Received: 18 June 2018 | Revised: 25 October 2018 | Accepted: 5 December 2018

DOI: 10.1111/jerd.12452

Check for updates

WILEY

RESEARCH ARTICLE

Laboratory and clinical reliability of two spectrophotometers

Anna-Luisa Klotz DMD | Yasamin Habibi DMD | Nicoleta Corcodel DMD | Peter Rammelsberg DMD | Alexander J. Hassel DMD | Andreas Zenthöfer DMD

Department of Prosthodontics, Dental School, University of Heidelberg, Heidelberg, Germany

Correspondence
Anna-Luisa Klotz, DMD, Department of Prosthodontics, Dental School, University of Heidelberg, Im Neuenheimer Feld 400, Heidelberg 69120, Germany.
Email: anna-luisa.klotz@med.uni-heidelberg.de

Abstract

Objective: To evaluate the repeatability, interexaminer, and interdevice reliability of two clinically applicable spectrophotometers under laboratory and clinical conditions.

Material and Methods: For the in vitro part of the study, measurements were performed by the use of Vita Easyshade Advance 4.0 (ES-A) and the Easyshade V (ES-V) at identical positions on different shade tabs (3D-Master; Vita Zahnfabrik, Bad Säckingen, Germany). To test repeatability, one shade tab was measured 50 times by one operator. To determine interrater and interdevice agreement, two operators used both devices to perform 10 measurements on five different shade tabs. Clinical interdevice and interexaminer reliability was checked with a positioning jig used (15 participants). Measurement accuracy of both devices was evaluated for the recommended color of shade tabs.

Results: Repeatability of results from both Easyshades was excellent for all color components (maximum deviation between measurements was ≤0.1 units). Interrater agreement was also perfect (intraclass correlation, ICC = 1.000). Interdevice agreement was lower, but still good (ICC ≥ 0.834). In the clinical environment, interrater and interdevice agreements were similar (ICC > 0.964 and ICC > 0.873). Accuracy was satisfactory for both devices, with both observers in full agreement for nearly 80% of ratings.

Conclusions: Both Easyshades produced reliable and accurate measurements and can therefore be recommended for clinical determination of tooth color.

Clinical Significance: The outcome of this study might help clinicians estimate the performance of a new digital shade determination device.

KEYWORDS

accuracy, Easyshade, *L**a**b**, reliability, spectrophotometer

1 | INTRODUCTION

In modern dentistry it is important to determine accurate tooth color for production of dental restorations, particularly for the anterior zone. Shade determinations are usually performed visually by use of shade guides.[1–3] This procedure is, however, affected by many variables related to the shade guide, the observer, and the surrounding environment.[2–6] With regard to the shade guide, the limited number of shade tabs and their range and distribution hinder selection of the correct color.[7] Studies have shown that shade tab colors in newer shade guides are more systematically arranged and more evenly spaced, which enables use of mixtures of two colors.[3] In addition to coverage errors, however, other inconsistencies in shade determination remain, for example, color vision of the observer and time taken to standardize illumination and surrounding colors.[7] In the last decade, electronic devices for determination of tooth color have been available for clinical use.[2] These devices can be divided into colorimeters and spectrophotometers on the basis of their measurement principles.[2] Colorimeters filter light using red, green, blue, and, where appropriate, neutral gray filters and measure tristimulus values.[8] Spectrophotometers, in contrast, measure the amount and spectral composition of the reflected light and convert these into tristimulus data.[2,9] Both types of device then provide

Anna-Luisa Klotz and Yasamin Habibi authors contributed equally.

 © 2018 Wiley Periodicals, Inc.

the colors measured in the color coordinates L^* (lightness), a^* (red-green), and b^* (blue-yellow), or L^*, C^* (chroma), and h° (hue).[10] If spectrophotometers and colorimeters contain an internal light source and can be used for contact measurements, they are largely unaffected by external light.[11,12]

The definition of L^*, a^*, and b^* follows the recommendations of the Commission Internationale de l'Eclairage (CIE; International Commission on Illumination) and enables three-dimensional description in the color space.[13] Use of the L^*C^*h° system entails cylindrical projection of the $L^*a^*b^*$ color space, and the two systems can be interconverted.[13] Previous studies have shown that the reliability and accuracy of spectrophotometers are superior to those of colorimeters.[2,14,15] However, measurements recorded with different devices can sometimes vary substantially,[8] so it is uncertain whether the "true color" is measured. Nevertheless, studies have shown that spectrophotometers are probably more reliable than visual shade determination.[9,14,16] Recent studies have found high repeatability, interrater reliability, and good accuracy for commonly used spectrophotometers.[17] In a comparison of several devices, however, it was determined that the Vita Easyshade Advance 4.0 (ES-A) was the most accurate[8], and it is one of the most frequently used devices in clinical routine and thematic studies. The ES-A has nevertheless now been replaced following the introduction of a successor model, the Easyshade V (ES-V). Very little information is available about the reliability and accuracy of the ES-V. To rank its performance, it is desirable to compare the new model with the previous, well-researched one. The previous model has also been assessed in comparison to a spectroradiometer and proved reliable; it can therefore be considered the gold standard against which new devices should be benchmarked.[17]

The purpose of this study was, therefore, to evaluate the repeatability, interexaminer, and interdevice reliability of the ES-V under laboratory and clinical conditions, and to compare the results with those from the ES-A. In addition, clinical accuracy was studied by means of operators' ratings on the shade tabs recommended by the devices. The null hypothesis stated that there would be no significant differences between the two devices regarding repeatability, all kinds of studied reliability, and accuracy both in vitro and in vivo.

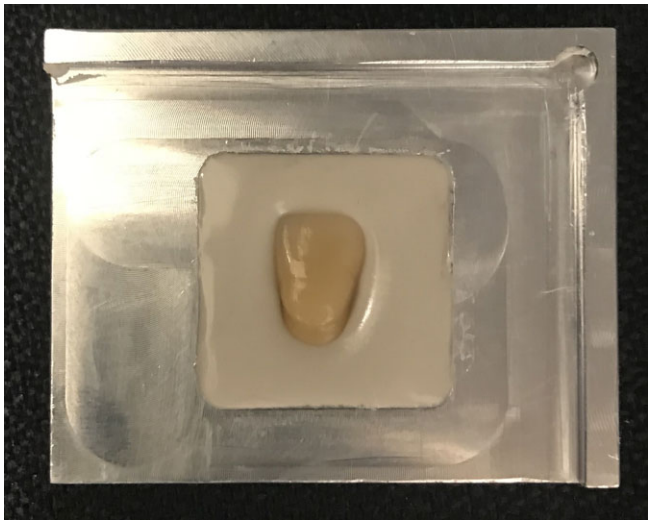


FIGURE 1 3D-Master shade tab embedded in standardized alumina holder

2 | MATERIALS AND METHODS

All measurements in this study were performed by two dentists from the Department of Prosthodontics (hereafter called operators) who had not previously used digital devices to determine tooth shade. The operators received instruction in handling the devices from an associate professor (AZ) before the start of the study. In accordance with CIE recommendations, color coordinates for all measurements were recorded as L^* (lightness), a^* (red-green), and b^* (blue-yellow).

2.1 | Laboratory study

2.1.1 | Repeatability

To investigate the repeatability of the ES-A and ES-V devices, one operator (YH) used both devices to measure the same spot (the middle third of the tooth body) of 3D-Master shade tab 3 M2 (Vita Zahnfabrik, Bad Säckingen, Germany), 50 times, by use of a positioning jig (Luxtemp A3; DMG, Hamburg, Germany). After each measurement the probe tip had to be completely removed from the shade tab and then repositioned. The shade tab was embedded by use of a gray vinylpolysiloxane impression material (Compact Putty; Detax, Ettlingen, Germany) in a standardized alumina specimen holder (Figure 1). Before the 50 measurements, the devices were calibrated once by using each of the corresponding white reflectance ports.

2.1.2 | Interrater and interdevice agreement

To evaluate interrater and interdevice agreement, each operator (YH/ALK) used both devices to perform 10 measurements on the same spot of 3D-Master shade tabs 1 M1, 2 M2, 3 M2, 4 M2, and 5 M3 (Vita Zahnfabrik, Bad Säckingen, Germany). As before, a jig was used and shade tabs were embedded in gray vinylpolysiloxane. Each device was calibrated before each shade tab measurement round and for each operator.

2.2 | Clinical study

The clinical part of this study was approved by the local review board (140/2007). Fifteen participants were recruited by the Department of Prosthodontics. Participants had to be at least 18 years old, have acceptable oral hygiene, and were required to have natural and unrestored teeth 12, 11, 21, and 22. All participants received written and verbal information and signed an informed consent form before the start of the study. The study population (n = 15) consisted of 6 women and 9 men. The mean age of the participants was 37 years (range 24 to 56).

A dentist (ALK/YH) took an impression of each participant's maxilla by use of an alginate material (Image; Dux Dental, Utrecht, Netherlands). Casts were then fabricated by use of class IV gypsum (Fujirock Polar White; GC Europe, Leuven, Belgium). These casts were used to manufacture individual splints (Erkoflex, 120 mm x 4 mm; Erkodent Erich Kopp GmbH, Pfalzgrafenweiler, Germany) with a 5-mm notch for the probe tip of the spectrophotometers. The splints were manufactured to guarantee readings at the same spot each time (Figure 2). After professional tooth cleaning (Zircate Prophy Paste; Dentsply DeTrey, Konstanz, Germany), the test teeth were rinsed with water

spray and dried with gauze. The ES-A and ES-V were calibrated for each participant and each operator using their respective white reflectance ports. Both operators measured the middle third of the test teeth by use of the positioning splint. The operators measured the test teeth 12, 11, 21, and 22 by use of the ES-A and ES-V (order of teeth, operator, and device were random for each participant). The readings (n = 57) for each device for each operator were used to calculate interexaminer and interdevice agreement. The clinical setting is shown in Figure 2. The shade tab colors recommended by the devices for each measurement were also visually matched with the natural teeth. Each tooth was independently rated by the operators ALK and YH by the use of 3D-Master shade tabs. The rating scale ranged from 1 to 3, where 1 = excellent match, 2 = acceptable match, and 3 = poor match. A 6500-K daylight lamp was used for visual evaluation (Dialite Color; System Eickhorst, Hamburg, Germany). All color determinations (visual and spectrophotometric) were performed chairside at the polyclinic of the Department of Prosthodontics, Heidelberg. External environmental light was not excluded.

2.3 | Statistical evaluation

All statistical analysis was performed by use of SPSS 19.0 (IBM Corporation, New York, USA). Local statistical significance was set at $P < .05$.

To evaluate repeatability, maximum differences between the color coordinates L^*, a^*, and b^* over the 50 measurements were calculated. Intraclass correlation coefficients (ICC) were calculated to analyze laboratory and clinical reliability (interrater/interdevice agreement). ICC analysis detects how strongly independent measurements, for example, those generated by use of different devices or operators, correlate with each other. In terms of persuasiveness, the lower border of the 95% confidence interval of the ICC was presented for both laboratory and clinical reliability. To assess the accuracy of electronic color measurements obtained by use of the devices, descriptive statistics (means/SD) were used to analyze the clinical ratings obtained by the two observers for the shade tabs recommended for the ES-A and ES-V. The ES-A and ES-V ratings were also compared by use of t-tests. The percentage of ratings for which the observers were in full agreement was evaluated by use of frequencies.

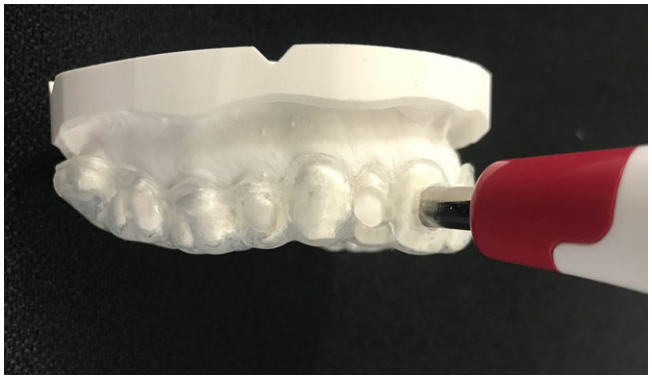


FIGURE 2 Use of a repositioning splint to obtain clinical readings

TABLE 1 Repeatability of ES-A and ES-V results for the single color coordinates L^*, a^*, and b^* (n = 50)

		ES-A	ES-V
Repeatability	L^*	0.1	0.1
	a^*	0.0	0.0
	b^*	0.0	0.0

Note: The maximum deviations of the color coordinates are reported.

3 | RESULTS

Repeatability of measurements was excellent for the color coordinates L^*, a^*, and b^*, for all color components, and for both Easyshades (Table 1). The absolute color coordinates L^*, a^*, and b^* measured by the ES-A and ES-V differed slightly but significantly, with the greatest deviation (1 unit) in L^* (Table 2).

Laboratory interrater agreement for the ES-A was perfect for all color coordinates (ICC = 1.000). The same was true for interrater reliability of measurements obtained by use of the ES-V (ICC = 1.000). Interdevice agreement was slightly lower but still good for L^* (ICC = 0.995), a^* (ICC = 0.834), and b^* (ICC = 0.992). Detailed results are listed in Table 3.

Overall, the reliability of both the ES-A and ES-V devices was confirmed by the clinical part of the study (Table 4). Interrater reliability was good but slightly lower than for the in-vitro trial (ICC ≥ 0.964). Interdevice reliability was also slightly lower in the clinical part of the study than in the in vitro part, although reliability for the color coordinate a^* was higher in the clinical part of the study than in the in vitro part (ICC = 0.873). Detailed correlations are listed in Table 4.

Mean (SD) ratings for the shade tabs recommended by the ES-A were 1.5 (0.6) and 1.6 (0.6). Ratings for the ES-V were equally good ($P > .05$). Both operators (ALK/YH) were in full agreement on the ratings in approximately 80% of cases. Agreement was the same for both devices ($P = .970$) (Table 5).

TABLE 2 Mean absolute color coordinates L^*, a^*, and b^* produced by ES-A and ES-V (n = 100)

	ES-A, mean (SD)	ES-V, mean (SD)	P value
L^*	76.5 (0.1)	77.4 (0.0)	**<.001**
a^*	2.2 (0.1)	2.0 (0.0)	**<.001**
b^*	22.9 (0.1)	23.3 (0.0)	**<.001**

Note: Significant P values are printed in bold.

TABLE 3 Intraclass correlation coefficients (ICC) for in-vitro interrater and interdevice agreement (n = 50)

		ES-A	ES-V
Interrater	L^*	1.000	1.000
	a^*	1.000	1.000
	b^*	1.000	1.000
Interdevice	L^*	0.995	
	a^*	0.834	
	b^*	0.992	

The lower border of the 95% confidence interval is reported; P value < .001.

TABLE 4 Intraclass correlation coefficients (ICC) for clinical interrater and interdevice agreement (n = 57)

		ES-A	ES-V
Interrater	L^*	0.964	0.973
	a^*	0.987	0.989
	b^*	0.993	0.983
Interdevice	L^*	0.928	
	a^*	0.873	
	b^*	0.970	

The lower border of the 95% confidence interval is reported; P value < .001.

4 | DISCUSSION

Excellent repeatability and interrater agreement (ICC = 1.000) were observed in the in vitro part of this study for the color coordinates L^*, a^*, and b^* measured by use of both the Easyshade Advance and the Easyshade V. Interdevice agreement was slightly lower but still good (ICC > 0.834). This favorable outcome is in agreement with results from other studies investigating repeatability of tooth color-matching devices.[8,16,18–23]

However, an in vitro study design cannot usually replicate clinical conditions; this limits the generalization and interpretation of our findings. In this context it should be remembered that ceramic specimens (shade tabs), which have optical properties different from those of natural teeth, were used for the laboratory part of this study. Nevertheless, the results from the laboratory part of this study were confirmed by those from the clinical part, in which good interrater (ICC > 0.964) and interdevice (ICC > 0.873) agreement were also observed. With regard to reliability of the ES-A, our results are in agreement with those of previous similar studies.[8,17,24,25]

Another important requirement for clinical shade measurements is device accuracy (identification of accurate color for fabrication of restorations). Previous studies have reported conflicting results. Some studies indicate that spectrophotometers determine tooth color more accurately than other digital devices, for example colorimeters, and that they probably produce more accurate results than visual determination of color.[2,9,14] With regard to comparison of visual and digital shade determination, however, other studies have not confirmed this.[18,26] Because digital devices are expensive, and because the plane surface of measurement probes is prone to edge loss, visual shade determination is still common in clinical practice.[2,3,7] Because a visual check of the color recommended by the digital device can provide additional assurance, it was, therefore, also used in this study to evaluate accuracy. 3D-Master shade tabs were used for this visual check, because they have been shown to result in fewer coverage errors than other shade guides.[3] The shade tabs suggested by the ES-A and ES-V were also rated by two independent observers who were in agreement on their ratings in approximately 80% of cases; this is a strength of this study. Although the ratings of the recommended shade tabs did not differ significantly between the devices, they suggest a slightly more favorable performance for the ES-V. In this context, one should also consider the differences between the ES-A and the ES-V for the single absolute color coordinates L^*, a^*, b^*. These differences were, however, small, ranging between 0.2 (a^*) and 0.9 (L^*).

TABLE 5 Mean (SD) rating for clinical shade determinations (n = 57)

	ES-A	ES-V	P value
Ratings, mean (SD)			
Examiner 1	1.5 (0.6)	1.3 (0.5)	>.05
Examiner 2	1.6 (0.6)	1.4 (0.5)	
Total agreement of ratings (%)	79.0	79.0	>.970

Matches were rated from 1 to 3 (1 = excellent match, 2 = acceptable match, 3 = poor match).
The values given are the means of the two examiners' ratings; t-tests on differences between the two devices.

The most significant criterion for the success of shade determination is acceptance of the selected color by both dentist and patient. The ratings given by the two observers indicate that the recommendations of both devices are acceptable to perfect. The results for the ES-A are in agreement with the results of a previous study.[17] It is not possible to compare the ES-V results with those from other studies because the applicable variables have not been investigated. However, it seems that the reliability and accuracy of the new ES-V are not significantly different from those of the ES-A.

It should be mentioned that spectrophotometric measurements were obtained without use of external standard illumination and that external light sources were not excluded. It has, however, been demonstrated that light conditions do not affect digital shade measurements when a spectrophotometer is used.[27] In addition, it should be noted that only two operators visually rated the shade tabs recommended by the devices. This might be a limitation of the estimation of the accuracy of the devices.

5 | CONCLUSIONS

Within the limitations of this study, both Easyshades (ES-A and ES-V) tested enable reliable measurements of color under both laboratory and clinical conditions. The visual ratings by the two independent observers reflect good agreement of the spectrophotometric measurements.

ACKNOWLEDGMENTS

The authors thank the participants in this study for their cooperation and Hazel Davies, copy editor, for English language revision. Anna-Luisa Klotz was supported by the GEROK program of the University of Heidelberg.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest in respect of authorship and/or publication of this article.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are included in this article.

ORCID

Anna-Luisa Klotz https://orcid.org/0000-0002-4551-7113

Andreas Zenthöfer https://orcid.org/0000-0002-4563-5646

REFERENCES

1. Van der Burgt TP, Ten Bosch JJ, Borsboom PC, Kortsmit WJ. A comparison of new and conventional methods for quantification of tooth color. *J Prosthet Dent*. 1990;63(2):155-162.
2. Chu SJ, Trushkowsky RD. Dental color matching instruments and systems: review of clinical and research aspects. *J Dent*. 2010;38:e2-e16.
3. Parameswaran V, Anilkumar S, Lylajam S, Rajesh C, Narayan V. Comparison of accuracies of an intraoral spectrophotometer and conventional visual method for shade matching using two shade guide systems. *J Indian Prosthodont Soc*. 2016;16(4):352-358.
4. Ahmad I. Three-dimensional shade analysis: perspectives of color--part II. *Pract Periodontics Aesthet Dent*. 2000;12(6):557-564.
5. Culpepper WD. A comparative study of shade-matching procedures. *J Prosthet Dent*. 1970;24(2):166-173.
6. Preston JD, Ward LC, Bobrick M. Light and lighting in the dental office. *Dent Clin North Am*. 1978;22(3):431-451.
7. Tsiliagkou A, Diamantopoulou S, Papazoglou E, Kakaboura A. Evaluation of reliability and validity of three dental color-matching devices. *Int J Esthet Dent*. 2016;11(1):110-124.
8. Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. *J Prosthet Dent*. 2009;101(3):193-199.
9. Paul S, Peter A, Pietrobon N, Hämmerle CH. Visual and spectrophotometric shade analysis of human teeth. *J Dent Res*. 2002;81(8):578-582.
10. Lee YK, Yu B, Lim HN. Lightness, chroma, and hue distributions of a shade guide as measured by a spectroradiometer. *J Prosthet Dent*. 2010;104(3):173-181.
11. Goldstein GR, Schmitt GW. Repeatability of a specially designed intraoral colorimeter. *J Prosthet Dent*. 1993;69(6):616-619.
12. Sarafianou A, Kamposiora P, Papavasiliou G, Goula H. Matching repeatability and interdevice agreement of 2 intraoral spectrophotometers. *J Prosthet Dent*. 2012;107(3):178-185.
13. International Commission on Illumination (CIE). *Colorimetry—technical report*, 3rd edn. Commission Internationale de L'Eclairage, Bureau Central de la CIE, Vienna, CIE Pub. No. 15; 2004.
14. Judeh A, Al-Wahadni A. A comparison between conventional visual and spectrophotometric methods for shade selection. *Quintessence Int*. 2009;40(9):e69-e79.
15. Paul SJ, Peter A, Rodoni L, Pietrobon N. Conventional visual vs spectrophotometric shade taking for porcelain-fused-to-metal crowns: a clinical comparison. *Int J Periodontics Restorative Dent*. 2004;24(3):222-231.
16. Hammad IA. Intrarater repeatability of shade selections with two shade guides. *J Prosthet Dent*. 2003;89(1):50-53.
17. Zenthöfer A, Cabrera T, Corcodel N, Rammelsberg P, Hassel AJ. Comparison of the Easyshade compact and advance in vitro and in vivo. *Clin Oral Investig*. 2014;18(5):1473-1479.
18. Hugo B, Witzel T, Klaiber B. Comparison of in vivo visual and computer-aided tooth shade determination. *Clin Oral Investig*. 2005;9(4):244-250.
19. Derdilopoulou FV, Zantner C, Neumann K, Kielbassa AM. Evaluation of visual and spectrophotometric shade analyses: a clinical comparison of 3758 teeth. *Int. J. Prosthodont*. 2007;20(4):414-416.
20. Lehmann KM, Devigus A, Igiel C, et al. Are dental color measuring devices CIE compliant? *Eur J Esthet Dent*. 2012;7(3):324-333.
21. Lagouvardos PE, Fougia AG, Diamantopoulou SA, Polyzois GL. Repeatability and interdevice reliability of two portable color selection devices in matching and measuring tooth color. *J Prosthet Dent*. 2009;101(1):40-45.
22. Llena C, Lozano E, Amengual J, Forner L. Reliability of two color selection devices in matching and measuring tooth color. *J Contemp Dent Pract*. 2011;12(1):19-23.
23. Tung FF, Goldstein GR, Jang S, Hittelman E. The repeatability of an intraoral dental colorimeter. *J Prosthet Dent*. 2002;88(6):585-590.
24. Zlatarić DK, Illeš D, Alajbeg IŽ, Žagar M. In vivo and in vitro evaluations of repeatability and accuracy of VITA Easyshade® Advance 4.0 dental shade-matching device. *Acta Stomatol Croat*. 2015;49(2):112-118.
25. Igiel C, Lehmann KM, Ghinea R, et al. Reliability of visual and instrumental color matching. *J Esthet Restor Dent*. 2017;29(5):303-308.
26. Ratzmann A, Treichel A, Langforth G, Gedrange T, Welk A. Experimental investigations into visual and electronic tooth color measurement. *Biomed Tech (Berl)*. 2011;56(2):115-122.
27. Witkowski S, Yajima ND, Wolkewitz M, Strub JR. Reliability of shade selection using an intraoral spectrophotometer. *Clin Oral Investig*. 2012;16(3):945-949.

How to cite this article: Klotz A-L, Habibi Y, Corcodel N, Rammelsberg P, Hassel AJ, Zenthöfer A. Laboratory and clinical reliability of two spectrophotometers. *J Esthet Restor Dent*. 2018;1–5. https://doi.org/10.1111/jerd.12452