EFFECT ON THE FARNSWORTH D-15 WHEN ADAPTING TO A SODIUM VAPOR LAMP

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ABSTRACT

Background: The sodium vapor lamp has many applications including lighting our roadways, parking lots and warehouses. This type of illumination may cause changes in color discrimination in persons with normal color vision. This study examines a subject's color discrimination pre- and post- adaptation to a sodium vapor lamp to determine whether color discrimination changes over time. **Methods:** The sodium vapor lamp was calibrated to 28 foot-candles. The color vision of 33 subjects was tested with the Farnsworth D-15. The test was administered immediately after exposure to the sodium vapor lamp and then repeated after ten minutes of exposure to the lamp. **Results:** The results were analyzed using the Color Vision Recorder and SPSS software. There was not a statistically significant difference in mean scores due to adaptation for the pre and post CCI, AC-CCI, and C-Index found in this experiment. The paired-samples T-Test did not reveal a statistically significant difference in mean scores for the S-index from the pre- and post-adaptation tests. **Conclusion:** Results show that color vision discrimination remains constant under sodium vapor lighting demonstrating agreement with previous studies that report nearly instantaneous chromatic adaptation for color vision discrimination under various lighting sources. The fact that the Farnsworth D-15 does not detect minor defects may be considered a source of limitation in this study. Nevertheless, the resultant data is sufficient to lay experimental designs for further investigation. Other more sensitive color vision tests should be implemented in studies similar in structure.

Background

Color discrimination has been studied extensively over the years for numerous reasons. Color deficiencies have been found to be congenital in nature as well as characteristic of various ocular pathologies. However, in the absence of ocular disease or congenital abnormality, color discrimination may be altered by artificial lighting conditions such as the sodium vapor lamp.

The sodium vapor lamp has many applications including lighting our roadways, parking lots and warehouses. Sodium vapor lamps are used widely for security lighting and also have industrial applications. The sodium vapor lamp is employed frequently due to its long life of 24,000 hours and its high efficacy of 140 Lumens per Watt.[1] The standard 60-Watt incandescent lamp in contrast has an average life of 1,000 hours and an efficacy of approximately 14.5 Lumens per Watt.

The economic advantages of employing sodium vapor lamps in the various modes already mentioned are clear. However, many people work under this lighting condition. Anyone that drives a vehicle on the roadways is exposed to this lighting condition. The question yet to be answered is whether color discrimination ability is affected when exposed to the sodium vapor lamp as a singular light source and after adaptation occurs, whether color discrimination improves.

The tendency for the color appearance of objects to remain somewhat constant across large changes in the color of the illumination is due to chromatic adaptation.[2] Research on chromatic adaptation of the human eye to various light sources has shown that adaptation occurs nearly instantaneously. In one such study, it was concluded that color-appearance changes reach 95% of their steady-state level after approximately 83 -100 seconds.[2]

It has long been thought that there are two mechanisms by which chromatic adaptation occurs. The results of a study by Fairchild and Reniff suggest two stages of adaptation: one extremely rapid (a few seconds) and the other somewhat slower (approximately 1 minute). [2] Another study conducted by Werner, Sharpe, Zrenner concluded that in accordance with previous studies, most of the adaptation takes place during a relatively fast initial phase within the first 5 s, and then, over the following minutes, approaches asymptotically a steady state. [3] Yet another study by Rinner and Gegenfurtner identified three components of adaptation and was particularly concerned with color appearance and discrimination. A slow exponential time course of adaptation with a half-life of about 20 s was common to appearance and discrimination. A faster component with a half-life of 40-70 ms was also common to both. Exclusive for color appearance, there was a third, extremely rapid mechanism with a half-life faster than 10 ms. [4] Longer times for complete adaptation (approximately 10 min) have been reported for light adaptation as measured by increment thresholds by Baker. [3] It may be concluded from well-established studies that chromatic adaptation occurs within the time frame of merely seconds up to 10 minutes regardless of the number of mechanisms involved.

The Farnsworth dichotomous test (D-15) is the color vision test selected for this particular study. The Farnsworth D-15 is an arrangement color vision test that allows for the differentiation of protan, deutan and tritan defects. The D-15 consists of 15 colored caps that the subject is asked to arrange such that they follow an orderly progression in color.[5] The D-15 is used extensively for the evaluation of color discrimination in congenital and acquired color vision defects.[6]

Scoring for the D-15 was quantified by the work of Bowman in 1982. Bowman's quantitative scoring method is based on the calculation of the sum of the color differences of the D-15 caps as placed by the test subject. This total color difference score (TCDS) is the smallest for correctly placed caps as the color difference between normally adjacent caps is also the smallest. Later this scoring parameter was converted in the Color Confusion Index (CCI), which is the TCDS divided by the TCDS of a perfect caps arrangement. In 1984 Bowman et al. evaluated the effect of age on the CCI for subjects with normal color vision. Based on this data also the Age Corrected Color Confusion Index (AC-CCI) is calculated using the Color Vision Recorder software. This parameter is only available for a patient age between 10 and 70 years.[6]

In 1988, Vingrys and King-Smith published a method for quantitative scoring of the D-15 based on a vector analysis of the color difference between adjacent caps. Three factors were used to quantify the cap arrangements: the first is the confusion angle which identifies the type of color defect; the second is the Confusion index (C-index) which quantifies the degree of color loss relative to a perfect arrangement of caps; and third is the Selectivity index (S-index) which quantifies the amount of polarity or lack of randomness in a cap arrangement.[7] A low S-index indicates a larger degree of randomness and is correlated with more normal color vision whereas a higher S-index correlates with a greater degree of polarity and corresponds to a dichromatic observer. The C-index will equal 1.0 when there is a perfect arrangement of caps. A C-index greater than 1.77 expected to indicate an abnormal D-15 cap arrangement with congenital color defectives having values as high as 4.21.[7] Both Bowman's CCI and AC-CCI and Vingrys C-Index and S-Index were used to analyze the data collected during this study.

The research question for this study was is there a statistically significant difference in the color discrimination measured by the D-15 and quantified by the CCI, AC-CCI, C-index and S-index over time when illuminated by a sodium vapor lamp. The hypothesis is that there is no statistically significant difference between the color discrimination as measured by the D-15 and quantified by the CCI, AC-CCI, C-index and S-index over time when illuminated by a sodium vapor lamp.

Methods

The Farnsworth D-15 was administered at the Michigan College of Optometry in Big Rapids, Michigan on April 25, 2006. The individuals participating in the screening were optometry students with normal color vision and free of ocular pathology. Permission to conduct the study was obtained from the Human Subjects Review Committee at Ferris State University.

All testing was administered in a room illuminated by a sodium vapor lamp emitting approximately 28 foot-candles. The testing was carried out in two parts: Test 1 pre-adaptation and Test 2 post-adaptation. Test 1 was initiated to the subjects under binocular conditions immediately after entering the room. The subject then sat in the sodium vapor illuminated room for 10 minutes. Test 2 was administered after the 10 minutes had elapsed.

The test caps of the Farnsworth D-15 were arranged in a pre-determined random order, which was held constant for each subject and each test. Each subject was assigned a random number, which was recorded on the collecting form along with the age and gender of the subject. All subjects were college students between the ages of 18 and 33. There were 20 females and 13 males, for a total of 33 subjects. All subjects were kept from being exposed to the sodium vapor illumination prior to Test 1.

Results

Of the 33 subjects, 21 made zero errors during both pre- and post-adaptation testing. Of the 33 subjects, 3 made simple reversal errors only during post-adaptation testing while making zero errors during the pre-adaptation testing. Of the 33 subjects, 1 subject consistently reversed the same two caps on pre- and post-adaptation testing. Of the 33 subjects, 2 subjects made simple reversals during pre-adaptation testing and then made different reversals on post-adaptation testing. Finally, 6 subjects made errors during pre-adaptation testing that later made zero errors during post-adaptation testing. Of these 6 subjects, 4 made the same reversal that was not consistent with a protan shift in color discrimination.

Using SPSS 13.0 for Windows, the data for 33 participants were analyzed. Table 1 reveals the descriptive means and standard deviations. Using SPSS, a paired-samples T-Test was performed on both the pre and post CCI, AC-CCI, C-Index and S-Index scores. In addition, a paired-samples T-Test was performed on the number of errors pre- and post- adaptation. Lastly, an Analysis of Variance (ANOVA) was performed on the mean difference between pre- and post-testing based on gender.

Table 2 reveals that the T-Test did not find a statistically significant difference at the alpha = 0.05 level between the pre- and post-CCI ($t = 1.618$, $p = .115$), the pre- and post-AC-CCI ($t = 1.657$, $p = .107$), the pre- and post-C-Index ($t = 1.629$, $p = .113$) and the pre- and post-S-Index ($t = 1.314$, $p = .198$). This signifies that there was not a statistically significant difference in mean scores due to adaptation for the pre and post CCI, AC-CCI, C-Index, or S-index. In addition, the paired-samples T-Test did not reveal a statistically significant difference in mean scores for the number of errors pre- and post- adaptation (t = 1.724, p = .094).

Table 3 reveals the results of the ANOVA, which evaluated the mean difference between pre- and post-testing based on gender. The ANOVA did not find a statistically significant difference at the alpha = 0.05 level between gender and the mean difference of the pre- and post-CCI (f = .732, p = .399), mean difference of the pre- and post-AC-CCI (f = .642, p = .429), mean difference of the pre- and post-C-Index (f = .618, p = .438), mean difference of the pre- and post-S-Index (f = .546, p = .466), and the mean difference between the number of errors per subject pre-adaptation and post adaptation (f = 2.399, p = .132). The results revealed no statistically significant difference between gender and the mean difference between pre- and post-scores.

Table 1 - Paired Samples Statistics

		Mean	N	Std. Deviation
Pair 1	Pre-CCI	1.05	33	.083
	Post-CCI	1.02	33	.046
Pair 2	Pre-AC-CCI	1.0430	33	.08320
	Post-AC-CCI	1.0200	33	.04617
Pair 3	Pre-C-index	1.07	33	.163
	Post-C-index	1.03	33	.076
Pair 4	Pre-S-index	1.5591	33	.23148
	Post-S-index	1.5076	33	.09634
Pair 5	Pre-Errors	.88	33	1.746
	Post-Errors	.36	33	.822

Table 2 - Paired Samples T-Test

Paired Differences		Mean	Std. Deviation	t	df	Sig. (2-tailed)
Pair 1	Pre-CCI - Post-CCI	0.023	0.081	1.618	32	0.115
Pair 2	Pre-AC-CCI - Post-AC-CCI	0.023	0.080	1.657	32	0.107
Pair 3	Pre-C-index - Post-C-index	0.043	0.151	1.629	32	0.113
Pair 4	Pre-S-index - Post-S-index	0.052	0.225	1.314	32	0.198
Pair 5	Pre-Errors - Post-Errors	0.515	1.716	1.724	32	0.094

Table 3 – ANOVA between Gender and Mean Difference Scores

ANOVA Table	Sum of Squares	df	Mean Square	F	Sig.
DifCCI * Gender	0.005	1	0.005	0.732	0.399
DifACCCI * Gender	0.004	1	0.004	0.642	0.429
DifCindex * Gender	0.014	1	0.014	0.618	0.438
DifSindex * Gender	0.028	1	0.028	0.546	0.466
DifErrors * Gender	6.769	1	6.769	2.399	0.132

Conclusion

The results of this study reveal strong evidence that chromatic adaptation to the sodium vapor lamp occurs quickly, perhaps instantly. According to the data, persons with normal color vision should maintain normal color discrimination when subjected to a specific light source such as the sodium vapor lamp. There was no statistical difference found between errors made during the pre- and post-adaptation testing for any of the 33 subjects. This study demonstrates agreement with past studies of color discrimination and chromatic adaptation in that adaptation must occur instantly to within 80-100 seconds.

Even though the Farnsworth D-15 allows for the differentiation of protan, deutan and tritan defects, it does not allow the differentiation of dichromats from anomalous trichromats, nor does it detect minor defects.[5] The fact that the Farnsworth D-15 does not detect minor defects is relevant to this study and may be considered a source of limitation. It may be possible that minor changes in color discrimination did occur under exposure to the sodium vapor lamp but were simply undetected by the Farnsworth D-15. This test may not be sensitive enough to render the resultant data conclusive for industrial application. Nevertheless, the resultant data is sufficient to lay experimental designs for further investigation. Other more sensitive color vision tests should be implemented in studies similar in structure.

References

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