adjacent teeth and soft tissues, which were not present in this controlled environment. Additionally, natural teeth are polychromatic, whereas the artificial teeth used in this study are monochromatic. Other factors such as moisture, which plays a significant role in the optical properties of teeth, were not accounted for in this in vitro setting. Future clinical research is suggested to address these limitations and explore a broader array of tooth shades and cavity configurations for both anterior and posterior teeth.

5. Conclusions

Within the limitations of this study and based on visual assessment of restorations in artificial acrylic teeth, it can be concluded that class I resin composite restorations exhibited superior color matching compared to class V, with lighter and low chroma tooth shades demonstrating more favorable color adjustment. Both single shade and group shade resin composites showed comparable color matching behavior across both cavity configurations.

CRediT authorship contribution statement

Javier Ruiz-López: Writing – original draft, Resources, Investigation, Formal analysis. **Bibiana Gabardo Perez Mariano da Rocha:** Writing – original draft, Methodology, Investigation. **Nicole Adrielli Monteiro Zemolin:** Methodology, Investigation. **Camila Schneider Altenhofen:** Methodology, Investigation. **Letícia Brandao Durand:** Writing – review & editing, Supervision, Investigation, Conceptualization. **María M. Pérez:** Writing – review & editing, Supervision, Resources, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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