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

by

Matthew Allan Johnson

Krystal Kay Kempf

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Doctor of Optometry

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ABSTRACT

Background: Many highways are illuminated with sodium vapor lights which have the potential to create color discrepancies for people with normal color vision. This study looks at a subject's color discrimination both immediately upon exposure and after a specified time of exposure to sodium vapor lamps to see if the subject's color discrimination changed over time. *Methods:* The sodium vapor lamp was calibrated to twenty-eight foot-candles. Subjects were initially tested using a Lanthony Desaturated D-15 color vision test immediately after being exposed to the sodium vapor lamp. The test was repeated after ten minutes exposure to the lamp. *Results:* The results were analyzed using the Color Vision Recorder and SPSS software. A statistically significant difference in mean scores due to adaptation for the pre and post CCI, AC-CCI, and C-Index was 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:* Our results show that color vision discrimination improves under sodium vapor lighting despite previous studies showing almost instantaneous adaptation for color vision discrimination in various circumstances. More research is indicated to determine if our results are based on actual adaptation to sodium vapor lighting or the improvements reflect a learning curve with experience taking the desaturated D-15.

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INTRODUCTION

High pressure sodium vapor lamps are a common light source that is ideal for illuminating roadways and warehouses or for security or industrial lighting situations. They are highly efficient and have a life span of approximately 24,000 hours; however they are mainly used in situations where color vision is not very important. The color temperature of a sodium vapor lamp is approximately 2100K, as compared to natural daylight at noon which has a color temperature of 6504K.[1] Higher color temperatures are perceived as cooler, bluish colors, while low color temperatures are perceived as warmer, reddish colors.[2] The color rendering index (CRI) is a numerical measurement of the ability of a subject to discriminate colors under certain lighting conditions. For natural sunlight, the CRI is 100. For comparison purposes, the CRI of fluorescent light ranges between 59 and 90. A common fluorescent light has a color temperature of 4100K. Judging by color temperatures and color rendering indices, sodium vapor lamps must have a very low color rendering index, making it very difficult to discriminate colors under these light sources.[1] This experiment set out to determine if color discrimination ability changes over time; if our subjects adapted to the warmer color spectrum of the sodium vapor lamp illumination; and if their color vision improved.

The test chosen for this experiment was the Lanthony Desaturated D-15. The most significant drawback to using the Farnsworth D-15 series of color tests in color vision studies is the fact that analyzing the results utilizes diagrams to determine the type of color vision defects people have. This makes it very difficult to analyze and compare results using statistical analysis programs. Several attempts have been made to quantify the results of the D-15 tests to make the comparison process simpler. One of these

methods is the Bowman score. The color differences were calculated by Bowman using the CIELAB color difference formula to calculate the differences between caps for both the D-15 and Desaturated D-15, giving all caps a specific numerical score. This score is based upon the tristimus values of each individual Panel D-15 Munsell color chips using the standard illuminant C. The equations to calculate this data are now available in computer analysis programs. Once the caps were placed in the final order by test subjects, the sum of all the color differences between all adjacent caps was calculated. The end result was called the total color difference score (TCDS) which was later converted in the Color Confusion Index (CCI) by dividing the TCDS by the TCDS of a perfect cap arrangement. The farther the CCI is from 1.00, the more errors the subject made.[3] Bowman had another study in 1984 in which he evaluated the effect of age on the CCI for subjects with normal color vision, thus creating the Age Corrected Color Confusion Index. This normalized data can only be used for patients between 10 and 70 years.

A second proposed method was proposed by Vingrys and King-Smith that uses vector analysis of the color difference between adjacent caps. They used the actual calculated chroma difference by transforming the tristimus values of each cap for scoring and then estimated a hue angle and generated a color difference vector for any cap arrangement. This method can be used with any panel tests. This analysis results in three factors that are used to quantify color vision discrimination: the confusion index (C-index), selectivity index (S-index) and confusion angle. The C-index quantifies the degree of color loss. Similar to the CCI in Bowman's scores, a C-index of 1.00 means a perfect arrangement of the caps. The S-index quantifies the amount of polarity or lack of randomness in the cap arrangement. The confusion angle is determined after performing

vector analysis and finding the axis angle that produces the minimum moment of inertia. This estimation of the confusion angle is associated with the type of color defect, such as protan, deutran, and tritan defects.[4]

This study assesses how the aforementioned criteria (CCI, AC-CCI, C-index, and S-index) change after subjects are allowed to adapt to the sodium vapor lamp. According to previous studies on color vision discrimination and adaptation, subjects adapt to different illuminations almost instantaneously.[5,6,7,8] We hypothesized there should be no statistically significant difference between the mean color confusion index, AC-CCI, C-Index, or the S-Index over time with the Desaturated D-15 panel illuminated by a sodium vapor lamp.

METHODS

Study Design and Testing Protocol

This study was approved by the Human Subjects Review Committee at Ferris State University (see Appendix A). All volunteer subjects signed a written consent form (see Appendix B). The subjects were randomly assigned a testing number by selecting one out of a box to ensure the results would be anonymous. The subjects waited in a well-lit hallway with fluorescent lighting and two were called into the testing room at a time. They performed the Lanthony Desaturated D-15 color vision test twice, once immediately after entering the room with the sodium vapor lamps and a second time after ten minutes of adaptation to the lights. The sodium vapor lamp used in this experiment was a Ceramalux 50 watt medium BF55 coated bulb manufactured by Philips.[1] The lamp had been calibrated to an illuminance of approximately 28 foot-candles.

Subjects

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 had no known ocular pathology and no color vision defects. If a subject was unsure if they had a color vision defect, Ishihara plates were administered to the subject and if they did not pass, they were not allowed to participate.

Test Conditions and Scoring

The caps on the D-15 were arranged in a specific pre-determined random order for the first trial (see Table 1). This order was held constant for each subject. Subjects were called into the room two at a time. A random number between one and 33 was assigned to each subject so results would be anonymous, this number was recorded on the

Farnsworth Dichotomous test for Color Blindness Panel D-15 results form (see Appendix C), along with the patient's age and gender.[9] Subjects were instructed to arrange the caps by placing the cap that looked most similar to the starting cap as best as they could, and continuing this process with the preceding cap until all were in order. The subjects were aware that there was no time limit for completing the test. After performing the test, the proctors took the panel of caps to a recording table and recorded the order of the caps on the subject's results form. The caps were then arranged in a second pre-determined random order held constant for each subject (see Table 1) and presented to the subjects after ten minutes had passed from the initial time of exposure to the sodium vapor lamps. The same instructions were given and the second trial was recorded on the form.

Table 1

Trial	**Pre-determined Random Cap Order**
1	5, 10, 8, 3, 11, 1, 7, 9, 6, 14, 2, 13, 15, 4, 12
2	10, 6, 15, 7, 2, 1, 8, 11, 9, 4, 12, 3, 14, 5, 13

RESULTS

Out of the thirty-three participants, 29 made some errors on the first test administration and 24 participants showed some sort of improvement between the two tests. Twelve participants had perfect scores on the second administration compared to only four on the first trial. Using SPSS, version 15.0 (SSPS, Inc., Chicago, IL), a paired-samples T-Test was performed on the number of errors per person and the number of reversals per person. Table 2 reveals that there was a statistically significant difference at the alpha = 0.05 level between the pre and post errors performed per subject ($t = 6.419$, $p < .001$). This shows that there was a statistically significant difference in mean scores due to adaptation in the number of errors per person between the two tests. The paired-samples T-Test did not show a statistically significant difference in the mean scores of the number of reversals per person ($t = .238$, $p = .813$).

Table 2

		Paired Differences						
				95% Confidence Interval of the difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pre and Post Errors/Subject	2.48485	2.22375	0.38711	1.69634	3.27336	6.419	32	0.000
Pre and Post Reversals/Subject	0.15152	3.65822	0.63681	-1.14563	1.44866	0.238	32	0.813

Each subject's responses were then imported into the Color Vision Recorder to tabulate the CCI, AC-CCI, C-index, and the S-Index. These numbers allow each subject's results to be quantified and then further analyzed.

The paired-samples T-Test was also performed on both the pre and post CCI, AC-CCI, C-Index and S-Index scores. Table 3 further reveals that the T-Test found a statistically significant difference at the alpha = 0.05 level between the pre- and post-CCI

($t = 5.522$, $p < .001$), the pre- and post-AC-CCI ($t = 5.540$, $p < .001$), and the pre- and post-C-Index ($t = 4.590$, $p < .001$). This means that there is also a statistically significant difference in mean scores due to adaptation for the pre and post CCI, AC-CCI, and C-Index. The paired-samples T-Test did not reveal a statistically significant difference in mean scores for the S-index ($t = 1.380$, $p = .177$).

Table 3

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pre and Post CCI	0.23818	0.24778	0.04313	0.15032	0.32604	5.522	32	0.000
Pre and Post AC-CCI	0.22515	0.23347	0.04064	0.14237	0.30794	5.540	32	0.000
Pre and Post C-Index	0.26000	0.32543	0.05665	0.14461	0.37539	4.590	32	0.000
Pre and Post S-Index	0.08152	0.33943	0.05909	-0.03884	0.20187	1.380	32	0.177

DISCUSSION

The results surprisingly showed that there was some adaptation that did occur after the subjects were initially placed under a sodium vapor lamp and after sitting under the light for ten minutes. Out of the 33 participants, 29 made some errors on the first administration of the test and 24 participants showed an improvement between the two tests. Twelve participants had perfect scores on the second administration compared to only four on the first trial. According to past research, there should have been very little change between the two administrations of the Lanthony D-15.

Why did this occur? There are a few different reasons that we will consider to investigate the results. There is some known adaptation that is associated with a human's color visual system; however these are for the most part quick adaptations, with ten minutes being well beyond that threshold. [5,6,7,8]

Retinal adaptation is thought to occur within the photochemicals deep within the retina. These photochemicals decompose as light is introduced to the eye. Adaptation is reached once a balance occurs between the processes of regeneration and decomposition. When a constant intensity of light is placed upon the eyes, the eyes adapt leaving the visual response at a constant adapted state. The instantaneous response that occurs by a change in visual stimuli is therefore directly proportional to the intensity of the stimulus.[10]

Both appearance and discrimination have slightly different mechanisms of adaptation in the visual system, both of which are influenced by chromatic adaptation. The two main elements responsible for adaptation are broken down into a fast and slow component, which both play a role in appearance and discrimination. The fast component

is nearly complete in under a second, with the slow being complete within two minutes after the introduction of the stimulus. The fast phase of both mechanisms occurs between forty and seventy milliseconds. The cones are thought to be the primary player in the fast phase since this is roughly the same time constants found for receptoral processing in light adaptation. It is known that chromatic adaptation is fully complete by this two minute mark. A third, little known component, is an extremely fast mechanism that occurs well under a second. Due to the speed of the third component, it is thought that it occurs at a higher cortical level.[6]

There is a slight adaptation that further occurs between different wavelengths, however this is known to only occur during the fast phase. The mid-wavelengths in the visible spectrum of light tend to allow adaptation to occur even faster than those at the lower or higher ends.[7] Different illuminance levels in a person's visual environment cause adaptation to occur. Changing the brightness level further creates a shift in color matching.[11] This refers to the CIE Diagram, which provides a visual spectrum. The graph, shown in Appendix D, is much in the shape of a horseshoe, with pure colors located on the outside and mixed colors on the inside of the plot. Colors are often matched on this plot through its corresponding color that travels through pure white, located in the central part of the graph.[12] Less bright colors, with this brightness contrast change, causes the particular color to correlate with a color that is further away from the brightest point on the visual color spectrum.[11]

For example, when yellow is matched with a mixture of red and green under bright conditions, more red is needed to counteract the change in brightness. The opposite occurs in dimmer conditions, with less red needed to blend with green to match the

yellow. However, the amount of green necessary remained at a constant level. These changes occur due to processes within the photoreceptors.[13] Looking even further at color adaptation, at higher illuminations the mechanisms of chromatic adaptations seem to be forced to be more efficient. This causes the adaptation to occur at a faster pace.[8]

It is likely that adaptation was not the cause of differences between the first administration and the second. Studies on the Lanthony D-15 have shown that it is common for the test to have reversals between different administrations of the test. Both errors and reversals were common for the subjects. This test is often more difficult that the Farnsworth D-15 because of the desaturated hues used. It makes the test more discriminatory in detecting color deficiencies; however, it is hard for even color normal people to obtain accurate results. To eliminate the risk of false positives, the Lanthony D-15 should be administered three times. The three trials are needed because with this particular test, subsequent attempts can show either improvement or worsening.[14]

CONCLUSION

A sodium vapor lamp is not natural for humans to view objects, yet is used often in illuminating everyday situations. Using the Lanthony Desaturated D-15, the results after sitting under the light for ten minutes surprisingly showed that there was improvement between the two administrations. There are two thoughts on what may have caused this, being there is a longer adaptation that occurs than is currently understood, or that there is a significant learning curve when using the Lanthony D-15. In order to gain enough evidence to make an educated answer to this question, the experiment should be re-run, this time allowing each participant to perform the test three times under natural lighting before actually entering the room with the sodium vapor lamp. This will help rule out adaptation and fully answer our hypothesis.

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APPENDIX A

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING HUMAN SUBJECTS
INITIAL REVIEW

APPLICATION FOR APPROVAL OF A PROJECT
INVOLVING HUMAN SUBJECTS
INITIAL REVIEW (and 5 yr. renewal)

HSRC

Dr. Connie Meinholdt, Chair

College of Arts and Sciences
Ferris State University
Big Rapids, MI 49307
PHONE 231-591-2759
FAX 231-591-2541

E-Mail connie_meinholdt@ferris.edu

DIRECTIONS: Please complete the questions on this application using the instructions and definitions found on the attached sheets.

1. Responsible Project Investigator:
(Faculty or staff supervisor)
Name: Dr. Robert Buckingham, OD
Social Security Number: 368-66-9124

Department: Director of Clinics
College: Michigan College of Optometry

I accept responsibility for conducting the proposed research in accordance with the protections of human subjects as specified by HSRC, including the supervision of faculty and student co-investigators.
Signature: _____

Additional Investigator(s):

Name: Matthew A Johnson
SS# or Student ID#: 102-53-627

Name: Krystal K Kempf
SS# or Student ID#: 102-41-716

Name: _____
SS# or Student ID#: _____

Name: _____
SS# or Student ID#: _____

2. Address: If there are more than two investigators, please indicate who should receive correspondence, and provide further addresses on a separate page.

Responsible Project Investigator
Dr. Robert Buckingham, OD
6385 N Cottonwood Ave
Big Rapids, MI 49307
Phone #: 231-796-1570
Fax #: 231-591-3551
Email: buckingr@ferris.edu

Additional Investigator(s)
Matthew A Johnson
6480 N State Rd
Orleans, MI 48865
Phone #: 616-902-3696
Fax #: N/A
Email: john152@fsuimail.ferris.edu

3. Title of Project: Effect on the Lanthony Desaturated D-15 Test when Adapting to a Sodium Vapor Lamp

FOR OFFICE USE ONLY
Subcommittee _____ Agenda _____

4. Funding (if any) N/A
FSU Contracts and Grants app. # _____ if applicable

5. Has this protocol been submitted to the FDA or are there plans to submit it to the FDA? No [**X**] Yes [ ]
If yes, is there an IND #? No [ ] Yes [ ] IND # _____

6. Does this project involve the use of Materials of Human Origin (e.g., human blood or tissue)?
No [**X**] Yes [ ]

7. When would you prefer to begin data collection? April 3, 2006
Please remember you may not begin data collection without HSRC approval.

8. Category (Circle a, b, or c below and specify category for a and b.

a. This proposal is submitted as EXEMPT from full review.
Specify category or categories: _____
b. This proposal is submitted for EXPEDITED review.
Specify category or categories: 2D
c. This proposal is submitted for FULL sub-committee review.

9. Is this a Public Health Service funded, full review, multi-site project?
No [**X**] Yes [ ]
If yes, do the other sites have a Multiple Project Assurance IRB that will also review this project?
[ ] No. Please contact the HSRC office for further information about meeting the PHS/NIH/OPRR regulations.
[ ] Yes. Please supply a copy of that approval letter when obtained.

10. Project Description (Abstract): Please limit your response to 200 words.

Many highways are illuminated with sodium vapor lights which has the potential to create color discrepancies in people with normal color vision. This project will look at a subject's ability to adapt under a sodium vapor lamp, calibrated to twenty-eight foot-candles, using a Lanthony Desaturated D-15. The test will be administered initially under the sodium vapor lamp and again under a pre-determined time to see if any

adaptation occurred. Each subject is to have normal color vision and no ocular pathology.

The data collected will be used to determine the Color Confusion Index, (CCI) for each subject. The CCI data will then be analyzed using SPSS software.

11. Procedures: Please describe all project activities to be used in collecting data from human subjects. This also includes procedures for collecting materials of human origin and analysis of existing data originally collected from human subjects

Each subject will be assigned a random number. The number, along with the subject's gender and age will be recorded on a form. The subjects will be instructed to arrange the pre-determined random caps of the Lanthony Desaturated D-15 color test in order immediately after exposure to the sodium vapor lamp. They will then wait a specified amount of time in only sodium vapor lighting. The subject will again complete the Lanthony Desaturated D-15 color test to see if any adaptation occurred. These results will also be recorded on the recording form.

12. Subject Population: Describe your subject population. (e.g., high school athletes, women over 50 w/breast cancer, small business owners)

The subjects will consist of mostly optometry students, but all subjects will have normal color vision and no ocular pathology.

a. The study population may include (check each category where subjects **may be included by design or incidentally**):

Minors	[ ]
Pregnant Women	[**X**]
Women of Childbearing Age	[**X**]
Institutionalized Persons	[ ]
Students	***[X]***
Low Income Persons	[**X**]
Minorities	[**X**]
Incompetent Persons (or those with diminished capacity)	[ ]

b. Number of subjects (including controls) >33

c. How will the subjects be recruited? (Attach appropriate number of copies of recruiting advertisement, if any.

Sign up sheet located in Optometry's Student Affairs Office, which may be passed around the classrooms.

d. If you are associated with the subjects (e.g., they are your students, employees, patients), please explain the nature of the association.

Dr. Buckingham is the Director of Clinics at the Michigan College of Optometry, at which the students attend. Matthew Johnson and Krystal Kempf are fellow students at the Michigan College of Optometry.

e. If someone will receive payment for recruiting the subjects please explain the amount of payment, who pays it and who receives it.

f. Will the research subjects be compensated? [**X**] No [ ] Yes.
If yes, details concerning payment, including the amount and schedule of payments, must be explained in the informed consent.

g. Will the subjects incur additional financial costs as a result of their participation in this study? [**X**] No [ ] Yes. **If yes**, please include an explanation in the informed consent.

h. Will this research be conducted with subjects who reside in another country or live in a cultural context different from mainstream US society? [**X**] No [ ] Yes.

(1) If yes, will there be any corresponding complications in your ability to minimize risks to subjects, maintain their confidentiality and/or assure their right to voluntary informed consent as individuals? [ ] No [ ] Yes.

(2) If your answer to h-1 is yes, what are these complications and how will you resolve them?

13. How will the subjects' privacy be protected?

The subjects will be assigned a number. The random assigned will be a means of tracking the corresponding data. No name or other means of personal identification will be collected. All data/ numbers will be reported in aggregate.

14. Risks and Benefits for subjects:

None

15. Consent Procedures

See attached form.

CHECKLIST: Check off that you have included each of these items. If not applicable, state N/A:

[X] Completed application

[X] The correct number of copies of the application and instruments, according to the category of review

[X] Consent form (or script for verbal consent), if applicable

[N/A] Advertisement, if applicable

[X] One complete copy of the methods chapter of the research proposal

Additional Investigator: *Main Contact*
Address: Krystal K Kempf
34 N Charlotte Hwy
Mulliken, MI 48861
Phone: 517-242-4069
Fax: N/A
Email: kemp8@fsuimail.ferris.edu

APPENDIX B

PARTICIPANT CONSENT FORM

Information for Participants

Effect on the Lanothony Desaturated D-15 Test when Adapting to a Sodium Vapor Lamp

This study will examine the effects of light adaptation on the performance on the Lanthony Desaturated D-15 color vision test. This project will look at a subject's ability to adapt under a sodium vapor lamp, calibrated to twenty-eight foot-candles, using a Lanthony Desaturated D-15. The test will be administered initially under the sodium vapor lamp and again under a pre-determined time to see if any adaptation occurred.

The volunteer will be required to spend approximately fifteen minutes adapting to the sodium halide lamp after initially completing the Lanthony Desaturated D-15. After this time, the volunteer will again complete the Lanthony Desaturated D-15.

Volunteers must have normal color vision and be free of any ocular pathology. If you wear contacts you may participate. If you do not need glasses or contacts then you may participate.

The volunteer is at no risk, physical or otherwise.

Participation is voluntary; volunteers may choose not to participate at all, may refuse to participate in certain procedures or answer certain questions or may discontinue the experiment at any time without penalty or loss of benefits to which the volunteer is otherwise entitled.

The volunteers will remain anonymous in any report of research findings. All data will be reported in aggregate groups. Your privacy will be protected to the maximum extent allowable by law.

If the volunteer has any questions regarding the study, Dr. Robert Buckingham may be contacted at 231-591-2202. Questions regarding volunteer's rights as research participants or complaints about the manner in which the study is conducted (ethical, moral or otherwise) may be directed to the Human Subjects Research Committee (HSRC) by contacting Dr. Connie Meinholdt at (231) 591-2759 or via email at Connie_Meinholdt@ferris.edu.

Participant Consent Form

1 I have read and understood the information for volunteers on the above research study.
2 I am aware of the requirements involved in the study and satisfy the requirements.
3 I freely choose to participate in this study and understand that I can withdraw without penalty at any time.
4 I understand that the research study is strictly confidential.
5 I hereby agree to participate in this research study.

Name: _____

Signature: _____ Date: _____

APPENDIX C

FARNSWORTH DICHOTOMOUS D-15 TEST FOR COLOR BLINDNESS

PANEL D-15 RESULTS FORM

FARNSWORTH DICHOTOMOUS TEST for Color Blindness – Panel D-15

Name..... Age..... Date..... File No.....

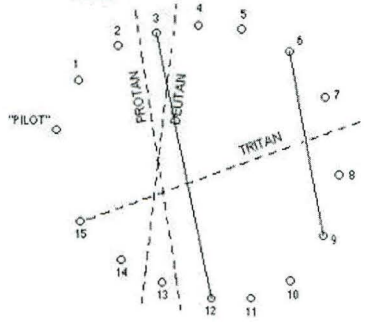
Department..... Tester.....

DICHOTOMOUS ANALYSIS

Type	Axis of Confusion			
PROTAN	(RED-bluegreen)	?	PASS	?
DEUTAN	(GREEN-redpurple)	?		
TRITAN	(VIOLET-greenishyellow)	?	FAIL	?

Test Subject's Order	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Retest Subject's Order	__	__	__	__	__	__	__	__	__	__	__	__	__	__	__

TEST



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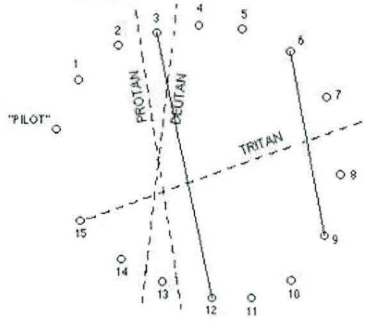
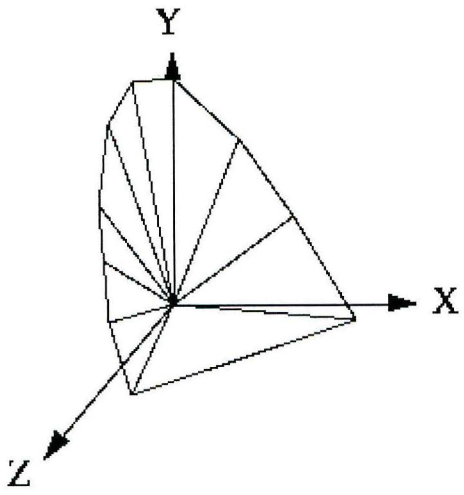


APPENDIX D

CIE CHROMATICITY DIAGRAM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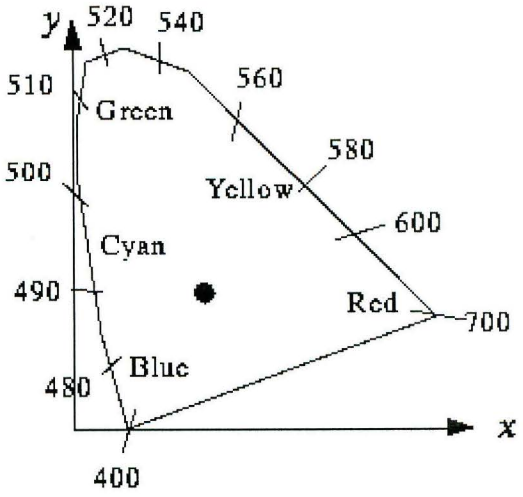
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Cyan
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Blue
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