BPR MCS
Bulletin of Pioneering Researches of Medical and Clinical Science

Bulletin of Pioneering Researches of Medical and Clinical Science

Available online: https://bprmcs.com
2026 | Volume 6 | Issue 1 | Page: 40-47

Effect of Visual Impairment on Tooth Color Determination: A Clinical Comparison of Objective and Subjective Methods

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Abstract

Tooth shade determination plays a critical role in the overall success of dental restorations, yet visual impairment can negatively affect its accuracy. The objective of this cross-sectional clinical study was to evaluate the potential impact of visual impairment on shade selection by employing two distinct approaches: spectrophotometry and conventional shade guides. The study sample comprised 2796 maxillary and mandibular teeth. Shade selection was assessed subjectively using a shade guide (VITA Classic, VITA Zahnfabrik) and objectively with a spectrophotometer (VITA Easyshade® V, VITA Zahnfabrik, Bad Säckingen, Germany). For each tooth, three separate measurements were recorded, allowing a 15 min interval between consecutive samples. Comparisons of shade selection were made between observers exhibiting normal vision and those with myopia, astigmatism, or hyperopia. Findings revealed that myopic observers perceived the lower central incisors (2.63, $P < 0.05$), upper lateral incisors (2.42, $P < 0.05$), lower lateral incisors (2.34, $P < 0.05$), and lower canines (2.64, $P < 0.05$) with greater clarity. In addition, non-astigmatic subjects rated the lower second premolar as lighter compared with astigmatic subjects (−2.01, $P < 0.05$). Individuals with myopia tend to perceive teeth more clearly; however, no significant differences were observed among those with astigmatism or hyperopia.

Keywords: Colour measurement, Refractive errors, Spectrophotometer, Dental colourimetry, Visual alterations

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Received: 02 November 2025
Revised: 23 January 2026
Accepted: 26 January 2026

How to Cite This Article: Tanaka H, Sato Y, Mori K, Okabe R, Ito T. Effect of Visual Impairment on Tooth Color Determination: A Clinical Comparison of Objective and Subjective Methods. Bull Pioneer Res Med Clin Sci. 2026;6(1):40-7. https://doi.org/10.51847/j5Io1IKkPH

Introduction

One of the primary difficulties encountered in contemporary aesthetic dentistry is accurately replicating the form and shade of a restoration to match those of the unrestored contralateral tooth [1-3]. Human color perception arises from the interplay of three fundamental factors: the characteristics of the illuminating light, the chemical composition of the object that governs its light absorption and reflection, and the physiological mechanisms of the human visual system [4].

Teeth possess several intrinsic attributes that modify their perceived color, including translucency, opalescence, fluorescence, and metamerism [3, 5-9]. Extrinsic factors can also alter tooth color perception, such as visual fatigue, the practitioner's age during shade assessment [10, 11], and the quality and intensity of the light source, which should ideally be ambient light encompassing the full spectrum of visible wavelengths [12, 13].

In routine dental practice, the predominant technique for shade determination remains visual comparison with shade guides, also known as subjective colorimetry [1]. Among these, the VITA Classic guide is among the most commonly used, grouping shades into distinct categories. Nevertheless, it fails to encompass the complete range of natural tooth shades [2, 14]. In response, the VITA 3D-Master guide was subsequently created, organized into five brightness-based groups that enhance shade selection by improving coverage and more even shade distribution [15].

Ongoing scientific progress has led to the introduction of advanced technologies designed to enhance the reliability of shade-taking, increase treatment predictability, and strengthen laboratory communication. These innovations help mitigate the limitations of subjective methods, although integrating both subjective and objective techniques remains a viable option [1, 3, 16]. Among the various color-measuring devices available, the spectrophotometer—classified as objective colorimetry—provides the highest level of accuracy [17]. It determines tooth color by quantifying the quantity of light reflected from the tooth surface [18]. Structurally, the spectrophotometer incorporates a light-scattering component, an optical system, and a detector that converts reflected light into electronic signals, ultimately yielding usable color data for the clinician [19]. Despite its higher cost and specialized training requirements, this method delivers notable benefits, including shorter chair time for patients and greater objectivity in shade evaluation [17, 20, 21].

Refractive errors encompass myopia, hyperopia, and astigmatism. Myopia is defined by impaired focus on distant objects, whereas nearby objects are sharply focused on the retina without requiring accommodative effort [22]. In hyperopia, near objects appear unfocused when the eye is in a relaxed state; prolonged near work or dim lighting may additionally provoke headaches, diplopia, or ocular redness [23]. Astigmatism causes objects to appear elongated or warped. Individuals free from refractive errors are termed emmetropic [22, 23].

The effects of visual impairments on subjective and objective colorimetry in dentistry have been investigated in existing research, yet findings remain inconsistent [9, 13-15, 24, 25]. A study by Khosla *et al*. examined the role of vision defects in color selection and found no statistically significant differences between visually impaired groups and those with normal vision when using subjective shade guides [25]. However, investigations that simultaneously evaluated vision status alongside subjective shade matching (via guides) and objective measurements (using spectrophotometers, digital photography, or even smartphone applications) have consistently shown that subjective methods exhibit lower reliability and reproducibility. These approaches are also heavily influenced by external conditions such as illumination type and observer fatigue [26]. Moreover, certain systemic conditions that impair vision, including type 1 diabetes, have been shown to adversely affect the perception of dental shades [27].

In a study published by Pohlen *et al*. [27], the researchers examined how varying degrees of impaired color vision affect the selection of dental shades. Their outcomes showed that people with more severe color vision deficits typically achieved lower accuracy when matching shades with conventional dental guides, resulting in unfavorable outcomes [28]. Even so, the body of scientific publications offers surprisingly little data on refractive vision problems such as myopia, astigmatism, and hyperopia. For this reason, the present study was planned to help bridge this noticeable shortfall in existing knowledge.

As a result, the main purpose of this investigation was to examine the way visual impairment affects dental color matching when performed with shade guides and spectrophotometric devices. The null hypothesis for the clinical trial asserted that visual impairment does not affect dental colorimetry results obtained with shade guides and spectrophotometry, specifically on brightness or luminosity measurements.

Materials and Methods

Study design

Approval for this research was granted by the Valladolid Health Area Drug Research Ethics Committee under protocol number PI 20-1911-2020. The entire protocol adhered strictly to the ethical standards outlined in the Declaration of Helsinki for biomedical research involving human participants. A cross-sectional clinical trial was conducted in which shade measurements were taken from 2768 natural teeth belonging to 294 patients. Before participation, every individual was fully briefed on the study's goals and provided voluntary, written informed consent. Objective shade recordings were obtained with the VITA Easyshade® V spectrophotometer (VITA Zahnfabrik, Germany), while subjective assessments relied on the VITA Classical A1-D4 shade guides (VITA Zahnfabrik, Germany). The decision regarding sample size was based on findings from several previously reported studies [29-32] that used considerably fewer participants.

Patient selection

A total of 294 Spanish Caucasian individuals participated, with the average age of male subjects being 36.5 years; the group comprised 154 females and 140 males. Eligible participants were required to possess young permanent teeth and, where possible, display the following unrestored natural teeth: maxillary and mandibular central incisors, lateral incisors, canines, first bicuspids, first premolars, and second bicuspids on both left and right sides. Any teeth that featured fillings, veneers, crowns, root canal treatment, palatal orthodontic retainers, prior bleaching, or other conditions interfering with accurate color evaluation were ruled out.

All shade assessments were carried out by final-year dental students enrolled at the European University of Valladolid. Among these students, 171 were female, and 123 were male. Their ages spanned from 21 to 51 years, yielding a mean age of 24.48 years. Before beginning the color measurements, each student completed a comprehensive eye examination to detect refractive errors and received instruction in dental color science and colorimetry techniques. Students diagnosed with dyschromatopsia were removed from the observer pool after the Ishihara test **(Figure 1)**. Of all observers, 154 used spectacles for correction, and 140 did not. The most prevalent refractive error was myopia, followed by astigmatism and then hyperopia **(Table 1)**. Within the complete cohort, 91 out of the 294 observers needed no visual correction. Furthermore, any students exhibiting serious color perception disorders—including full color blindness, significant vision loss in both eyes, systemic diseases such as type-1 diabetes involving the eyes, or progressive ocular conditions such as cataract development—were disqualified from the study.

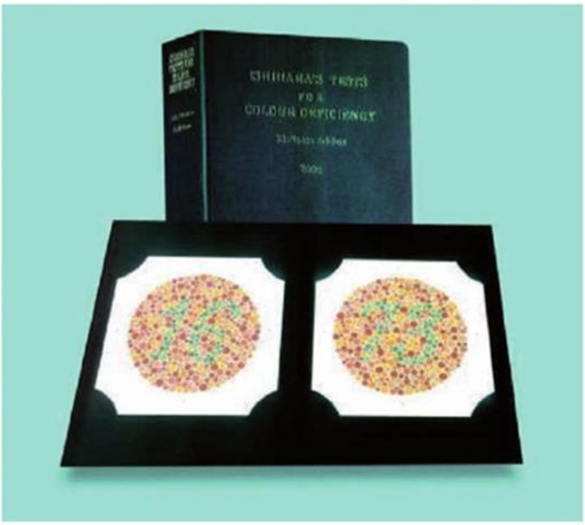

Figure 1. Ishihara test.

Table 1. Distribution of participants according to gender, percentage of lens wear, and vision impairment.

Category	Subgroup	%	N
Gender	Male	41.8	123
	Female	58.2	171
Visual Conditions	Myopia	48.8	139
	Astigmatism	29.6	86
	Hyperopia	7.0	20
Use of Corrective Lenses	Wearing lenses	53.8	154
	Not wearing lenses	46.2	140

Analysis of the sample characteristics revealed that 58.2% of participants were women, while 41.8% were men. Myopia emerged as the most common visual problem, present in 48.8% of cases, followed by astigmatism (29.6%) and hyperopia (7%) **(Table 1)**.

Measurement process

Color evaluations took place inside a compact 8 m² testing booth that received illumination from both artificial sources and natural daylight entering through two windows, each 1 meter wide by 1.5 meters tall. A photometer was used within the booth to pinpoint zones with illumination near 5500 degrees Kelvin, ensuring optimal lighting conditions for reliable color assessment. The specific instrument used was the Sekonic Dual Spot L-778 (Sekonic Co., Tokyo, Japan). In the subjective shade-matching procedure, the VITA Classical guide was positioned approximately 25–30 mm away from the patient's tooth. The tab that provided the closest overall color match was identified first, followed by selecting the appropriate saturation (degree of grey content) and value (degree of black or white content) from the matching group of strips. For objective readings with the VITA Easyshade spectrophotometer, the tooth surface was kept moist, the probe tip was aligned perpendicular to the tooth's facial surface, and the device was held completely still until the full color analysis was completed **(Figure 2)**.

Figure 2. Objective and subjective color measurements.

Both subjective and objective colorimetry involved three separate readings per tooth for each observer, separated by a 15-minute rest interval. Only those values that matched consistently across all three repetitions were entered into the data collection form.

To facilitate analysis based on brightness levels from the classical VITA guide, the shades were converted to an ordinal ranking system arranged as follows: B1 (15), A1 (14), A2 (13), D2 (12), B2 (11), C1 (10), C2 (9), D4 (8), D3 (7), A3 (6), B3 (5), A3.5 (4), B4 (3), C3 (2), A4 (1).

Statistical analysis

Study data were initially recorded in an Excel spreadsheet (Microsoft, Redmond, WA, USA) before undergoing statistical processing with SPSS version 29.0 (IBM, Armonk, NY, USA). Descriptive statistics such as arithmetic means, variance, and standard deviation were calculated, along with the Chi-square test for deriving inferential results.

Given that the variables under examination were dichotomous or categorical, the Chi-square test ($P < 0.05$) was used to explore associations between accurate shade selection and subject-specific factors, including myopia or astigmatism. Agreement between visual judgments made by observers and spectrophotometer outputs was quantified using Pearson's correlation coefficient ($P < 0.01$).

Results and Discussion

Table 2 summarises the correlations observed between brightness measurements and spectrophotometer readings, and between dental guide selections and corrective lens wearers. Within the lens-wearing group, the strongest correlation was observed at the upper central incisor (0.65), whereas the weakest was at the lower second premolar (0.31), achieving statistical significance at $P < 0.01$. In the group without lenses, the peak correlation was recorded for the upper canine (0.60) and the lowest for the upper second premolar (0.37), also at $P < 0.01$. Correlation strengths remained broadly comparable across both groups, consistently higher in anterior teeth and lower in posterior or molar regions.

Table 2. Correlations of lens and non-lens wearers per tooth measured with a spectrophotometer and dental guides of brightness.

Tooth category	Participants without lenses (n = 140)	Participants using lenses (n = 154)
Maxillary central incisor	0.47 *	0.65 *
Mandibular central incisor	0.52 *	0.47 *
Maxillary lateral incisor	0.44 *	0.43 *
Mandibular lateral incisor	0.54 *	0.50 *
Maxillary canine	0.60 *	0.55 *
Mandibular canine	0.55 *	0.54 *
First maxillary premolar	0.46 *	0.37 *
First mandibular premolar	0.47 *	0.59 *
Second maxillary premolar	0.37 *	0.36 *
Second mandibular premolar	0.44 *	0.31 *

* Significant $P < 0.01$.

Additional analysis explored potential variations in average perceived clarity (based on the classical guide) between lens users and non-users. The outcomes are presented in **Table 3**, which compares the mean clarity differences between the two groups. The most pronounced differences emerged in the anterior teeth, with the upper lateral incisor displaying the largest gap (1.71, $P > 0.05$) and the lower second premolar the smallest (−0.46, $P > 0.05$). Despite these observations, none of the differences proved statistically significant.

Table 3. Mean difference between lens wear (n = 154) and no lens wear (n = 140).

Tooth category	Lens use	Significance (P-value)	Student's t-value	Mean
Maxillary central incisor	Yes	P > 0.05	1.41	12.35
	No			11.85
Mandibular central incisor	Yes	P > 0.05	1.48	10.96
	No			10.32
Maxillary lateral incisor	Yes	P > 0.05	1.71	11.46
	No			10.84
Mandibular lateral incisor	Yes	P > 0.05	0.90	9.90
	No			9.49
Maxillary canine	Yes	P > 0.05	1.57	7.09
	No			6.65
Mandibular canine	Yes	P > 0.05	1.60	6.36
	No			5.69
First maxillary premolar	Yes	P > 0.05	0.68	8.57
	No			8.28
First mandibular premolar	Yes	P > 0.05	0.38	6.80
	No			6.65
Second maxillary premolar	Yes	P > 0.05	−0.49	8.43
	No			8.65
Second mandibular premolar	Yes	P > 0.05	−0.46	6.68
	No			6.87

Significant $P < 0.05$.

The research further examined variations in mean perceived clarity (classical guide) between participants with myopia and those without. **Table 4** presents the mean differences and their corresponding significance levels. Distinct differences were evident in this cohort. Myopic observers recorded significantly higher perceived clarity scores for the lower central incisors (2.63; $P < 0.05$), upper lateral incisors (2.42; $P < 0.05$), lower lateral incisors (2.34; $P < 0.05$), and lower canines (2.64; $P < 0.05$).

Table 4. Difference in averages for myopes and non-myopes.

Tooth category	Myopia status	Significance (P-value)	Student's t-value	Mean
Maxillary central incisor	Yes	P > 0.05	1.88	12.48
	No			11.82
Mandibular central incisor	Yes	P < 0.05 *	2.63	11.23
	No			10.11
Maxillary lateral incisor	Yes	P < 0.05 *	2.42	11.66
	No			10.81
Mandibular lateral incisor	Yes	P < 0.05 *	2.34	10.30
	No			9.25
Maxillary canine	Yes	P > 0.05	1.77	7.34
	No			6.59
Mandibular canine	Yes	P < 0.05 *	2.64	6.62
	No			5.51
First maxillary premolar	Yes	P > 0.05	1.18	8.73
	No			8.20
First mandibular premolar	Yes	P > 0.05	0.60	6.81
	No			6.57
Second maxillary premolar	Yes	P > 0.05	−0.31	8.52
	No			8.66
	Yes	P > 0.05	−0.32	6.68

Second mandibular premolar	No			6.82

* Significant P < 0.05.

The research further examined potential differences in mean perceived clarity (using the classic guide) between students with astigmatism and those without astigmatism. **Table 5** displays the mean values and their corresponding significance levels. Only one statistically significant difference emerged, concerning the lower second premolar. Non-astigmatic participants rated this tooth as lighter than astigmatic participants did (−2.01, P < 0.05).

Table 5. Mean differences for astigmatism and non-astigmatism in students.

Tooth category	Astigmatism status	Significance (P-value)	Student's t-value	Mean
Maxillary central incisor	Yes	P > 0.05	0.20	12.14
	No			12.06
Mandibular central incisor	Yes	P > 0.05	0.09	10.68
	No			10.64
Maxillary lateral incisor	Yes	P > 0.05	0.45	11.27
	No			11.08
Mandibular lateral incisor	Yes	P > 0.05	−0.06	9.67
	No			9.70
Maxillary canine	Yes	P > 0.05	0.31	6.99
	No			6.84
Mandibular canine	Yes	P > 0.05	0.44	6.16
	No			5.96
First maxillary premolar	Yes	P > 0.05	−0.63	8.21
	No			8.53
First mandibular premolar	Yes	P > 0.05	−0.92	6.40
	No			6.81
Second maxillary premolar	Yes	P > 0.05	−0.82	8.25
	No			8.65
Second mandibular premolar	Yes	P < 0.05 *	−2.01	6.09
	No			7.00

* Significant P < 0.05.

An evaluation was also conducted to determine whether the mean perceived clarity (classic guide) differed between hyperopic and non-hyperopic individuals. The outcomes are shown in **Table 6**. No statistically significant differences were detected between the two groups; however, a noticeable trend emerged, with larger differences in the posterior regions than in the anterior regions, except for the first lower premolar.

Table 6. Differences between hyperopic and non-hyperopic averages.

Tooth category	Hypermetropia status	Significance (P-value)	Student's t-value	Mean
Maxillary central incisor	Yes	P > 0.05	0.86	12.65
	No			12.06
Mandibular central incisor	Yes	P > 0.05	−0.33	10.40
	No			10.67
Maxillary lateral incisor	Yes	P > 0.05	0.78	11.68
	No			11.13
Mandibular lateral incisor	Yes	P > 0.05	0.30	9.95
	No			9.69
Maxillary canine	Yes	P > 0.05	0.72	7.45
	No			6.86
Mandibular canine	Yes	P > 0.05	0.17	6.15
	No			6.01
First maxillary premolar	Yes	P > 0.05	1.26	9.42
	No			8.35
First mandibular premolar	Yes	P > 0.05	0.22	6.84
	No			6.67
Second maxillary premolar	Yes	P > 0.05	1.31	9.55
	No			8.46
Second mandibular premolar	Yes	P > 0.05	0.95	7.42

Significant P < 0.05.

The present investigation assessed the impact of various vision defects on dental color determination, treating spectrophotometer-based objective measurements as the reference standard. Numerous earlier publications have compared objective and subjective methods for shade selection [33-37], while several others specifically recruited dental students as participants [38-40]. The current work revealed frequent inaccuracies during subjective shade matching with dental guides, a finding supported by multiple authors who report that subjective techniques produce more errors than objective approaches [33-36]. In contrast, Parameswaran *et al.* recommend integrating visual assessment with spectrophotometer readings as the optimal strategy for shade selection [37].

This study employed the classical VITA guide under properly controlled illumination conditions, as outlined earlier. Adequate lighting is recognized as a critical factor for reliable shade selection with dental guides, according to the findings of Śmielecka and Dorocka-Bobkowska [41], who emphasized that lighting quality directly affects the consistency and repeatability of results.

All color assessments were performed by final-year dental students. Participants exhibiting color vision deficiencies were excluded from the observer group. One previous investigation even suggested that the clinician's personality traits can influence shade acquisition outcomes [42]. Pohlen *et al.* [27] reported statistically significant results, confirming that individuals with impaired color vision performed worse when selecting shades.

The current study did not specifically evaluate whether dedicated training in dental colorimetry improves subjective shade accuracy. Nevertheless, several researchers maintain that targeted training yields better outcomes in tooth shade determination [32, 40, 41, 43]. Jain *et al*. [40] studied shade selection among dental undergraduates at all levels and found that accuracy increased as students progressed to more advanced academic years. These observations differ from the conclusions drawn by Pohlen *et al*. [38] and Udiljak *et al*. [44], who noted that a single one-hour lecture on shade taking produced no meaningful improvement in subjective performance, and that greater clinical experience does not necessarily translate into more accurate shade selection.

Brightness (value) rankings in the VITA classical guide were assigned following the methodology described by Gómez-Polo *et al*. [45]. Their work indicated that the value dimension of color shows the highest level of agreement between human observers and spectrophotometer measurements. **Table 2** demonstrates stronger correlations between dental guide selections and spectrophotometer readings for anterior teeth compared to posterior teeth in the lens-wearing group. In the non-lens group, correlations were generally similar but overall lower. These patterns suggest that the presence or absence of corrective lenses has little effect on the accuracy of tooth color measurement. Samra *et al*. [32] explored the role of prior training in shade selection with dental guides. They concluded that students with normal vision, myopia, or hyperopia all showed improved color perception following education and practical training. In the present study, all observers received this training beforehand, yet the most pronounced differences were observed between the myopic and non-myopic groups in **Table 4**. Since myopia is a highly prevalent refractive error, affected individuals may also present with additional defects, such as astigmatism. Differences linked to other conditions, including hyperopia, were smaller, likely due to the limited sample size and lower prevalence of that particular defect.

Because myopia, hyperopia, and astigmatism constitute refractive errors that primarily influence visual acuity, the current findings indicate that myopia exerts the strongest negative effect on tooth color determination, as evidenced in **Table 4**. In theory, myopia mainly impairs distance vision and, therefore, might not be expected to produce the largest statistical differences when compared with hyperopia or astigmatism. Given that the observer population consisted of young adults, accommodation-related distance-vision issues were unlikely. The observed statistical significance may stem from the fact that only the luminance (brightness) parameter was analyzed, whereas hue and saturation were not. Consequently, the clinical relevance of this difference requires further evaluation in subsequent studies.

The present research had several limitations, notably its reliance on supplementary instruments such as spectrophotometers, colorimeters, and scanners. In addition, the participant sample could be broadened in future work to encompass individuals across a wider range of ages and levels of professional experience. Prior literature, however, indicates that clinical experience alone does not ensure superior shade selection with dental guides. These aspects will be addressed in upcoming investigations to better identify potential sources of variability.

Conclusion

Corrective lenses do not affect observers' accuracy in selecting tooth color.

Among the various refractive errors examined, myopic individuals perceive the anterior teeth more clearly than non-myopic participants. In contrast, neither astigmatic nor hyperopic observers showed any statistically significant differences in their color perception.

Acknowledgments: None

Conflict of interest: None

Financial support: None

Ethics statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee, reference: PI 20-1911 NO HCUV Ethics Committee of the Clinical University Hospital of Valladolid (27 August 2023).

Informed consent was obtained from all subjects involved in this study.

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