**INTRODUCTION**

The use of manual shade guides remains the most common method of selecting dental shades.1 The use of spectrophotometers are useful adjuncts to manual shade selection, but they are not without their limitationsI2 Manual shade selection is affected by the environment (lighting conditions), sex, age, experience and acquired dyschromatopsia.3-8 Determining dyschromatopsia or color vision deficiency (CVD) is a complex process influenced by the same factors affecting dental shade selection as well as the test that is employed to examine for CVD. Dyschromatopsia may be either congenital or acquired from systemic diseases such as diabetes mellitus.9 It is commonly cited that the prevalence of red-green CVD is approximately 8% in men and about 0.4% in women.10 When an individual exhibits CVD it may limit their work in fields such as esthetic dentistry, microscopic pathology, electrical and combat engineering, aviation, navigation, pharmacy, chemistry and medical technology.11,12 It may be prudent to screen dental students for red-green CVD. When identified as having CVD training and exercises are available to individuals that may improve their dental shade matching skill.

The perception of color depends upon different wavelengths of light being perceived by three types of retinal cones centrally located at the retinal fovea centralis. The cones are identified as red (protan), yellow-green (deutan) and blue-violet (tritan).13 Dyschromatopsia is named after the cone with the impaired function while the degree of impairment is identified as an anomaly (partial impairment), or anopia (complete impairment). Thus, protanopia is the total absence of the ability to distinguish red objects which are usually interpreted as having a dull or green hue. Tritanopia is the total inability to distinguish blue objects which appear as green to an individual. Deuteranomaly is the partial impairment to distinguish objects containing yellow and green hues. Deuteranomaly impairs the determination of tooth shades.14 It is the most common CVD, is typically X-linked, and predominately affects males.15

The three most common tests for identifying dyschromatopsia are the Ishirara test, Farnsworth-Munsell D-15 (X-rite Corp, Grand Rapids, MI), and the Farnsworth-Munsell 100 Hue test (FM-100) (X-rite Corp).13 The most commonly employed test is the Ishirara test which consists of a number of colored plates. Each plate contains a circle of dots appearing randomized in color and size. Within the pattern are dots which form a number or shape clearly visible to those with normal color vision, and difficult to see to those with a red-green CVD. Other plates are intentionally designed to reveal numbers only to those with a red-green CVD and be non-distinguishable to those with normal red-green color vision. The complete test consists of 38 plates, but there are Ishihara tests consisting of 10, 14 or 24 test plates.

Developed in 1957 the FM-100 test is the most highly effective test assessing an individual’s color vision. It is considered the benchmark to which other tests are compared. The FM-100 test consists of four trays containing a total of 85 removable color reference caps of incremental hue variation spanning the visible spectrum. Each tray contains an anchor cap at both ends of the tray. The individual four trays encompass the following hues: yellow/green, blue/purple, purple/magenta, and orange/magenta. Color vision aptitude and abnormalities are identified by the subject’s ability to arrange the caps in order of hue between the two anchor caps. Test results are recorded as total error scores (TES) and are based on frequency and magnitude of cap misplacements. An individual’s color acuity is ranked into three classes; superior (TES 0-16), average (TES 20-100), and low or poor color discrimination (TES>100). Figures 1-3 illustrate FM-100 test results. The Farnsworth-Munsell D-15 is an abridged version of the FM 100 test that is designed to allow for a quick evaluation of individual’s color vision aptitude. The test consists of a reference cap and 15 removable chips of incremental hue variation. The FM-100 test reported sensitivity is 1.0 and specificity is 0.83.13 Whereas, the Ishirara and Farnsworth-Munsell D-15 tests are used to screen for the presence of CVD, the FM-100 test identifies both the nature and magnitude of perceived color deficiencies.

Dental school admission committees use performance on the Dental Admissions Test (DAT) as one of many criteria for applicant selection. The Perceptual Ability Test (PAT) is a component of the DAT that is used to ascertain an applicant’s spatial visualization skills. There is slight evidence to suggest that it may also be useful to evaluate CVD and dental shade matching ability.16 Therefore primary purpose of the study was to determine if there was an association between PAT scores and CVD in first-year dental students.

**MATERIALS AND METHODS**

This study received expedited approval from our university’s Institutional Review Board (#HM20002312). There were three cohorts of test subjects consisting of 291 first-year dental students from the graduating classes of 2019, 2020 and 2021. All voluntarily participating students provided informed consent, information on age, ethnicity, sex, and PAT scores. Subject ethnicity was categorized as “White”, “Asian”, or “Other” (combination of “African Americans”, “Hispanics”, and “Middle Easterners”). Testing was administered beneath a Macbeth Judge II booth (X-Rite) (Figure 4). The booth provided ideal room color temperature of 6500°K, color rendering index of 90, balanced spectral distribution, and a neutral gray background. All participants were required to wear gray disposable nitrile gloves so as not leave oil or debris on the shade caps of the FM-100 test. Caps in each of the four trays of the FM-100 test were randomly arranged and remained consistent for all three cohorts of test subjects. Each student was given one tray of randomized caps and instructed to arrange them according to their perceived hue between the two anchor caps. As stated in the instructions for the FM-100 test each subject was informed when the 2:00 minute mark was obtained for each individual tray but was allowed to continue until finished. This was repeated until the subject completed arranging all four trays. Trays were administered in the same order for the three cohorts of students. Total time to arrange each tray was calculated and summation of the four times was recorded as the time to complete the FM-100 test. Total error scores (TES) were calculated using scoring software (X-Rite). Subjects were deemed to have Superior color acuity (TES 0-16) or not (TES > 16). To determine the association between PAT and CVD, a multiple linear regression model was implemented. The log-transformed TES was used as a proxy for CVD in modeling the association with PAT, while also adjusting for subject age, sex, ethnicity, and time to test completion. A post-hoc Tukey’s Honest Significant Difference (HSD) was used to assess the mean difference in PAT between students that had Superior color acuity and those that did not. All statistical analyses were performed in R (version 3.6.1) at the 0.05 alpha level of significance.

**RESULTS**

Demographics of the study population are illustrated in Table 1. There were 144 males and 147 females. The average age of the subjects was 24.9 (SD=3.9). The ethnic composition of the group consisted of 149 Whites and 89 Asians, with 53 subjects considered as Others. Average PAT score was 20.4 (SD=2.5). The median TES was 20.0 (IQR=(8.0-32.0)), with 132 subjects classified as having Superior color acuity (45.4%). The average time to completion of the FM-100 test was 9 minutes (SD=2.8).

Table 2 presents the results from the multiple linear regression analysis to model the association between PAT and TES while adjusting for age, sex, ethnicity, and time to test completion. The results indicated that there was a strong association between PAT and TES (p=0.0002). A 1% increase in the average TES was found to result in an average decrease of 0.005 in the PAT score, while holding all other patient characteristics constant. This indicated that, on average, worse TES (i.e. poor color acuity) led to worse PAT scores. Table 3 presents the results from Tukey’s HSD. Subjects with Superior color acuity were found to have, on average, 0.83 higher PAT scores compared to students that were not considered as Superior (p=0.004).

**Table 1.** Subject Demographics

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| --- | --- |
| **Variable** | **N=291** |
| **Age (SD)** | 24.9 (3.8) |
| **Sex (%)** |  |
| Male | 144 (49.5) |
| Female | 147 (50.5) |
| **Ethnicity (%)** |  |
| White | 149 (51.2) |
| Asian | 89 (30.6) |
| ꬹOther | 53 (18.2) |
| **TES (IQR)** | 20.0 (8.0-32.0) |
| **Superior Color Acuity (%)** | |
| Yes | 132 (45.4) |
| ꬹNo | 159 (54.6) |
| **Time to test completion (SD)** | 9.0 (2.8) |
| **PAT (SD)** | 20.4 (2.5) |

ꬹCombination of African Americans (N=14), Hispanics (N=17), Middle Easterners (N=19), and Unknown (N=3).

ꬹCombination of TES 16-100 (N=151) and TES >100 (N=8)

**Table 2.** Parameter estimates from the multiple linear regression model.

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| --- | --- |
| **Parameter** | **Estimate (95% CI)** |
| Intercept | 20.70 (18.50, 22.90) |
| Age | 0.09 (0.01, 0.16) |
| Sex (Male) | 1.00 (0.43, 1.57) |
| Ethnicity (Asian) | 0.22 (-0.42, 0.85) |
| Ethnicity (Other) | -0.71 (-1.47,0.04) |
| Log(TES) | -0.52 (-0.79,-0.24) |
| Time to test completion | -0.16 (-0.26,-0.06) |