The Influence of the Extent of Color-Vision Deficiency on Shade-Matching Ability

Uvod

Određivanje boje svakodnevni je zadatak u restaurativnoj i estetskoj dentalnoj medicini. Boja se određuje vizualnim ili instrumentalnim metodama. Iako postoje mnogi instrumenti za određivanje boje, najčešće se ipak primjenjuje vizualna metoda. Vizualna metoda određivanja boje obavlja se s pomoću ključa boja. Zubi ili restauracije uspoređuju se sa standardima boja, obično u obliku zuba izrađenih od keramičke, akrilata ili kompozita. Čimbenici koji utječu na određivanje boje važniji su za vizualnu metodu (1). Kogentalni poremećaji kolornoga vida utječu na vizualno određivanje boje (2, 3). Mogu se podijeliti na protanopiju (pretrećno smanjena osjetljivost za crvenu) i deutanopiju (pretrećno smanjena osjetljivost za zeleno). Hardy-Rand-Rittlerov (HRR) test (4) identificira poremećaje kolornoga vida u crveno-zelenom...
ed). Hardy-Rand-Rittler (HRR) test (4) identifies color-vision deficiency in red-green and blue-yellow deficiencies and can differentiate the extent of the deficiency in mild, medium, and strong, separately for red-green and blue-yellow color-vision deficiencies. To the present authors’ knowledge, the influence of the extent of the participant’s color-vision deficiency measured with the HRR test on the visual shade-matching ability on Toothguide Training Box (5) (TTB) or VITA 3D-Master shade guide has yet not been published. The purpose of this study was to evaluate the influence of the extent of color-vision deficiency on the visual shade-matching ability. The null hypothesis was that shade-matching score, $\Delta E^*_{ab}$, of participants with strong color-vision deficiencies would not differ from the score of participants with medium or mild color-vision deficiencies. The second null hypothesis was that shade-matching score, $\Delta E^*_{ab}$, of the control group would not differ from the score of all other groups with color-vision deficiencies.

**Materials and methods**

The work has been approved by the appropriate Ethics Committee related to the institution in which it was performed. Informed consent was obtained for experimentation with human subjects. The study was presented in a broader extent in a previous article by Pohlen et al (3). The color vision of the participants was evaluated monocularly using the HRR test. The test is a color-vision-deficiency test with 24 pseudoisochromatic plates in a book. The participants with a color-vision deficiency found on the HRR test were also tested on an HMC Anomaloskop MR (Rayleigh test, OCULUS Optikgerate) to confirm the diagnosis for red-green color-vision deficiency. Six groups were formed based on the results obtained on the HRR test: the control group (without color-vision deficiencies) ($N = 68$), the protan medium deficiency (PMED) group ($N = 5$), the protan strong deficiency (PSTD) group ($N = 5$), the deutan mild deficiency (DMD) group ($N = 5$), the deutan medium deficiency (DMED) group ($N = 5$) and the deutan strong deficiency (DSTD) group ($N = 8$). One color-vision-deficient participant (diagnosis based on the Rayleigh test on the anomaloscope) was excluded from the study, because no color-vision deficiencies were found on the HRR test.

The HRR test differentiates color vision into normal if correct responses were given to all six screening plates. Proton red-green deficiency (predominantly red axis affected) was classified if the total number of checks in the proton column was greater than in the deutan column. Deutan red-green deficiency (predominantly green axis affected) was classified if the total number of checks in the deutan column was greater than in the proton column. The extent of all the defects could be mild, medium, or strong. The last group of plates in which errors occur gave the extent of the participant’s color-vision deficiency (4).

Color-vision-deficient participants were also tested monocularly on an HMC Anomaloskop MR (Rayleigh test). An anomaloscope is an optical device designed to test color vision by matching a yellow light which may be varied in intensity with a combination of red and green lights of constant intensity.

**Istraživanje**

Istraživanje je odobrilo Etičko povjerenstvo institucije u kojoj je provedeno. Dobivena je suglasnost za istraživanje na ljudima. Istraživanje je opširnije predstavljeno u ranijem radu Pohlena i suradnika (3). Kolorni vid sudionika ocijenjen je monokularno primjenom HRR testa. Riječ je o testu poremećaja kolornoga vida s 24 pseudoizokromatske ploče u knjizi. Sudionici s poremećajem kolornoga vida koji su otkriveni HRR testom također su testirani na HMC anomaloskopu MR (Rayleigh test, OCULUS Optikgerate) kako bi potvrdili dijagnozu za crveno-zeleni daltonizam. Na temelju rezultata dobivenih HRR testom formirano je šest skupina: kontrolna skupina (bez poremećaja kolornoga vida) ($N = 68$), skupina sa srednjom protanopijom (PMED) ($N = 5$), skupina sa jakom protanopijom (PSTD) ($N = 5$), skupina sa blagom deuteranopijom (DMED) ($N = 5$), skupina sa srednjom deuteranopijom (DMED) ($N = 5$) i skupina sa jakom deutanopijom (DSTD) ($N = 8$). Jedan sudionik s poremećajem kolornoga vida (dijagnoza na temelju Rayleighova testa na anomaloskopu) isključen je iz istraživanja jer na HRR testu nisu utvrđeni nedostaci.

**HRR test diferencira kolorni vid na normalan ako su na svih šest ploča za provjeru dobiveni pravilni odgovori. Crveno-zelena protanopija (pogođena pretežno crvena os) prisutna je ako je ukupni broj pogodaka u protanskom stupcu bio veći negoli u deutanском. Crveno-zelena deutanopija (pretežno zelena os) prisutna je ako je ukupni broj pogodaka u deutanском stupcu bio veći negoli u protanskom. Stupanj svih poremećaja može biti blag, srednji ili jak. Posljednja skupina ploča u kojima se pojavljuju pogreške daje informaciju o poremećaju kolornoga vida kod sudionika (4).**

Sudionici s poremećajem kolornoga vida također su testirani monokularno na HMC anomaloskopu MR (Rayleigh test). Anomaloskop je optički uređaj za ispitivanje kolornoga vida i spaja žutu svjetlost različitog intenziteta sa kombinacijom crvene i zelene svjetlosti stalnog intenziteta.

Protokol s Toothguide Training Boxom (5) bio je jednak kao u istraživanju Pohlena i suradnika (3). Završno testiranje bilo je binokularno i sastojalo se od 15 zadataka za određivanje svjetline – zasićenja – tona. Ti rezultati za podudara-
The protocol on the Toothguide Training Box (5) was the same as in Pohlen et al (3). The final exam was tested binocularly and it consisted of 15 lightness–chroma–hue tasks. These shade-matching records were recorded on a laptop computer connected to the TTB and were subsequently processed. The color difference \( \Delta E_{ab} \) between the task tab and the selected tab was computed as follows:

\[
\Delta E_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}
\]

where \( \Delta L^* \), \( \Delta a^* \) and \( \Delta b^* \) denote the differences in the lightness, chroma and hue coordinates.

The \( L^* \), \( a^* \) and \( b^* \) values of all 26 shade tabs were obtained from measuring three completely new shade guides with a spectrophotometer VITA Easyshade Advance. Each tab was measured three times under color-corrected light (Dialite Color, Eickhorst, Germany) with a color-correlated temperature of 5500 K, 1500 lux and 92 CRI. The average of all nine measurements was taken as the \( L^* \), \( a^* \) and \( b^* \) values of each of the 26 shade tabs, as in Pohlen et al (6) (Table 1).

The shade-matching score, \( \Sigma \Delta E_{ab} \), for each participant was computed as the sum of the color differences \( \Delta E_{ab} \) between all the task tabs and the selected tabs. The lower \( \Sigma \Delta E_{ab} \) scores corresponded to better shade-matching results and vice versa. For a set of 15 exact matches this score would be zero. The means and the standard deviations for \( \Sigma \Delta E_{ab} \) were calculated.

An independent t-test was used for statistical analyses of the data and a comparison of means (\( \alpha = .05 \)) for protan groups and a one-way analysis of variance (ANOVA) and a post-hoc Bonferroni test (\( \alpha = .05 \)) for deutan groups. A one-

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**Table 1**

| Tablica 1. L*, a* and b* vrijednosti 26 uzoraka VITA 3D-Mastera mjerenih spektrofotometrom VITA Easyshade Advance |
|---------------------------------------------------------------|
| 1M1 | 85.06 | -1.91 | 11.43 |
| 1M2 | 85.46 | -1.86 | 17.59 |
| 2M1 | 81.24 | -0.76 | 12.96 |
| 2L1.5 | 80.97 | -1.48 | 16.21 |
| 2L2.5 | 81.22 | -1.26 | 21.61 |
| 2M2 | 81.58 | -0.38 | 18.33 |
| 2R1.5 | 80.94 | -0.06 | 15.34 |
| 2R2.5 | 80.68 | 0.09 | 21.2 |
| 2M3 | 81.21 | -0.44 | 24.04 |
| 3M1 | 75.77 | 0.26 | 13.94 |
| 3L1.5 | 74.29 | -0.1 | 17.88 |
| 3L2.5 | 75.26 | 0.52 | 23.77 |
| 3M2 | 76.79 | 1.07 | 21.07 |
| 3R1.5 | 75.01 | 1.17 | 16.06 |
| 3R2.5 | 75.21 | 1.63 | 22.84 |
| 3M3 | 76.69 | 1.38 | 26.32 |
| 4M1 | 70.62 | 1.57 | 15.34 |
| 4L1.5 | 71.2 | 1.27 | 19.64 |
| 4L2.5 | 70.91 | 2.1 | 25.7 |
| 4M2 | 71.57 | 2.48 | 21.97 |
| 4R1.5 | 71.22 | 2.83 | 18.93 |
| 4R2.5 | 70.99 | 3.46 | 24.7 |
| 4M3 | 71.47 | 3.24 | 29.3 |
| 5M1 | 65.99 | 2.52 | 16.87 |
| 5M2 | 67.16 | 4.2 | 24.56 |
| 5M3 | 68.06 | 5.54 | 33.3 |
way analysis of variance (ANOVA) and a post-hoc Bonferroni test \((\alpha = .05)\) was also used for comparison of all groups with the control group. The data analysis was performed using SPSS 22.0 for Windows (IBM).

**Results**

The PSTD group had a mean \(\Sigma \Delta E_{ab}^*\) of 63.38 ± 9.52, which means their selections were significantly worse in comparison to the PMED group \(\Sigma \Delta E_{ab}^* = 47.62 ± 9.88, p = 0.033\), Tables 2, 3, Figure 1). The selections of the control group were significantly better in comparison to all groups with color-vision deficiency (control – PMED, \(p = 0.031\); control – PSTD, \(p < 0.0001\); control – DMED, \(p < 0.0001\); control – DSTD, \(p < 0.0001\), except in comparison with DMID group \(p = 0.082\)). The comparisons between deutan groups were not significantly different (DMID – DMED, \(p = 0.352\); DMID – DSTD, \(p = 0.323\); DMED – DSTD, \(p = 1.000\)) (Tables 2–4). The \(\Sigma \Delta E_{ab}^*\) of the final exam for all groups are presented in Table 2.

**Rezultati**

Skupina s PSTD-om imala je prosječnu vrijednost za \(\Sigma \Delta E_{ab}^*\) od 63.38 ± 9.52, što znači da su njihovi odabi-ri bili značajno lošiji u usporedbi sa skupinom s PMED-om \(\Sigma \Delta E_{ab}^* = 47.62 ± 9.88, p = 0.033\), tablice 2. i 3., slika 1.). Odabiri kontrolne skupine bili su značajno bolji u usporedbi sa svim skupinama s poremećajem kolornoga vida (kontro- 

| n | Mean • Sredina | SD | t | df | p |
|---|---|---|---|---|---|
| 68 | 31.57 | 13.50 | | | |
| 5 | 47.62 | 9.88 | -2.569 | 8 | 0.033 |
| 5 | 63.38 | 9.52 | | | |
| 10 | 55.50 | 12.36 | | | |
| 5 | 47.92 | 11.93 | | | |
| 5 | 64.73 | 13.20 | 1.831 | 2 | 0.194 |
| 8 | 63.52 | 19.16 | | | |
| 18 | 59.52 | 16.76 | | | |

**Table 2** The results of the final exam on the TTB (\(\Sigma \Delta E_{ab}^*\) ± Std. Deviation) and test statistics (independent test for protan groups and a one-way analysis of variance (ANOVA) for deutan groups) for \(\Sigma \Delta E_{ab}^*\).

**Table 3** A one-way analysis of variance (ANOVA) for the control and protan groups. Jednosmjerana analiza varijance (ANOVA) za kontrolnu skupinu i skupinu s protanopijom.

**Table 4** A one-way analysis of variance (ANOVA) for the control and deutan groups. Jednosmjerana analiza varijance (ANOVA) za kontrolnu skupinu i skupinu s deuteranopijom.

**Figure 1** \(\Sigma \Delta E_{ab}^*\) for the final exam on the TTB.
**Slika 1.** \(\Sigma \Delta E_{ab}^*\) za završni test na TTB-u
Discussion

Approximately 8% of males have congenital color-vision deficiencies (7-9) in comparison with 0.5% females (7,9). Research on the effect of color-vision deficiencies on visual shade matching is rare, because congenital color-vision deficiencies are rare and are an "immensely well-kept secret" (10). Secondly, research is mostly not able to discriminate different color-vision deficiencies (i.e., anomalous trichromats - protanomalia, deuteronomalja, tritanomalja from dichromats (more severe deficiency - protanopia, deuteronopia, and tritanopia)). In addition, it is not able to evaluate the extent of the subject’s color-vision deficiency measured with the HRR test and differentiate it in mild, medium or strong deficiency, separately for protan and deutan red-green deficiency. Five color-vision deficiency groups were formed: the protan medium deficiency (PMED) group (N = 5), the protan strong deficiency (PSTD) group (N = 5), the deutan mild deficiency (DMID) group (N = 5), the deutan medium deficiency (DMED) group (N = 5) and the deutan strong deficiency (DSTD) group (N = 8). In addition, it was able to evaluate the influence of the extent of the subject’s color-vision deficiency on visual shade-matching ability (Tables 2-4). The results of the present study showed that PSTD group (ΣΔE*ab = 63,38 ± 9,52) was significantly worse in shade matching than PMED (ΣΔE*ab = 47,62 ± 9,88, p = 0,033). To the present authors' knowledge, the information that a greater protan color-vision deficiency extent has more influence on visual shade-matching ability on Toothguide Training Box (TTB) or VITA 3D-Master shade guide has yet not been published before. On the contrary to protan color-vision deficiency, there were not significant differences between deutan groups. This is the reason why the first null hypothesis can be rejected only for protan (predominantly red axis affected) color-vision deficiency.

The selections of the control group were significantly better in comparison to all groups with color-vision deficiency, except in comparison with mild deutan red-green color-vision deficiency group. The piece of information that color-vision deficiency affects shade matching is not new. It is in accordance with many previous studies, (2, 3, 12-15) and it is in fact "common sense". This is the reason why the second null hypothesis can be rejected for all protan and deutan color-vision deficiency groups, except for DMID group. Further investigations with more participants with different extents of color-vision deficiencies are needed in future.

Conclusion

The extent of the participant’s color-vision deficiency measured with the HRR test partially affects the visual shade-matching ability. 

Rasprava

Opširnije 8% muškaraca ima kongenitalni poremećaj kolornoga vida (7 – 9) u usporedbi s 0,5% žena (7, 9). Istraživanje utjecaja poremećaja kolornoga vida na vizualno određivanje boje rijetka su jer su kongenitalni poremećaji kolornoga vida rijetka (10). Isto tako, u istraživanjima se uglavnom ne mogu razlikovati različiti poremećaji kolornoga vida (tj. trikromatske anomalije – protanomalija, deuteronomalija, tritanomalija od drikromatskih anomalija – protanopija, deuteronopije i tritanopije). Uz to, ne mogu se procijeniti opseg subjektivnog nedostatka kolornoga vida mjeren HRR testom (tj. blagi, srednji, jak) i njegov utjecaj na sposobnost vizualnog određivanja boje. Razvrstavanje prema težini poremećaja kolornoga vida u crveno-zelenom spektru korisnije je za predviđanje sposobnosti razlikovanja boja (11). Spalding (11) je istaknuo da su ispitanici (liječnici) s umjerenim i teškim poremećajem kolornoga vida imali više poteškoća u usporedbi s rezultatima onih s blagim poremećajem. U ovom su istraživanju autor-studijski uspjeli procijeniti opseg poremećaja kolornoga vida mjenjenjem HRR testom i podijeliti ga na blagi, srednji ili jak protanopiju i deuteronopiju. Formirano je pet skupina sa poremećajem kolornoga vida: skupina sa srednjom protanopijom (PMED) (N = 5), skupina sa jakom protanopijom (PSTD) (N = 5), skupina sa blagom deuteronopijom (DMID) (N = 5), skupina sa srednjom deuteronopijom (DMED) (N = 5) i skupina sa jakom deuteronopijom (DSTD) (N = 8). Uz to, mogao se procijeniti utjecaj stupnja poremećaja kolornoga vida na subjektivnu sposobnost određivanja boje (tablice 2. do 4.). Rezultati ovog istraživanja pokazali su da je skupina s PSTD-om (ΣΔE*ab = 63,38 ± 9,52) bila značajno lošija u određivanju boje u odnosu na onu s PMED-om (ΣΔE*ab = 47,62 ± 9,88, p = 0,033). Prema spoznajama autora, nema objavljivih podataka o tome kako stupanj poremećaja kolornoga vida utječe na sposobnost određivanja boje u Toothguide Training Box (TTB) ili ključu boja VITA 3D-Master. Za razliku od protanopije, nije bilo statistički značajnih razlika između skupina sa deuteronopijom. To je razlog zašto se može odbaciti prva nulta hipoteza.

Odabir kontrole skupine bili su značajno bolji u usporedbi sa svim skupinama sa poremećajima kolornoga vida, osim u usporedbi s blagom deuteronopijom. Podatak da poremećaj kolornoga vida utječe na sposobnost određivanja boje nije nov. To je u skladu s mnogim dosadašnjim istraživanjima (2, 3, 12 – 15) i zapravo je zdraznovanuški. To je razlog zbog kojeg se druga nulta hipoteza može odbaciti za sve skupine, osim za onu s DMID-om. U budućnosti su potrebna daljnja istraživanja s više sudionika sa različitim poremećajem kolornoga vida.

Zaključak

Opseg poremećaja kolornoga vida mjeren HRR testom djelomično utječe na sposobnost vizualnog određivanja bo-
matching ability. Participants with strong protan red-green color-vision deficiency are worse in shade matching than participants with medium protan red-green deficiency. The selections of the control group were significantly better in comparison to all groups with color-vision deficiency, except in comparison with the mild deutan red-green color-vision deficiency group.

**Conflict of interests**

All authors disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) our work.

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