EFFECT OF FIVE DIFFERENT LIGHT SOURCES ON LANTHONY DESATURATED D-15

by

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ABSTRACT

In order to predict the effects of various light sources on an individual's perception of color, the Lanthony Desaturated D-15 color vision test was administered to optometry students with normal color vision and no ocular pathologies under five illumination sources. The sources of illumination include illuminant C (as a control), an incandescent lamp, a sodium vapor lamp, a metal halide lamp, and a fluorescent bulb. All of the illumination sources were calibrated to 28 foot-candles.
The data collected was used to determine the Color Confusion Index for each subject. The Color Confusion Index (CCI) data was then analyzed using the Analysis of Variance (ANOVA) test. Finally, Mauchly's Test of Sphericity was used to compare the variance within the light sources.

Mauchly's Test of Sphericity showed a significant variance for each of the light sources showing that equal variance between the light sources cannot be assumed. The Huynh-Felydt correction did not reveal a statistically significant difference between the light sources while using the S-index per subject. Using pairwise comparisons there was a statistically significant difference found with 1) the mean CCI sodium vapor score 2) the ACCCI sodium vapor score 3) the C-Index sodium vapor score and 4) the mean number of errors per subject with the sodium vapor light when compared to all other light sources. There also was a statistical difference when comparing the S-index sodium vapor score with the illuminant C and fluorescent scores.

This study has shown how a change in lighting conditions can affect a person's ability to discriminate colors. This can show importance because it can affect how a person may perform color discriminating tasks at work, home or elsewhere.

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INTRODUCTION

This study was done to determine the effects of various light sources on an individual's perception of color. The perception of color is wavelength dependent. When light is projected on an object, certain wavelengths are absorbed. The ones that are reflected enter our eyes and we perceive it as color. There are two theories that in conjunction describe the physiology of color vision. The first is the trichromatic theory. The trichromatic theory states that there are three different types of cones in the human retina that respond to a peak stimulus of three different wavelengths. These three photopigments are labeled the S-cone (short wavelengths), the M-cone (mid wavelengths) and L-cones (large wavelengths). The absorbance spectra of these three cone types overlap and hence the numerous color combinations can be perceived. There are wavelengths that are more easily distinguished than others. The "W curve" of wavelength discrimination shows that the regions of best discrimination for the human eye are 495nm and 590nm.[1]

The second theory is the opponent theory. This theory was first described toward the end of the 19th century. It was observed that certain colors could not co-exist. For example, the colors red and green cannot simultaneously be perceived. An object is either red or green, there is no such thing as a mixture of the two colors. The same can be said of blue and yellow. In the opponent theory, there believed to be a channel which signals red or green but not both at the same time. A similar yellow-blue channel signals either yellow or blue, but not both concurrently. Modern models of color vision state that there are three color sensitive cones and there are color opponent neurons in the retina and dLGN. L- and M- cones oppose each other to form L-M opponent cells. The addition of S- cones to the L-M opponent cells form the S-(L+M) cells.[2] The combination of these two theories allow us to code for both hue and brightness information.

Color vision deficiencies are classified into two broad categories; dichromacy and anomalous trichromacy. Dichromats are those individuals who are missing a certain type of color sensitive cone. These individuals suffer from severe color perception loss. Their ability to distinguish fine color differences is greatly reduced. Anomalous trichromats have all three types of color sensitive cones; however, the peak absorption of cone is displaced resulting in color confusion. They have all three color cones, and hence have better color determination then the dichromats; however, abnormalities can be picked up during certain conditions.[3]

Chormatopsias are not true color vision defects but they cause difficulty in color perception. Classic examples of chormatopsias include the yellowing of a nuclear sclerotic cataract. The cataract acts as a yellow filter and hence distorts color perception. Upon cataract removal, the patient suddenly notices a lot more blueness in their vision. Certain medications can also cause chormatopsia effects. And lastly, as in this study, lighting can cause a decreased color discrimination chormatopsia.[4]

The purpose of this study was to determine the extent of chormatopsia, if any, commonly used light sources have on the perception of color. We believe the further a hue differs the from the hue of the illuminance-C lighting source, the more the difficulty the subjects would have in performing a standard color test.

The test used in this study was the Lanthony Desaturated D-15. The desaturated D-15 is an arrangement test. The participant is asked to find the closest match to the fixated color reference chip. The procedure is then repeated so the participant tries to match the previous chip after the fixed reference color chip until all 15 chips are placed in order. The test is scored by connecting the dots of the scoring card in the order the participant placed the chips. The angle of crossovers during scoring determines the type of color confusion the patient has. The Lanthony Desaturated D-15 is a desaturated version of the Farnsworth Dichotomous test. The Lanthony Desaturated test is more sensitive to picking up more subtle color abnormalities. Optimal lighting conditions for the test is standard illuminant C lighting.

The Lanthony Desaturated D-15 is scored on a scoring system called the Color Confusion Index (CCI). The CCI is calculated by a sum of the differences between all adjacent caps in the subject's order divided by the sum of the perfect cap arrangement.[5] Hence if a subject arranges the caps perfectly, their CCI score will be 1.00. The Age Corrected Color Confusion Index (AC-CCI) takes into account the effect of age on the CCI. The normative data ranges from subjects aged 10 to 70 years. The scoring is further analyzed based on vector analysis of the color differences of a cap and the most adjacent cap to it. This gives us quantitative measurements of cap arrangement. The C-index (confusion index) determines the amount of color vision loss. The S-index (selectivity index) determines the lack of randomness in the cap arrangement. Both of these together give us a way to quantify a color defect and distinguish a true color defect versus an arbitrary nonsensical arrangement of the color caps. The confusion angle allows us to determine what classification of color vision defect a subject has.[6]

The different lighting sources used in this experiment were Illuminant C with a color temperature of 6740 using the MacBeth Easel Lamp. This is the standard lighting for all color vision testing and was used as a control in this experiment. The four other lighting sources used were 1) Fluorescent Sylvania 13-Watt CFT13WDS/EC/841 with a color temperature of 4100, 2) Incandescent Phillips 60-Watt Duramax Soft White with a color temperature of 2700, 3) Sodium Vapor Phillips 50-Watt C50S68/M with a color temperature of 2100, and 4) Metal Halide GE Mercury 100-Watt HR100DX38/Med with a color temperature of 3900. The higher the color temperature the more blue (short wavelength) the light color. Conversely the lower the color temperature, the more yellow the lighting source looks.[7] Looking the color temperatures, the lighting source with the closest color temperature to the standard Illuminate C is the Fluorescent and the furthest is Sodium Vapor. Hence we hypothesize that the Fluorescent lighting would cause the least amount of color vision impairment whereas the Sodium Vapor would cause the most. The extent of color vision impairment could be quantified in this experiment.

Results of this study apply to conditions where color discrimination could possibly be diminished due to the effects of lighting such as, in situations where a police officer is chasing a light colored car down a highway lit by sodium vapor street lights, or an electrician working in a warehouse under fluorescent lights. With this knowledge we could see how much lighting plays a role in color determination and analyze it's potential implications.

METHODS

The Ferris State University Human Subjects Review Committee (HSRC) reviewed the methods and procedures and allowed the use of human subjects for this experiment.

Thirty-two optometry students and one optometry professor were used in this study. The age range was from 21 years old to 49 years old. There were 14 males and 19 females. Each participant completed a history page stating that they had no ocular pathologies and had normal color vision. The five lighting sources used in this experiment were 1) Illuminant C with a Color temperature of 6740 using the MacBeth Easel Lamp, 2) Fluorescent Sylvania 13-Watt CFT13WDS/EC/841 with a color temperature of 4100, 3) Incandescent Phillips 60-Watt Duramax Soft White with a color temperature of 2700, 4) Sodium Vapor Phillips 50-Watt C50S68/M with a color temperature of 2100, and 5) Metal Halide GE Mercury 100-Watt HR100DX38/Med with a color temperature of 3900.

Each lighting source was calibrated to the same illuminance of approximately 28 foot-candles. Under each lighting source was a Lanthony Desatutated D-15 color vision test. The color caps were arranged in a pre-determined random order that was held constant under each light source and was held constant for each participant.

A random number was assigned to each participant and each subject was kept from being exposed to the various lighting sources prior to testing. Each participant was then asked to arrange the color caps in correct order under each of these lighting conditions. The sequence of the test was as follows. The subjects would perform the test under the standard illumination C prior to testing under any other illumination. The testing then proceeded to the fluorescent lamp, then the incandescent lamp, followed by the sodium vapor lamp and ending with the metal halide lamp. The test was not timed.

The numerical order of the caps arranged by the subject was recorded. From the recorded data, the number of volunteers making errors was calculated, the number of errors per subject was calculated and the total number of errors/reversals was also calculated. In addition, the Color Vision Recorder was employed to compute Bowman's scores for the Color Confusion Index (CCI) and Age Corrected Color Confusion Index (AC-CCI) were calculated. Also the Color Vision Recorder was employed to compute Vingrys and King-Smith's Confusion Index (C-index) and Selectivity Index (S-index) were calculated. Bowman's method for evaluating the Color Confusion Index is given the value of 1 when the test has been performed correctly. Each error made would add to this score. The more errors made, the higher the score of the CCI will be. Vingrys and King-Smith's C-Index provides the degree of error relative to a perfect score while the S-Index provides the polarity of the impairment.[8] An Analysis of Variance (ANOVA) test was then applied to the data to evaluate if there was any difference between the means.

RESULTS

Using SPSS, a repeated measures within-subjects ANOVA test was performed on the five different light sources using 1) the CCI per subject, 2) the AC-CCI per subject, 3) the C-index per subject, 4) the S-index per subject, and 5) the number of errors per subject. In addition to the ANOVA, a pairwise planned contrast was performed.

Mauchly's Test of Sphericity, which compares the variance within the light sources, was also calculated. Mauchly's Test of Sphericity was found to be significant ($p<0.001$) for all the above comparisons. This means that equal variances between the light sources cannot be assumed. Since equal variances could not be assumed, a Huynh-Feldt correction was employed in the data analyses.

When using the Huynh-Feldt correction to evaluate the repeated measures analysis, a statistically significant difference at the alpha = 0.05 was observed between the means for the five different light sources using 1) the CCI per subject (Table 1); 2) the AC-CCI per subject (Table 2); 3) the C-index per subject (Table 3); and 4) the number of errors per subject (Table 5). The Huynh-Feldt correction did not reveal a statistically significant difference between the means for the five different light sources using S-index per subject (Table 4).

As for the pairwise comparisons, Table 6 reveals there was a statistically significant difference between the mean CCI sodium vapor score and all the other light sources. Table 7 reveals there was a statistically significant difference between the mean ACCCI sodium vapor score and all the other light sources. Table 8 reveals there was a statistically significant difference between the mean C-Index sodium vapor score and all the other light sources. Table 9 reveals there was a statistically significant difference between the mean S-Index sodium vapor score and the illuminant C and fluorescent scores. Table 10 reveals there was a statistically significant difference between the mean number of errors per subject with the sodium vapor light and all other light sources. In addition, there was a statistically significant difference between the mean number of errors per subject for the illuminant C as compared to the incandescent light source.

DISCUSSION

Our subjects were asked to perform the Lanthony desaturated D-15 color vision test, an arrangement task, under five different light sources. Each light source produced a different color temperature (illuminant C – 6740K, fluorescent – 4100K, incandescent – 2700K, sodium vapor – 2100K, and metal halide – 3900K.) Lower color temperatures have more energy in the long wavelength end of the spectrum, and higher color temperatures have more energy in the shorter wavelength end of the spectrum.[9] The ability to continue to recognize colors under different illuminations is known as chromatic adaptation.

We found that of the five light sources used, our subjects experienced greatest color confusion when performing under the sodium vapor lighting versus any of the other light sources. Of the provided light sources, the sodium vapor lighting has the lowest color temperature of 2100K thereby producing longer wavelengths. By introducing these longer wavelengths, the subjects were more likely to perceive the caps as being similar because the ability to discriminate between these hues is weaker in this region of the spectrum.

The results of this study has shown there to be a decreased likelihood of properly identifying some colors especially noticeable under conditions that utilize sodium vapor lighting. Many tasks require a significant degree of color discrimination. An electrician has to discriminate between different colored wires, a pharmacist has to identify various colored pills, or a graphic design artist choosing what colors may be the most appropriate for a project they are working on. One example would be how sodium vapor lighting is widely used for security purposes, and outdoor lighting including streetlights. This may present as an added obstacle for security personal and police officers when color discrimination is necessary.

This research study may have been limited by the fact that the ages of the participants were relatively close. Therefore the effects of age on the perception of color in different lighting situations were not analyzed. These participants were also mostly college students in doctorate level of studies, so hence all of the participants were educated individuals and were able to perform tests efficiently. Also, since this experiment was performed on those attending or teaching at the Michigan College of Optometry, they had further understanding of color vision and color vision testing. The testing was also performed in an arranged order from one light source to the next and so the effects of the light source prior may have altered the outcome of subsequent tests.

The results of this experiment can serves as a basis for additional studies in the effects of lighting on color perception. It would be interesting to investigate the effects of lighting on those individuals with known color deficiencies. Would certain light sources be more beneficial in the discrimination of color in such individuals? Since all of our subjects were of approximately the same age, testing over different age ranges could be done to assess if there is a correlation between age of the individual, and their ability to discriminate colors under different light conditions. Would a child perform differently than a college aged subject or an elder individual?

References

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Appendix A

Tables

Table 1 – Huynh-Feldt CCI

Tests of Within-Subjects Effects

Source		df	F	Sig.	Observed Power
CCI	Sphericity Assumed	4	11.855	.000	1.000
	Greenhouse-Geisser	1.614	11.855	.000	.981
	Huynh-Feldt	1.687	11.855	.000	.984
	Lower-bound	1.000	11.855	.002	.916

Table 2 – Huynh-Feldt ACCCI

Tests of Within-Subjects Effects

Source		df	F	Sig.	Observed Power
ACCCI	Sphericity Assumed	4	11.491	.000	1.000
	Greenhouse-Geisser	1.628	11.491	.000	.979
	Huynh-Feldt	1.703	11.491	.000	.982
	Lower-bound	1.000	11.491	.002	.908

Table 3 – Huynh-Feldt C-Index

Tests of Within-Subjects Effects

Source		df	F	Sig.	Observed Power
CINDEX	Sphericity Assumed	4	10.795	.000	1.000
	Greenhouse-Geisser	1.511	10.795	.000	.963
	Huynh-Feldt	1.569	10.795	.000	.967
	Lower-bound	1.000	10.795	.002	.890

Table 4– Huynh-Feldt S-Index

Tests of Within-Subjects Effects

Source		df	F	Sig.	Observed Power
SINDEX	Sphericity Assumed	4	2.267	.066	.649
	Greenhouse-Geisser	2.430	2.267	.100	.496
	Huynh-Feldt	2.644	2.267	.094	.519
	Lower-bound	1.000	2.267	.142	.309

Table 5– Huynh-Feldt Number of Errors per Subject

Tests of Within-Subjects Effects

Source		df	F	Sig.	Observed Power
ERROR	Sphericity Assumed	4	10.755	.000	1.000
	Greenhouse-Geisser	1.743	10.755	.000	.977
	Huynh-Feldt	1.835	10.755	.000	.981
	Lower-bound	1.000	10.755	.003	.889

Table 6

Pairwise Comparisons CCI

(I) CCI	(J) CCI	Mean Difference (I-J)	Std. Error	Sig.
Illuminant C	Fluorescent	-1.818E-02	.019	.356
	Incandescent	-7.273E-03	.004	.095
	Metal Halide	-8.182E-03	.010	.399
	Sodium Vapor	-.160	.039	.000
Fluorescent	Illuminant C	1.818E-02	.019	.356
	Incandescent	1.091E-02	.020	.596
	Metal Halide	1.000E-02	.023	.668
	Sodium Vapor	-.142	.042	.002
Incandescent	Illuminant C	7.273E-03	.004	.095
	Fluorescent	-1.091E-02	.020	.596
	Metal Halide	-9.091E-04	.009	.920
	Sodium Vapor	-.152	.039	.000
Metal Halide	Illuminant C	8.182E-03	.010	.399
	Fluorescent	-1.000E-02	.023	.668
	Incandescent	9.091E-04	.009	.920
	Sodium Vapor	-.152	.038	.000
Sodium Vapor	Illuminant C	.160	.039	.000
	Fluorescent	.142	.042	.002
	Incandescent	.152	.039	.000
	Metal Halide	.152	.038	.000

Table 7

Pairwise Comparisons ACCCI

(I) ACCCI	(J) ACCCI	Mean Difference (I-J)	Std. Error	Sig.
Illuminant C	Fluorescent	-1.727E-02	.019	.358
	Incandescent	-6.364E-03	.004	.120
	Metal Halide	-7.576E-03	.009	.425
	Sodium Vapor	-.149	.037	.000
Fluorescent	Illuminant C	1.727E-02	.019	.358
	Incandescent	1.091E-02	.020	.583
	Metal Halide	9.697E-03	.022	.664
	Sodium Vapor	-.132	.040	.003
Incandescent	Illuminant C	6.364E-03	.004	.120
	Fluorescent	-1.091E-02	.020	.583
	Metal Halide	-1.212E-03	.008	.887
	Sodium Vapor	-.143	.037	.001
Metal Halide	Illuminant C	7.576E-03	.009	.425
	Fluorescent	-9.697E-03	.022	.664
	Incandescent	1.212E-03	.008	.887
	Sodium Vapor	-.142	.036	.000
Sodium Vapor	Illuminant C	.149	.037	.000
	Fluorescent	.132	.040	.003
	Incandescent	.143	.037	.001
	Metal Halide	.142	.036	.000

Table 8

Pairwise Comparisons C-Index

(I) CINDEX	(J) CINDEX	Mean Difference (I-J)	Std. Error	Sig.
Illuminant C	Fluorescent	-1.636E-02	.015	.286
	Incandescent	-1.333E-02	.012	.282
	Metal Halide	-1.212E-02	.012	.314
	Sodium Vapor	-.178	.045	.000
Fluorescent	Illuminant C	1.636E-02	.015	.286
	Incandescent	3.030E-03	.024	.901
	Metal Halide	4.242E-03	.022	.845
	Sodium Vapor	-.162	.051	.003
Incandescent	Illuminant C	1.333E-02	.012	.282
	Fluorescent	-3.030E-03	.024	.901
	Metal Halide	1.212E-03	.016	.939
	Sodium Vapor	-.165	.047	.001
Metal Halide	Illuminant C	1.212E-02	.012	.314
	Fluorescent	-4.242E-03	.022	.845
	Incandescent	-1.212E-03	.016	.939
	Sodium Vapor	-.166	.043	.001
Sodium Vapor	Illuminant C	.178	.045	.000
	Fluorescent	.162	.051	.003
	Incandescent	.165	.047	.001
	Metal Halide	.166	.043	.001

Table 9

Pairwise Comparisons S-Index

(I) SINDEX	(J) SINDEX	Mean Difference (I-J)	Std. Error	Sig.
Illuminant C	Fluorescent	-3.636E-03	.008	.662
	Incandescent	-2.333E-02	.021	.273
	Metal Halide	-2.636E-02	.017	.132
	Sodium Vapor	-6.667E-02	.026	.016
Fluorescent	Illuminant C	3.636E-03	.008	.662
	Incandescent	-1.970E-02	.021	.365
	Metal Halide	-2.273E-02	.021	.296
	Sodium Vapor	-6.303E-02	.025	.016
Incandescent	Illuminant C	2.333E-02	.021	.273
	Fluorescent	1.970E-02	.021	.365
	Metal Halide	-3.030E-03	.031	.924
	Sodium Vapor	-4.333E-02	.031	.177
Metal Halide	Illuminant C	2.636E-02	.017	.132
	Fluorescent	2.273E-02	.021	.296
	Incandescent	3.030E-03	.031	.924
	Sodium Vapor	-4.030E-02	.035	.259
Sodium Vapor	Illuminant C	6.667E-02	.026	.016
	Fluorescent	6.303E-02	.025	.016
	Incandescent	4.333E-02	.031	.177
	Metal Halide	4.030E-02	.035	.259

Table 10

Pairwise Comparisons Number of Errors per Subject

(I) ERROR	(J) ERROR	Mean Difference (I-J)	Std. Error	Sig.
Illuminant C	Fluorescent	-.182	.160	.263
	Incandescent	-.242	.115	.044
	Metal Halide	-.576	.450	.210
	Sodium Vapor	-2.909	.676	.000
Fluorescent	Illuminant C	.182	.160	.263
	Incandescent	-6.061E-02	.162	.712
	Metal Halide	-.394	.477	.415
	Sodium Vapor	-2.727	.691	.000
Incandescent	Illuminant C	.242	.115	.044
	Fluorescent	6.061E-02	.162	.712
	Metal Halide	-.333	.414	.427
	Sodium Vapor	-2.667	.654	.000
Metal Halide	Illuminant C	.576	.450	.210
	Fluorescent	.394	.477	.415
	Incandescent	.333	.414	.427
	Sodium Vapor	-2.333	.825	.008
Sodium Vapor	Illuminant C	2.909	.676	.000
	Fluorescent	2.727	.691	.000
	Incandescent	2.667	.654	.000
	Metal Halide	2.333	.825	.008