1984

The development of a low cost microcomputer generated color vision exam

Larry L. Bradshaw
Iowa State University

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THE DEVELOPMENT OF A LOW COST MICROCOMPUTER GENERATED
COLOR VISION EXAM

Iowa State University

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The development of a
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generated color vision exam

by

Larry L. Bradshaw

A Dissertation Submitted to the
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DOCTOR OF PHILOSOPHY

Major: Industrial Education and Technology

Approved:
Signature was redacted for privacy.
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For the Graduate College

Iowa State University
Ames, Iowa
1984

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CHAPTER I

INTRODUCTION

For many years it has been recognized that some persons observed colors differently than most of the population. This phenomenon has been studied, tests devised and results published as to the occupations for which discriminating color vision was important. Color vision testing in the U.S. is conducted by the military services, vision examiners, and university clinics. With the availability of color television and microcomputers, the testing of color vision may be more widely available if a test can be developed using these tools.

The problem

The problem of this study involved assessing the degree to which a microcomputer could provide the same diagnostic capability to identify color vision deficiencies as compared with currently available tests.

Statement of the problem

The problem of this study was to assess the degree to which a low cost microcomputer can provide accurate identification of color vision differences among humans. The criterion for accuracy was the measure of color vision acuity provided through the use of a currently available commercial instrument for the detection of color vision deficiencies.

Purpose of the study

It was the purpose of this study (a) to develop a computer program which would generate visual displays for use in testing color vision,
(b) to investigate if relationships exist between these displays and accepted color screening tests, and (c) to present the results as found in an experimental study.

Need for the study

Knowledge about our own color perception is important for knowing the ways one must adjust to educational systems, for vocational choices, and to make choices which lead to safe living.

Color vision has been identified as an important factor in the following occupations: aircraft pilot, railway engineer, electronic technician, analytical chemist, interior designer, graphic designer, graphic artist, and auto refinisher as a partial list.

Diabetic individuals use color matching to determine sugar levels in their blood and urine. Persons employed in the medical profession need excellent color discrimination to avoid some life threatening diagnostic errors.

There is a general recognition that color stimulation enhances the enjoyment of visual material. Color may have a negative effect on 17,760,000 males and 2,200,000 females in the United States when the results of a study by Dwyer (1974) are projected to the national population. Teachers need to have color vision information about themselves and each student to help the teachers understand how this condition may effect behavior and learning. The director of color vision research for the U.S. Navy (Paulson, 1983) indicated, that a need existed for color vision testing in the public schools along with an
understanding of the phenomena of differences in color vision. New strategies might be needed to help textbook designers, computer programmers, and any other category of persons involved with the preparation of educational media. Teachers might need a more complete understanding of pupils comprehension difficulty due to color confusion. Asay and Schneider (1974) found persons with deviant color vision unimpressed by color-coded reading material. These same persons were critical of the use of color to transmit information when it was not absolutely necessary. Dwyer (1974) found color perception deviant biology students performed with less accuracy after color coded transparencies were used when compared with performance following the use of black and white transparencies.

Since many American schools presently have microcomputers, the feasibility of developing a program for screening persons quickly and inexpensively for color vision characteristics was considered.

Research questions

1. Is the Computer Color Vision Exam a valid instrument for screening persons with poor color perception?

2. To what degree does the COVE agree with the Ishihara pseudoisochromatic plates?

Research hypotheses

A hypothesis was made that the Cohen K coefficient of agreement (Bishop, Fienberg, & Holland, 1975) between the total score on the Computer Color Vision Exam and the Ishihara pseudoisochromatic plates
total did not differ from .50 beyond that expected by chance at the ninety-five percent level of confidence.

The alternative hypothesis was that the coefficient of agreement between the Computer Color Vision Exam total score and Ishihara Pseudoisochromatic Plate total score would be greater than .50 beyond that expected by chance at the ninety-five percent level of confidence.

A second hypothesis was that all the betas between the Ishihara pseudoisochromatic total score and the seven color scores of the Computer Color Vision Exam would not deviate from zero beyond that expected by chance on a test of multiple regression at the ninety-five percent level of confidence.

The alternate hypothesis was that not all the betas between the Ishihara pseudoisochromatic total score and the seven color scores of the Computer Color Vision Exam would depart from zero beyond the ninety-five percent level of confidence.

Assumptions

1. Color vision testing results were independent of the variations in the testing conditions.

2. The Ishihara pseudoisochromatic plates are a valid measure of color vision.

3. Any learning which results from the ordered administration of the Ishihara pseudoisochromatic plates and the CCVE will produce an equal effect on subsequent administration of either form.
Limitations

1. Color picture tubes do not allow all hues and saturation of the human visual spectrum to be displayed.

2. Hue, saturation, brightness, and contrast were controls available to the Computer Color Vision Exam administrator. Instructions were required to set the color images on the screen to a standard.

3. Validating the CCVE required a much higher percentage of persons with color perception difficulty than the normal population.

Procedure of the study

1. Review the literature pertaining to color vision, color vision testing, and validating color vision examinations.

2. Define the population to be studied.

3. State the hypothesis.

4. Develop the model for data collection.

5. Write a computer program which will generate a color display which can be used for vision testing.

6. Pilot test the examination.

7. Obtain approval for testing human subjects.

8. Complete arrangements for data collection.

9. Collect the data.

10. Analyze the data.

11. Report the findings, conclusions, and pose questions for further study.

The initial plan for this study was to prepare a computer program for the Texas Instruments 99/4 color microcomputer which would generate
a color vision screening exam. This exam was to be validated at the vision clinic, College of Medicine, the University of Iowa, Iowa City, Iowa, against the Farnsworth 100 Hue test in a correlation study making use of the canonical correlation statistical procedure.

Several factors confounded the proposed plan.

1. The Texas Instrument computer malfunctioned frequently and was required for use by other people.

2. The University of Iowa clinic was understaffed at the time for data collection.

3. Without the aid of a mainframe computer, the Farnsworth 100 Hue test required excessive administration and scoring time.

These factors led to alterations in the plan. A new low cost microcomputer, the Commodore 64, became available on the market. The researcher was able to purchase this machine and a General Electric 10" television set for a monitor. Development of the instrument began again. The Ishihara pseudoisochromatic plates were recommended for the validation study by Ms. Helen Paulson, director for vision research, United States Naval Submarine Base, Groton, Connecticut. The Ishihara exam was designed to screen for red/green defective vision. To complete the testing program Ms. Paulson sent a copy of the F2 Tritan plate which screens for a tritan defect, a rare nonsex-linked congenital variety of color vision. The plate was administered to subjects in the study to identify persons with this defect.

The sample for the study was taken from two Iowa school districts which granted permission for collecting data. Approval of the study by
the Human Subjects for Research Committee led to the completion of a pilot study to determine the test-retest reliability of the CCVE. Iowa State students and Iowa residents from two rural communities participated in the pilot study. After the pilot study was completed and the arrangements were completed for data collection in Cedar Rapids and Des Moines, two CCVE sets were prepared and two teams of examiners were prepared to help in the data collection process. Upon completion of the data collection, analyses was undertaken.

Definitions of terms

Achromat  A person who perceives visually only black and white and their intermediate tones.

Anomaloscope  An instrument used to measure color vision and other ocular properties and is a standard against which other color measures are compared. This is a laboratory piece of equipment and is not practical for mass use.

Brightness  This term is a description of value and chroma (Munsell, 1976).

Chroma  The term used to indicate the degree of departure of a hue from a neutral gray of the same value (Munsell, 1976).

Chromatic aberration  The result of unequal refraction of light for various wavelengths of the visual spectrum.

Color  The word color used in the psychological sense means a sensation; the physical meaning refers to specific wavelengths of visible radiation (Tuttle and Schottelius, 1961).
Color blind  A term used inappropriately to indicate visual discrimination problems often designated as "visually color confused", "color deficient", or "color deviant".

Color temperature  The relationship between the temperature of an incandescent body and the color of the light emitted. The scale used is degrees Kelvin.

Color vision tests  These tests are referred to as measurement instruments for color vision. Some of these tests are for screening persons who observe color different from the majority of the population. Tests have been developed to screen deviant observers by means of color matching, discriminating hues against differing backgrounds, arranging hues, and concealing information by using different hues of equal density.

Dichromatic  This word is used to describe visual characteristics of persons who can perceive only two colors, blue and yellow, in addition to the shades of gray.

Hue  This term is used to indicate the relationship of a color to a visually linear scale of 100 (Munsell, 1976).

Intensity (Saturation)  The amount of a hue mixed with other hues.

Metamerism  A phenomenon shown by two matching hues under one source of illumination to be nonmatching under other sources of illumination.

Pseudoisochromatic plates  These instruments are designed to screen color confused from normal viewers. Their design is based on
equal intensity of hue as a background compared with different hues but equal intensity in the foreground. The hue wavelength is chosen for maximum critical error.

**Saturation** The amount of a hue mixed with other hues.

**Spectrum** The range of electromagnetic frequencies in our known environment (Figures 1 and 2).

**Value** This term applied to the degree lightness or darkness of a color in relation to a neutral gray scale. The gray scale is linear extending from zero for absolute black to 10 for absolute white (Munsell, 1976).

**Wavelength** The distance from crest to crest of sine waves. The visible portion of the spectrum is from 400 millimicrons to 700 millimicrons (Figures 1 and 2).
Figure 1. Wavelengths of Different Colors of the Visible Light Spectrum
Standard luminosity and relative brightness curves for the visible spectrum.

Tri-stimulus curves for the red, green, and blue sensitive cones of the retina.

Photopic and scotopic curves comparing cone vision by day with rod vision by night.

Figure 2. Visual Spectrum for the Human Eye.
CHAPTER II

REVIEW OF THE LITERATURE

There is an increasing volume of literature on the subject of color vision. Some sources of value to this study included how the human eye perceives color, test descriptions for measurement of color vision, theories of color vision, and studies undertaken on the effects of color when presenting material to enhance learning. Material was reviewed on the functional processes of color television receivers and programming of the microcomputers for color graphic displays.

Literature on the proportion of population experiencing limited color vision

Waaler (1973) studied genetic patterns of visually color-limited school children and their parents and grandparents. He generated a model which explained the frequency of limited color vision in populations and frequencies expected in subcategories of color vision. Studies taken from different populations around the world were summarized by Burnham, Hanes, and Bartleson (1963). This summary showed the incidence of limited color vision to vary from one ethnic group to another. Eight percent of the Caucasian males and .76 percent of the females were found to be limited in color vision. The frequency for Asian males was 4.9 percent and was .64 percent for females. A heterogenous group including American Indian, Black, Eskimo, and Mexican had frequencies of 3.12 percent for males and .69 percent for females. De Reuck and Knight (1965) reported that "color blindness" was defined
as two standard deviations below the mean on color vision screening tests.

The Committee on Vision (1981) identified color vision problems in the following manner. Two distinct causes of color vision problems were congenital and acquired. The congenital group included members with a sex-linked chromosome for color vision change and members with a chromosome for color vision shift which was not sex-linked. Members with sex-linked color vision were classified according to their matching performance on the Nagle I anomaloscope. The acquired color vision group gained their vision problem through accident, disease, toxicity to the body, or aging. Discrimination loss on the blue-yellow axis is greater than the color vision loss on the red-green axis. This may be due to the greater area for the cones for blue vision in relation to the area for the cones for yellow, red, and green (Chapanis, 1956). Some persons are members of both congenital and acquired groups. The congenital color vision problems were:

1. Achromatic vision is insensitive to hues. The rods are functioning but the cones are not.

2. An anomalous trichromat views all colors but needs extra light for matching dark colors. This group can be subdivided into four groups.

3. Dichromats make their color matches with two of the three primary colors available. Dichromats can be classified as either protanopes or deuteranopes.

4. Tritans are the inheritors of a color defective chromosome that is not sex-linked. These viewers cannot detect color differences
when the difference is either the amount of yellow or the amount of violet in the color.

Acquired color defective persons may be identified by their difficulty with blues and yellows rather than the reds and greens associated with most congenital visual difficulties. In addition it is not uncommon to find the color vision different for the two eyes for persons with acquired color vision loss, a phenomenon not associated with the genetic types of deviant color vision.

Literature on theories of color vision

The oldest theory first proposed by Thomas Young (1802) and later developed by Herman von Hemholtz (1852) held that the three identified types of cones found in the retina of the eye were allowing the eye to be sensitive to the three primary colors of red, blue, and green. This theory was widely accepted by physicists but has been shown to be too simplistic.

Ewald Hering developed another theory of color vision (1895). He thought the three identified cones each carried a pair of colors. The color pairs were red and green, blue and yellow, black and white. This theory offered an explanation for the color yellow which was observed when red and green were not. Yellow in the Young/Hemholtz theory was available as the result of adding green light to red light. This theory also allowed for perception of differing tints and tones of hues.

Christine Ladd-Franklin presented a theory (1929) which held that primitive eyes were capable of perceiving only black and white or gray
tones. She felt the next evolutionary stage for humans, allowed perception of blue and yellow and a later evolution the perception of red and green. This theory based on the Hering "Paired Cone" theory didn't attempt to explain how persons perceive color.

Johannes von Kries reported in 1894 that rods in the retina respond to light waves producing the sensation of colorless twilight vision (Harriman, 1947). He additionally reported cones also respond to light waves allowing chromatic daylight vision.

Hartridge (1949) was one researcher who felt there might be more than three types of cones. He advocated a "cluster" hypothesis, where cones of common types tend to be found in clusters, each cluster being sensitive to one particular wavelength.

Hurvich (1981) has been carrying out research on color vision since the mid 1950's. He proposed an "Opponent-Process" theory. This theory accounts, by means of mathematical models, how color vision is possible. It answers the limitations of both the Young/Helmholtz and the Hering "Paired Cone" theories.

**Literature on the physiology of color vision**

In order to perceive light and color the human brain requires electrical signals. The reception and decoding of wavelengths of light is accomplished by the eye. The eye has several different media for light to pass through before reaching the decoders.

The cornea, a transparent glassy coat adjacent to the outside environment, seals in the aqueous humor, a transparent liquid which lubricates the iris as it opens and closes on the lens as shown in
Figure 3. The iris is the colored portion of the eye which is easily observed by others and which we use to specify a person's eye color. The iris functions much like the f-stop on a camera, automatically opening and closing according to the amount of light present. The transparent crystalline lens is behind the iris but in front of a spheroid-shaped cavity, the vitreous humor, filled with a transparent substance of gelatin consistency. Figure 4 illustrates the inner most portion of the eye, the retina, is a specialized receptor area for the optic nerve. It has three layers of neurons; rods and cones are the light receptors found in one layer. Bipolar cells and ganglion cells each form an additional layer. Axons of the ganglion layer make up the optic nerve (Figure 5). The number of cones decrease progressively from the central portion to the periphery of the retina, while the number of rods correspondingly increase. For normal color vision, all the parts of the eye must be transparent, (Tuttle and Schottelius, 1961). Since these elements of the eye have densities greater than air, light waves refract on the front of the cornea and both surfaces of the lens.

Overheim and Wagner (1982) reported that when the lens is removed in cataract surgery the patients are able to observe wavelengths in the ultraviolet region which are filtered out by the lens. The lens yellows as a person ages resulting in varying amounts of loss of color vision in the violet and blue portion of the visual spectrum. When light waves strike the retina, a change of energy from light to electrical impulses is performed. The cones have a pigment, rhodopsin, which bleaches when hit by light waves.
Figure 3. Cross Section of the Human Eye
Figure 4. Schematic of Retinal Area of the Human Eye
Figure 5. A Schematic Representation of Retina Cells
Exactly how the cones are selective is still unknown and results in a variety of theories and hypotheses of how we observe color. When the cones are bleached, an electrical impulse is sent to the brain, the brain interprets the signals to produce a mental impression of color.

Acquired deviant color vision can be explained but it is unknown exactly how or what portion of the decoding process is different for persons with congenital color vision than for the portion of the population who perceive color normally.

**Literature on color vision and education**

Dwyer (1974) studied the effect of presenting biology instruction material with color-coded media on the outcomes of student performance. He suggested caution and understanding of color confusion when presenting information which could be misinterpreted by visually color limited persons. Similar results were observed in the use of color-coded material for instruction in a study by Asay and Schneider (1974). Chen (1971) also raised questions as to whether color-coded instruction might hinder comprehension for visually color limited students, although pleasant and enhancing for students with normal color perception. Richards and Macklin (1971) presented material indicating colored overhead transparencies may cause loss of information to a portion of the viewing audience.

Color terms, according to Lyons (1971), for a particular language do not correlate with color terms for another language. The boundaries are often different and even the number of terms for a given color may
vary greatly. Color vision exams should avoid terminology if at all possible.

**Literature on color vision tests**

Alarik Frithiof Holmgren (1877) developed a color vision test using a series of skeins of wool. The object of the test was to match colors from the series with either red, green, or rose. The test was based on an assumption that three forms of color blindness existed; red blindness, green blindness, and visual insensitivity to violet.

Some color vision test were developed which used colored beads. Oliver developed a bead test in 1902, Abney in 1906, and Edridge-Green in 1920 (Harriman, 1947). Fridenberg used square pieces of colored cardboard for the exam he developed in 1903 (Harriman, 1947).

A lantern test was devised by Williams in 1903 to find men suited for sailing. These men needed to be able to read color coded signals from other ships at night (Harriman, 1947). The administration of this test required a dark environment (Chapanis, 1956). Yellow, red, and green lights were displayed from a distance. The potential sailors were asked to identify the three colors.

Figure 6 is an example of another type of test, the pseudoisochromatic plates, which became popular. Stilling (1873) developed a set in Germany. Ishihara (1943) developed a different set in Japan. The first plate of this set is a demonstration plate which was designed so all observers could read it correctly. Plates two through nine were designed to screen for difficulty of red-green color perception. Plates two through five are transformation plates.
This plate is used to demonstrate the test. The 12 can be perceived by all sighted persons.

Most people perceive the figure 8. Those with low red-green perception perceive the figure 3. Those with no color perception see no figure on this plate.

Most people with low red-green perception observe the figure 45. Most normal and those without color perception cannot read this plate.

Figure 6. Plates from a Pseudoisochromatic Color Vision Exam
Transformation plates are those that are designed so both normal and
defective observers perceive an object. The two groups of observers,
however, perceive different objects. Plates six through ten are
vanishing plates. A number can be easily perceived on these plates by
persons with normal color vision but the image has vanished for those
with red-green vision difficulty. Plate nine can be observed by persons
with low red-green perception but has no distinguishable pattern for
those with normal color vision. Plates eleven and fourteen were
developed to collect information about red-green perception from
illiterates and were not used in this validation study. Plates twelve
and thirteen were diagnostic plates of the vanishing variety. These two
plates were designed to categorize persons with low perception of
red-green into two groups.

The Ishihara test was scored by allowing one point for each plate
observed as a person with normal color vision would observe it. Two or
fewer errors are considered normal on this version of the Ishihara test
(Committee on Vision, 1981).

While taking the Ishihara test, the examinee is instructed to hold
the plates under illumination that represents north sky daylight. The
plates are to be held at a distance of 75 cm from the face in a line
perpendicular to the nose. Each plate is to be read before a three
second interval has elapsed. The next plate then is read until the test
is completed.

Test-retest data was not found on the Ishihara test. The test has
been compared with the Nagle anomaloscope several times. The Cohen K
statistic of agreement was reported as follows: Hardy K=1.00, Sloan and Habel K= .97, and Belecher K=.95 (Committee on Vision, 1981).

The Ishihara pseudoisochromatic plates are recognized by many licensing authorities as an efficient screening exam for red-green vision defect.

Dvorine (1944) developed a set in the United States. He thought color vision could be taught, a hypothesis later rejected. Also in the United States, Hardy, Rand, and Rittler (1944) developed a set of plates using shapes rather than the usual numbers in hopes that illiterates and small children could be screened for color vision.

An arrangement test was introduced by Pierce (1934). This test indicated the wide range of color discrimination ability and aptitude which existed among "normal" sighted persons.

Contemporary arrangement tests include the Farnsworth 100 Hue and the Farnsworth Dichotomous 15 panel. The 1953 Intersociety Color Council of America Aptitude Arrangement Test discriminated for saturation rather than hue (Committee on Vision, 1981).

Lanthony developed two arrangement tests for identifying persons who had acquired color vision defects, the D-15 Desaturated Panel and the New Color Test (Committee on Vision, 1981).

The Nagle I anomaloscope is a piece of laboratory equipment used in validating color vision tests designed to find red and green color vision and has been used as the standard in classification of color vision types (Committee on Vision, 1981). On this instrument, the viewer observes a circle split in two parts, a top and bottom. The
lower half is yellow. This yellow can be made darker or brighter by
turning a knob. The upper half of the circle is filled with a mixture
of red and green. The proportion of red-green can be adjusted by a
knob. Color matches are performed by the adjustment of the the two
knobs. The knobs are calibrated for the wavelengths being displayed.

The Cohen K coefficient of agreement is the statistic indicated for
validation of color vision screening tests (Committee on Vision, 1981).

A color vision examination which is part of a vocational screening
battery of tests was published by Valpar International, Tucson, Arizona,
in 1982. The test was developed for the Apple and IBM microcomputers.
Two rows of three colors were displayed on the screen. A cursor was to
be moved to the color which matched a color square at the bottom center
of the viewing area. The results of the test were reported on a scale
where 1 = high and 5 = low. These ratings were chosen according to the
Dictionary of Titles, a dictionary of vocational job titles (Valpar
Corporation, 1983).

Dr. Rastatter, vice president of technical services, indicated this
test has not been validated against an existing test. An anticipated n
of 3000+ for an internal validation is to be available by the end of
1983. He felt the Valpar test was a screening exam which indicated
levels of color perception and was not concerned with which colors were
problematic. The only feedback about color vision was if the subject
was a 1 or a 5. The subject was then advised to have further testing
done with a normative color vision exam by a eye specialist. The test
is a criterion referenced exam, the results used as a factor to match a
person with possible jobs as defined by the Dictionary of Titles.

**Literature on test validation**

The process of evaluating an instrument is a necessary step toward the description of an instrument's appropriateness, precision, and repeatability. Validation is the statistical procedure of analyzing test results in relation to criterion data (Super, 1949). Ebel (1979) concluded that only when test scores are used to draw conclusions in particular situations does the question of validity arise. The question of validity is projected to the use of the scores rather than to the instrument itself. The most important characteristic for a test is that subjects achieve scores which accurately indicate their ability in relation to other subjects on the construct being measured. The reliability of an instrument is dependent upon the instrument being administered in a defined manner to a defined population sample (Polit and Hungler, 1978).

The reliability of a new color vision test is assessed by administering the test on two separate occasions. To determine the validity for a test designed to screen or detect red-green visual defects, the test results should be compared with the results of a standard test (Committee on Vision, 1981).

A statistical measure the Cohen K of agreement is a useful in the determination of validity (Bishop et al., 1975). This statistic is encouraged for color vision studies so the coefficient reported can then be readily interpreted (Committee on Vision, 1981).
Literature on illumination

Color perception is influenced by the frequency spectrum of the source of illumination. A standard illuminant must be used if the results from the test are to be considered valid. If color matching is critical, then a color perception test should be administered each time the illuminants are changed. Laboratory tests for color vision in the northern hemisphere usually specify the illuminant to match the spectrum given off by the north sky (Committee on Vision, 1981). This specification is the control for the illumination variable and must be followed if the results are to be valid. Freeman devised the Illuminant Stable Color Vision Exam to be valid under all illuminants (Committee on Vision, 1981). The test was not successful and is no longer being produced. A major problem with illuminants is called metamerism, that is, a single color viewed under different illuminants appear to be unmatched. The Vitalite lamps manufactured by the Durotest Company were found to not have metamerism with north daylight sky when an evaluation of the lamps was conducted by a lighting technician from Macbeth Color Corporation for the Vision Clinic, College of Medicine, University of Iowa. A special metamerism test kit was provided by the Macbeth Color Corporation, Newburgh, New York, for testing illuminants used for this study. The Vitalite lamps were specified for the validation of the Computer Color Vision Exam in this study.

The fluorescent lamp has some desirable characteristics. They maintain their color emission within a very small tolerance for long periods of time. The lamps are more efficient in their electrical use
than tungsten lamps and the illumination they provide is nearly shadowless (Henderson and Marsden, 1972). The color needed for vision testing if accomplished by the mixture of phosphors. The phosphors used in the manufacture of these lamps are alkaline earth-halogen-containing phosphates of the hexagonal apatite crystal structure. They require either antimony or manganese. The alkali metals are either calcium or strontium. The emitted color depends on a ratio of fluorine to chlorine gas and the concentration of manganese. A number of inorganic phosphors are available which can be mixed or be used alone for fluorescent lamp preparation. Some of the important phosphor used in producing special color emissions are:

1. zinc silicate emitting green
2. calcium silicate emitting pink
3. calcium halophosphates emitting blue to pink.
4. cadmium borate emitting red
5. strontium magnesium phosphate emitting light pink
6. magnesium fluorogermanate emitting deep red
7. magnesium gallate emitting cyan
8. yttrium emitting red
9. magnesium tungstate emitting pale blue
10. calcium tungstate emitting deep blue
11. barium titanium phosphate emitting blue-white.

The fluorescent lamp produces its light by having mercury in a gaseous state produce short wave radiation in the nonvisible ultra violet (253.7 nm) region of the spectrum. These frequencies excite the
various phosphors causing them to emit light in the visible spectrum (Henderson and Marsden, 1972).

**Literature on color picture tubes**

The current technology allows for the phosphor coatings on the screen to be in strips of red, blue and green. The array of vertical shaped strips is deposited in horizontal rows. Close behind the phosphor coating two color grids are placed parallel to the phosphor strips. The two grids are insulated from each other and spaced with respect to the phosphor strips so that an electron beam passing between them can with slight deflection strike either a red, green, or blue phosphor strip. The remainder of the construction is like that of a monochrome picture tube. Deflecting and focusing the electron beam is accomplished electrostatically after the beam is passed through the grids, by applying proper voltage between the color grid wires. The grid wires are called red and blue grids because of their position behind those two color phosphors. The green phosphor strips are halfway between the adjacent red and blue strips. A straight undeflected electron beam causes the green phosphor to emit green light. When a red grid becomes positive with respect to the blue grid, the beam is deflected to the red phosphor and red light is emitted. When the voltage on the red grid is negative with respect to the blue grid, the blue phosphor is excited. Computer monitors send signals to the picture tube at this point of input.
To obtain a three color display or use a television receiver as a computer monitor with normal horizontal scanning, a sine wave voltage at 3.58 Mhz. frequency is applied between the red and blue grids. As the beam travels horizontally between a pair of grids, it follows a sine wave path and alternately strikes each of the three phosphor strips as it moves across the viewing screen. As the beam is scanning horizontally with the sine wave, color video signals are applied to the grid so proper saturation information modulates the beam that scans and strikes the phosphors (RETMA, 1954).

The manufacture of the television screen is a process of extreme accuracy. In addition to physical accuracy, the luminous characteristics for the three colors must be nearly equal for correct color balance to be achieved. The green phosphor was gold activated zinc cadmium sulfide, blue was gold activated zinc sulfide. In order to take advantage of the fluorescent intensity of these phosphors a red emitting phosphor was needed which could match the intensity for the blue and the green phosphors. Europium activated yttrium oxide or yttrium oxysulfide were the compounds found to yield the desired results for the red phosphor (Henderson and Marsden, 1972). The present tube design does not require purity coils or convergence magnets, simplifying the television set and reducing the number of adjustments required for color (RETMA, 1954).

Santucii et al. (1953) were searching for answers about the most effective color variables in visual communications for a new generation of aircraft instrumentation using color picture tubes. Screen intensity
was held at 15 candles per meter square. The screen background was held black at two candles per meter square. Red with blue or violet was found to be most accurately perceived. Increased saturation improved visual acuity for this study. Six colors were found to project information satisfactory: red, yellow, green, cyan, blue, and violet. Visual sensitivity to blue was lowest, concurring with previous findings about human color perception. Green is the color perceived with the greatest sensitivity.

**Literature on chromaticity**

Many colors can be simulated by adding suitable intensities of red, blue, and green. Some colors may be found which cannot be specified by the three transmitted primary colors alone. The Commission Internationale de l'Elairge (CIE) defined three arbitrary primary colors X, Y, and Z which allow specification for any actual color (Hurvich, 1981). The amounts of these primaries needed to match a color of a particular wavelength is called a tristimulus coefficient. The trichromatic coefficients x, y, and z are defined as:

\[
x = \frac{X}{X + Y + Z}
\]

\[
y = \frac{Y}{X + Y + Z}
\]

\[
z = \frac{Z}{X + Y + Z}
\]

and \[x + y + z = 1\]

A two dimensional plot formed by using two of the trichromatic coefficients to represent colors on a cartesian coordinate chart is a
coefficients to represent colors on a cartesian coordinate chart is a chromaticity diagram (Figure 7). The scales on the X and Y axis are linear. The gumdrop shaped boundary is calibrated in millimicrons representing the pure colors. The colors which are observable by the human eye are within the boundary. When three distinct physical colors are represented by points on the diagram and lines are projected between the points to form a triangle, all possible colors produced by the addition of the wavelengths were found within the triangle. When the points are plotted at .365x, .65y for red, .2x, .725y for green, and .5x, .15y for blue a triangle can be drawn which is the boundary for the colors possible to be emitted and observed on a color picture tube. Referring to Figure 7, it can be observed that the red which is emitted on a picture tube is a pure color but the frequency is not 652 millimicrons which is the frequency for pure red. Thus, when the television red is compared with the red on the CCVE standard, most observers perceived the picture tube color as orange. The blue and green colors are not pure colors on the picture tube but most viewers can easily discriminate them. Normal television viewing is comprised of moving scenes which prevent the close discrimination of color. The human visual receptors and the mental processes allow us to perceive color through association when the colors are relatively close to what we perceive in actual scenes. Therefore, the color on picture tubes is adequate for normal television viewing but was not as precise as the researcher would have desired for the CCVE.
Figure 7. Chromaticity Diagram
Summary

Color vision is not the same for all humans. Perception of color which differs from the majority is thought to be caused by genetic transmission of a recessive trait or it is caused by some form of trauma to the body. Males have a higher incidence of deviant color vision than do females. There is variability in the frequency of occurrence for deviant color perception among ethnic groups. Color perception can differ according to age. It is difficult to determine what young children perceive. Adults beyond the age of 65 often have their color vision shifted because the lens takes on a yellow color as age increases. This yellow is added to the colors reaching the lens. Presentation of educational concepts by means of colored media may be misunderstood by persons whose color perception is different than that of the instructor. Many color vision examinations have been developed since 1800. A popular form for red/green visual difficulty was the pseudoisochromatic plates. Illumination was found to be a factor in obtaining standardized results from these examinations. Accepted color picture tubes meet close tolerances for color emissions. The entire visual spectrum is not available in the present manufacture of color picture tubes.
CHAPTER III

METHODOLOGY

The problem of this study was to assess the degree to which a microcomputer could provide the same diagnostic capability to identify color vision deficiencies as compared with currently available tests. The method of studying the problem evolved into several steps: (a) development of a program for a color microcomputer which would display information which could be used to determine if colors were being perceived correctly, (b) determining the physical variables for standardizing the examination, (c) pilot testing the examination for reliability, (d) testing the examination for validity, and (e) determining if the examination should be used as a visual screening instrument.

This chapter describes the procedure used to develop the instrument used during the collection of data and the data collection process which allowed for decisions to be reached regarding the research questions for this study.

Research questions

The first research question raised on page 5 was expanded to the following two questions.

1. Does the examination yield the same results each time it is administered?

2. Does the examination discriminate for the same variable as accepted instruments?
A third question was posed pertaining to this examination.

3. To what degree does the CCVE agree with the Ishihara pseudoisochromatic plates?

**Research hypotheses**

Two hypotheses and their alternative hypotheses were stated as follows:

1. The Cohen K coefficient of agreement between the total score on the Computer Color Vision Exam and the Ishihara pseudoisochromatic plates total did not differ from .50 beyond that expected by chance at the ninety-five percent level of confidence.

   1a. The Cohen K coefficient of agreement between the total score on the Computer Color Vision Exam and the Ishihara pseudoisochromatic plates total would be greater than .50 beyond that expected by chance at the ninety-five percent level of confidence.

2. All betas between the Ishihara total score and the seven color scores from the CCVE do not depart from zero beyond that expected by chance at the ninety-five percent level of confidence.

   2a. At least one beta between the Ishihara total score and the seven color scores from the CCVE depart from zero beyond that expected by chance at the ninety-five percent level of confidence.

**Population and sample**

The population of interest consisted of school age and older citizens of Iowa. Letters of request for permission to carry out testing for the validation of the CCVE were sent to several superintendents of
Iowa public and parochial schools. Permission was granted to test students in the seventh grade at McCombs Junior High School in Des Moines, Iowa. This sample of the population was not preselected by screening. Permission to test students in the Cedar Rapids Community School district also was granted. Students in Cedar Rapids had been screened for color vision difficulty. The students participating in this portion of the sample were those previously screened to have color vision perception difficulty and students whose name appeared alphabetically next on the class list and previously selected as having normal color perception. The sample was 158 subjects who completed the validation study included 60 elementary students from Cedar Rapids, 27 junior high students from Des Moines, 29 students from Iowa State University, and 42 subjects from rural Grinnell and rural Williamsburg communities.

Description of the variables

There exists a large number of variables for any study dealing with color. The variables for this study were categorized as research variables and controlled variables.

Research variables

The dependent variable for this study was the total number of Ishihara pseudoisochromatic plates scored correctly. The independent variables were the scores for the colors which made up the CCVE: brown, red, orange, yellow, green, blue, and violet.

Description of the Ishihara Pseudoisochromatic Plates

The
first plate is a demonstration plate which is designed so all observers can read it correctly. Failure to observe the demonstration plate is an indication of observer malingering or hysteria. Plates two through nine are designed to screen for red-green color vision difficulty. Plates two through five are transformation plates. Transformation plates are those that are designed so both normal and defective observers can observe an object. The two groups of observers perceive different objects. Plates six through ten are vanishing plates. Plates six, seven, eight, and ten can be easily perceived by persons with normal color vision but the image has vanished for those with red-green vision difficulty. Plate nine can be observed by observers with red-green difficulty but has no distinguishable pattern for those with normal color vision. Plates eleven and fourteen were developed to garner the same information from illiterates and were not used in the validation of the CCVE. Plates twelve and thirteen were diagnostic plates of the vanishing variety designed to categorize the persons who have red-green visual difficulty into two groups.

**Scoring**  The test was scored by allowing one tally for each plate observed as a person with normal color vision would observe it. Two or fewer errors are considered normal on this version of the Ishihara test (Committee on Vision, 1981).

**Administration**  The examinee is instructed to hold the plates under illumination that represents north sky daylight. The plates are to be held at a distance of 75 cm from the face in a line perpendicular to the nose. The plates are to be read before a three
second interval has elapsed. The next plate then is to be read until the test is completed. A scoring sheet was prepared so all responses could be recorded for this study.

**Reliability and validity**

The Committee on Vision had not located test-retest data on the Ishihara pseudoisochromatic plates test so no reliability statistic was given (Committee on Vision, 1981). The test has been compared with the Nagle anomaloscope and the Cohen K statistic of agreement is reported as follows: Hardy et al. $K = 1.00$, Sloan and Habel $K = .97$, and Belecher and others $K = .95$ (Committee on Vision, 1981).

**Description of the Computer Color Vision Exam (CCVE)**

School age persons were in mind during the development of this exam. There are 56 color combinations each requiring a match response. These responses are entered on the computer keyboard (see Figure 8). On the left side of the viewing screen a color chart is aligned. Special lighting illuminates this reference chart of color blocks which has background of both black and white so each color observed can be referenced. A colored horse appears on the right side of the screen. The examinee manipulates keys on the console to move an arrow, found just to the right of the color reference chart, up or down until the position for the best color match is found. Pressing the "M" key enters the color matched into the computer program for scoring. If the examinee observes more than one match per horse color, multiple matches are allowed. The "C" key is pressed when the examinee desires to change the color of the horse and proceed to the next displayed color combination. The test
Figure 8. CCVE Physical Layout
begins with colors observed against a black background in an attempt to simulate a lantern color vision exam. The matching scheme was developed to simulate the matching of yarn required for the Holmgren wool test and to avoid a semantic problem found with "Which color did you observe?", used in an earlier version of the CCVE. After the colors have been observed against a black background, they are viewed against a white background. Each color is later presented against various background colors allowing for differences in color perception to be found. The size of the horse, and the space between the horse and the color reference were variables which influence the perception difficulty of the examination.

**Scoring the CCVE** Each time the horse color was perceived correctly a tally was kept by the computer for the color score and for the total score unless the subject saw two color matches or more. If more than one match was entered per horse, no tally was performed.

**Administration of the CCVE** The testing station was equipped with the standard illuminate, the television set was checked for adjustment, the keyboard was located 24 inches from the viewing screen, and the program readied for the examinee to type in the requested data. Instructions were programmed to be read from the screen but were difficult to read after the set was adjusted for colors so the instructions were read for the examinee. The examiners for this study were registered nurses and educators who were trained to observe for misinterpretation of the instructions. If the instructions were not clear, the exam was restarted.
Reliability and validity

The procedures for determining the reliability and validity for the CCVE are found toward the end of Chapter 3; the results are presented in Chapter 4.

Controlled variables

There were many variables which entered into the design and administration of the CCVE. More complete description of the actual procedures for the control of the variables not entered into the statistical models, follows in this chapter. The variables for the computer generated image were size, viewing distance to the color standard, and color. The color standard variables were background color, area of color, and colors. The illuminate for viewing the color standard was an important variable. The television set had several variables associated with it including hue, saturation, brightness, and contrast controls, the viewing distance from the examinee, the angle between the receiver and the illuminant to prevent screen glare.

Developing the instrument

A Commodore 64 computer and a General Electric television model 10AS3406W were purchased to provide the hardware portion of the Computer Color Vision Exam (CCVE).

The program developed was written in the Basic language with machine language used as required to obtain color, size and shape for the horse (see Appendix A).

The completed instrument was a program which displayed a three-fourths inch high, one inch wide horse on the right side of the
television screen to be matched to a set of standard colors mounted on the viewing screen (see Figure 8). Both colors for the horse figure and the background were systematically varied to provide a total of 56 color combinations. The computer console was located at a distance of 24 inches in front of the television set. The color computer and television combination often leaves a ring of color surrounding the object different than the object color. The larger colored objects had less percentage of confusing color which should reduce some error. The horse was projected against a background color. This colored horse was to be matched with a color from the color standard which is mounted external to the viewing screen on the left side. The distance between the colored horse and the standard determined the viewing angle. An angle great enough to require a scanning motion of the eyes or head was provided to prevent an absolute color-on-color match which might be made on intensity rather than color. The program provided an arrow which could be moved up or down along the color standard by pressing the appropriate keys on the computer keyboard. When the observer found the closest visual color match between the horse and the color standard, the "M" key was to be pressed.

The preferred location for the Vita Lite lamps was ceiling fixtures eight feet above the floor. The television receiver was oriented to allow the color standard to be illuminated but not causing a reflection on the screen. A secondary location of the illumination was necessary for the data collection in Cedar Rapids. The lighting fixture was placed behind the examinee to illuminate the standard and moved to
avoid reflection on the picture tube.

Immediate feedback was given to the subject by the computer program to indicate the input was received. A statement appeared on the screen which read, "Your match was entered", and a short tone was emitted from the television speaker. The computer stored the response, along with the information of the color of the horse and the background color at the time of response. As soon as the feedback was completed, the horse changed color, ready for the next response.

The matching of color for vision exams has been used since Elaric Holmgren developed his "Worsted Test" in the 1800s. The matching idea was expanded upon in attempt to simulate lantern tests. Lantern tests are usually administered in a blackened room. Examinees are asked to name a small color projected from a small lens in the darkened environment. The lantern tests led to the choice of a black background for the first set of colors being displayed for the CCVE. A white background was chosen for the second set of colors. The white background allowed the examinee to perceive color without confounding stimuli. The background colors which complete the test are the same as those used for the horse. The horse is never displayed against its own color. Studies in art and psychology indicate perception of size and spatial relationships change as color is viewed with varied colored surroundings (Ruch, 1958). Different background colors were used in the CCVE to help identify persons whose color perception was not the same as the major proportion of the population.
Development of the standard

The standard (see Figure 8) used with the CCVE is a set of seven color patches mounted on a base of half white and half black paper. The material for the white was coated cover stock. The black stock was nonfading black paper designed for halftone windows for the printing industry. The color patches were obtained from ink manufacturers' color matching tablets. The colors chosen were picked to match those available on the computer/television combination. Red was also chosen, although it is not available on the television screen (Hurvich, 1981). The color specifications for each color according to the Munsell (1976) Color System are as follows:

<table>
<thead>
<tr>
<th>Color</th>
<th>Hue</th>
<th>Value</th>
<th>Chroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>blue</td>
<td>10 blue</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>violet</td>
<td>10 purple</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>red</td>
<td>2.5 red</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>orange</td>
<td>10 red</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>yellow</td>
<td>5 yellow</td>
<td>8.5</td>
<td>14</td>
</tr>
<tr>
<td>green</td>
<td>7.5 green/yellow</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>brown</td>
<td>5 yellow/red</td>
<td>4</td>
<td>14</td>
</tr>
</tbody>
</table>

The patches are 7/16 X 11/16 inches mounted 5/16 inches apart. The patches at the ends of the standard were cut to conform to the shape of the television screen. The spacing between colors was determined by the spacing allowed by the computer for programming.
Illumination

Standardized illumination for the CCVE colors was established to allow each observer to perceive the standard the same as every other observer. The lighting system chosen for the CCVE was Vita Lite fluorescent lamps manufactured by the Duro Test Company, Elk Grove Village, Illinois. These lamps were in use at the vision testing laboratory at the University of Iowa Medical School. A lighting technician from Macbeth Corporation tested these lamps for metamerism with afternoon northern daylight sky and found the lamps to be free of metamerism for these two illuminants. Each lamp cost $8.00 for a standard 40 watt variety. A metamerism test kit was obtained by request from the Macbeth Corporation, Newburgh, New York.

Television adjustment

Reliable adjustment of the television receiver for color was an important factor for the CCVE. The General Electric television had four controls available on the front panel: color, tint, brightness, and contrast. Yellow was discovered to be the most difficult color to obtain by adjusting the controls. The brightness control was adjusted until the background turned black. The contrast control was adjusted for maximum acuity. The tint and color adjustments were made until the yellow appeared yellow. Final adjustment was made by comparing light filtered with a #15 yellow filter with the yellow on the screen, the difference being monitored by an electronic color comparator circuit. The controls on each set used in the study were marked for their proper adjustment for the exam so the sets could easily be adjusted if these
controls were bumped while transporting the equipment from one testing site to another.

Pilot administration

A pilot test study was undertaken with the CCVE instrument to ascertain its test-retest reliability. Request for participants was made in psychology classes, aviation ground school class, and classes in the department of Industrial Education at Iowa State University. Twenty-two students from Iowa State University, five citizens from rural Williamsburg and twenty from Grinnell, Iowa, completed the test-retest for the pilot study. Seventy two took the initial administration of the Ishihara, CCVE, and the F2 Tritan plate. Each person was tested first with the Ishihara pseudoisochromatic plates, the F2 Tritan plate and then the CCVE. The standard procedure for administering the Ishihara pseudoisochromatic plates was followed according to the 1970 edition. The plates were held 75 cm from the examinee so that they were at right angles to the line of sight. Three seconds were allowed for indication of which numbers were observed on each plate. Instructions for the CCVE were programmed to print on the screen but were very difficult to read after the color adjustments had been performed. Because of this, the instructions were read to the subjects and the subjects were observed to find if the instructions were being carried out accurately. Following at least one day time interval, to reduce the amount of spurious scoring due to learning, a retest of the CCVE was undertaken. The data from the pilot study (Appendix C) were analyzed by: (a)
plotting frequency distributions for each color score and the CCVE total score, (b) means and standard deviations were calculated for each score, (c) a scatterplot was prepared showing the results of the first CCVE administration compared with the results of the second administration, (d) the Pearson product-moment coefficient was calculated as the statistic for the reliability of the CCVE (Figure 9). The distribution of scores for the sample taking the pilot test was found to be discontinuous. Validation of the instrument was the next step toward the completion of the study.

Validating the exam

Permission for testing the CCVE was sought from several school districts. Norman E. Miller, executive director, extended permission for the Des Moines Community School District to carry out validation testing of the CCVE at McCombs Junior High School. The permission was to screen members of the seventh grade class. This population sample had not been screened for color vision previously. Permission slips were sent home to the parents of 217 students accompanied by a letter of explanation from McCombs' principal, Mr. Jerry Stilwell. Sixty-six students were tested with the Ishihara pseudoisochromatic plates and the F2 tritan plate. Twenty-six of these students also had the CCVE instrument administered to them. The participants presented their permission slips at the beginning of each period of class in the gymnasium, then came to the room assigned for the administration of the CCVE. The testing environment allowed administration to two students simultaneously. The school principal, the school nurse, a school
First administration

Second administration

N = 47
\( \bar{X}_1 = 40.35 \)  \( S = 6.13 \)
\( \bar{X}_2 = 44.74 \)  \( S = 6.93 \)
\( r = .848 \) for 56 items

Figure 9. Scatterplot for Pilot Study
psychologist, and classroom teacher each had opportunity to observe a student taking the CCVE who had color perception difficulty.

Dr. George Ross, Director of Research, responded to a request for permission to test in the Cedar Rapids Community School District. Initially, it was planned that data collection would be carried out in three Cedar Rapids elementary schools. Dr. Ross then found that screening for color vision had been undertaken by the Grant Wood Area Agency. Because of that screening, Dr. Ross granted permission to administer the color vision exams to students already identified as having color vision difficulty and an equal number of students identified as having no color perception difficulty. Based on the expected percentages of the population (Committee on Vision, 1981) it was thought the number of students found in three schools would be sufficient for this study. However, the number of students reported to have color vision difficulty based on the previous screening was a very small percentage of the school population. Permission was granted to administer the tests in each elementary school for which arrangements could be made. A description of the CCVE was prepared for Dr. Ross (see Appendix B). A packet containing the description, a letter of introduction for the study to the school principals, and a copy of the approved parent permission form was sent to Dr. Ross. Dr. Ross distributed copies of the information to the principals with a personal letter of introduction about the researcher and outlined the time frame for obtaining parent permission slips and the time when the researcher would call to make final scheduling for testing the students in each
school. Two days were identified for the data collection. Each principal was to be contacted by telephone on the afternoon previous to the day of testing so a schedule could be made as to where the testing would be held and to assess the number of students who would be participating in the study. A schedule was prepared for collecting data in thirteen schools in the two days. Two teams, led by the author and his wife were prepared to collect data simultaneously. Each team had a Commodore 64 computer, a 10" General Electric television, several color standards, several copies of the computer program, a lighting fixture, and the Ishihara pseudoisochromatic plates. Each team had a registered nurse or a teacher accompanying the examiner. Fifty-eight students and two faculty were participants in the study representing thirteen elementary schools. During the two days of testing faculty members, nurses, and two parents occasionally observed the testing process. The teachers expressed concern about their students identified as having color perception difficulty. They were unsure what colors were confusing to their students and when the use of color in instruction would be appropriate.

Two students identified the previous year as having color perception difficulty after completing the screening by the Grant Wood agency were shown to have no color vision difficulty during the screening for the current year. The school nurse requested these students be administered the Ishihara and CCVE exams. Both students were shown to have color perception difficulty from the results on the Ishihara and Computer Color Vision Exam.
Two teachers who knew they did not perceive color correctly requested to be included in the study. One described the difficulty he had encountered that week with a new instructional computer program. It seemed that the clue for an appropriate response was an item changing color on the screen. This teacher never observed the change. This caused a great deal of enjoyment for his students and a large amount of frustration for the teacher.

When students correctly observed all the Ishihara pseudoisochromatic plates and also achieved a CCVE total score greater than 30, they were advised their color perception was accurate for these two examinations. When students had color difficulty, the school nurse was advised. The nurses felt it was their responsibility to notify the student and the parents of our findings. It was suggested that if doubt or other concern existed, additional color vision examination would be advisable.

The data collected from the two school districts yielded an N of 86. Since there had been no changes following the reliability study the first administration scores were used in the validation calculations.
CHAPTER IV

FINDINGS

This study examined three research questions. The first question asked "does the CCVE yield the same results each time it is administered?" The CCVE was administered twice to the same sample to determine if the instrument was reliable.

The second question asked "does the CCVE discriminate for the same variable as accepted instruments?" A contingency table was prepared and the chi-square statistic calculated to help in this determination. The Cohen K statistic of agreement between the total scores on the two exams was calculated to find the degree to which the CCVE had agreement with the Ishihara exam.

The third question asked "if the subscores on the CCVE were known, could the passing or failing of the Ishihara be predicted?" The dependent variable of the study was a score of 0 (failure) or 1 (passing) determined by subject's responses to each Ishihara plate. Failing to correctly observe three or more plates on the Ishihara examination constituted failure on that examination. The independent variables were the scores obtained on the colors chosen for the CCVE: brown, red, orange, yellow, green, blue, and violet.

CCVE reliability

Prior to the validation study for the CCVE, a pilot study was conducted. The purpose of this study was to collect data from which a Pearson product-moment coefficient could be calculated for the
correlation between the two administrations of the CCVE (Figure 9). The
test-retest reliability was calculated to be .85 for the 56 response
Color Computer Vision Exam. There were 47 subjects in the pilot sample.
This sample was a nonrandom sample, a sample of convenience. Color
vision is not a normally distributed trait as shown in Figure 10.

CCVE validation

Descriptive statistics of the research variables for 158 subjects
are shown in Table 1. This table shows the variables are not normally
distributed but are leptokurtic and skewed. The variable sex (see
Tables 1 and 5 and Figure 19) was coded with 1 = males and 2 = females.
The other variables were continuous data used on interval scales.
Figures 11, 12, 13, 14, 15, 16, 17, 18, and 19 are frequency polygons of
the distributions for each of the variables.

The chi-square statistic was used to ascertain the degree of
association between the results on the CCVE and Ishihara color vision
exams (Table 2). A score below which subjects failed the CCVE had to be
assigned in order to complete the contingency table for the chi-square
statistic. This score was a total score of 27 on the CCVE. Figure 19
illustrates the distribution of scores on the CCVE and the frequencies
at the cut off point. The number of observations was 158 with 1 degree
of freedom. The calculated chi-square was 67.66. The calculation led
to the conclusion that there was association between the results of the
two examinations.

The Cohen K statistic was used as a test for agreement between the
Figure 10. Pilot Study Polygon
Table 1

Descriptive Statistics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Age</th>
<th>Sex</th>
<th>Brown</th>
<th>CCVE</th>
<th>Red</th>
<th>CCVE</th>
<th>Orange</th>
<th>CCVE</th>
<th>Yellow</th>
<th>CCVE</th>
<th>Green</th>
<th>CCVE</th>
<th>Blue</th>
<th>CCVE</th>
<th>Violet</th>
<th>CCVE</th>
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<tbody>
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<td>2.7</td>
<td>2.05</td>
<td>5.55</td>
<td>5.38</td>
<td>7.21</td>
<td>7.16</td>
<td>5.75</td>
<td>35.75</td>
<td>2.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>15.38</td>
<td>.22</td>
<td>2.49</td>
<td>1.81</td>
<td>2.18</td>
<td>2.55</td>
<td>1.60</td>
<td>1.68</td>
<td>2.81</td>
<td>9.22</td>
<td>4.36</td>
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<td></td>
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<tr>
<td>Mode</td>
<td>13.00</td>
<td>1.0</td>
<td>0.0</td>
<td>1.00</td>
<td>7.0</td>
<td>7.8</td>
<td>8</td>
<td>8</td>
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<td>0</td>
<td></td>
<td></td>
<td></td>
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<td>Max.</td>
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<td>8</td>
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<td>8</td>
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<td>13</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Min.</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>66</td>
<td>1</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>42</td>
<td>13</td>
<td></td>
<td></td>
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<tr>
<td>Skew</td>
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<td>.72</td>
<td>.54</td>
<td>1.05</td>
<td>-.74</td>
<td>-.79</td>
<td>-2.69</td>
<td>-2.23</td>
<td>-1.03</td>
<td>-.92</td>
<td>1.19</td>
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<tr>
<td>Kurtosis</td>
<td>4.67</td>
<td>1.58</td>
<td>2.13</td>
<td>3.63</td>
<td>2.56</td>
<td>2.38</td>
<td>10.35</td>
<td>7.48</td>
<td>2.61</td>
<td>3.17</td>
<td>2.78</td>
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</tr>
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</table>

Number of cases = 158
Figure 11. Frequency Polygon for the Responses to the Variable Brown
Figure 12. Frequency Polygon for the Responses to the Variable Red
Figure 13. Frequency Polygon for the Responses to the Variable Orange
Figure 14. Frequency Polygon for the Responses to the Variable Yellow
Figure 15. Frequency Polygon for the Responses to the Variable Green
Figure 16. Frequency Polygon for the Responses to the Variable Blue
Figure 17. Frequency Polygon for the Responses to the Variable Violet
Figure 18. Frequency Polygon for the Total Scores on the Ishihara Pseudoisochromatic Plates
Number of females = 52
Number of males = 106

Figure 19. Frequency Polygon of the Results on the CCVE
Table 2

Chi-square Statistic of Association between the Ishihara Plates and the Computer Color Vision Exam

<table>
<thead>
<tr>
<th></th>
<th>Pass</th>
<th>Fail</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CCVE Pass</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>96</td>
<td>8</td>
<td>104</td>
</tr>
<tr>
<td>Expected</td>
<td>73</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>CCVE Fail</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>16</td>
<td>38</td>
<td>54</td>
</tr>
<tr>
<td>Expected</td>
<td>38</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>112</td>
<td>46</td>
<td>158</td>
</tr>
</tbody>
</table>

Chi-square = 67.66

Degrees of freedom = 1

Probability = .0001
results on the two examinations. The Cohen K was the statistic suggested by the Committee on Vision for use in validating all color vision examinations. This statistic has a value between 0 and 1 (Bishop et al., 1975). Any positive number indicates agreement. For this study a K of .50 was set as a minimum for determining that the agreement between the results was great enough to indicate that a color microcomputer and color television can be used as an instrument for color vision screening. The Cohen K statistic was calculated to be .72 (Table 3). A 95% confidence interval was calculated to determine if the K would be greater than .50. The calculation showed .65 < K < .78.

A multiple linear regression model was calculated to find how accurately the score on the Ishihara pseudoisochromatic plates could be predicted when age, sex, and the individual color scores were known for the CCVE exam. The multiple correlation among the independent variables of the CCVE was \( R = .76 \) accounting for 57% of the variability of the Ishihara scores (Table 4).

The obtained regression model was: 

\[
\text{Ishihara score} = 16.04 + (-.50 \text{ violet}) + (-.45 \text{ blue}) + (-1.62 \text{ sex}) + (-.29 \text{ yellow}) + (-.21 \text{ brown}) + \text{error}.
\]

A post hoc factor analysis procedure was completed. Table 5, the correlation table, shows the intercorrelations between the variables of the study. The significant correlations between variables and the results on the Ishihara are indicated on the table by asterisks. The multiple correlations and R-squared are shown in Table 6. The trace, a summation of the multiple correlation of each variable with remaining
Table 3

Cohen's K Statistic of Agreement between the Ishihara Pseudoisochromatic Plates and the Computer Color Vision Examination

<table>
<thead>
<tr>
<th>Pseudoisochromatic Plates</th>
<th>Pass</th>
<th>Fail</th>
<th>Totals</th>
<th>Proportions</th>
<th>Totals</th>
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<tbody>
<tr>
<td>CCVE</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Observed Pass</td>
<td>96</td>
<td>8</td>
<td>104</td>
<td>.61</td>
<td>.66</td>
</tr>
<tr>
<td>Expected Pass</td>
<td>73</td>
<td>30</td>
<td></td>
<td>.47</td>
<td>.19</td>
</tr>
<tr>
<td>Observed Fail</td>
<td>16</td>
<td>38</td>
<td>54</td>
<td>.10</td>
<td>.24</td>
</tr>
<tr>
<td>Expected Fail</td>
<td>38</td>
<td>15</td>
<td></td>
<td>.24</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>112</td>
<td>47</td>
<td>158</td>
<td>.71</td>
<td>.29</td>
</tr>
</tbody>
</table>

$\Theta_1 = .61 + .24 = .85$ actual agreement

$\Theta_2 = \frac{(.61 + .10)(.61 + .05)}{.53} = .47$ chance agreement

$K = \frac{\Theta_1 - \Theta_2}{1 - \Theta_2} = \frac{.85 - .47}{.53} = .72$

$\sigma[R] = \frac{\Theta_2^2 - (\Theta_2 \times \hat{\Theta} \times \hat{\Theta})}{N (1 - \Theta_2)^2} = .001$

$\sigma[R] = \sqrt{\sigma^2[R]} = .0316$

CI$_{.95} = K + 1.96 (.0316)$

$.69 < K < .75$
Table 4

Multiple Linear Regression

Criterion = Results on the Ishihara pseudoisochromatic plates by 158 Iowans

Multiple correlation coefficient = .76
Adjusted for numerator d.f. of 1 and denominator d.f. of 148 = .74
F value for analysis of variance = 22.16*
Standard error of estimate = 2.91
S. e. adjusted for d.f = 2.99

<table>
<thead>
<tr>
<th>Predictor</th>
<th>beta</th>
<th>regression coefficient</th>
<th>standard error</th>
<th>computed F value</th>
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</thead>
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<tr>
<td>violet</td>
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<td>-.50</td>
<td>.11</td>
<td>20.97*</td>
</tr>
<tr>
<td>blue</td>
<td>-.18</td>
<td>-.45</td>
<td>.21</td>
<td>4.75*</td>
</tr>
<tr>
<td>sex</td>
<td>-.18</td>
<td>-1.62</td>
<td>.52</td>
<td>9.55*</td>
</tr>
<tr>
<td>yellow</td>
<td>-.17</td>
<td>-.29</td>
<td>.12</td>
<td>6.00*</td>
</tr>
<tr>
<td>green</td>
<td>-.14</td>
<td>-.39</td>
<td>.22</td>
<td>3.13</td>
</tr>
<tr>
<td>brown</td>
<td>.12</td>
<td>-.21</td>
<td>.10</td>
<td>4.20*</td>
</tr>
<tr>
<td>age</td>
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<td>red</td>
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<td>-.20</td>
<td>.14</td>
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</tr>
<tr>
<td>orange</td>
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<td>-.06</td>
<td>.14</td>
<td>.21</td>
</tr>
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</table>

Constant = 16.04

* F significant at .05
### Table 5

Product Moment Correlations between Research Variables

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<tr>
<th></th>
<th>Age</th>
<th>Sex</th>
<th>Brown</th>
<th>Red</th>
<th>Orange</th>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
<th>Violet</th>
<th>Ishihara</th>
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</thead>
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<td>.14</td>
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<td>.23**</td>
<td>.22**</td>
<td>-.26**</td>
</tr>
<tr>
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<td>.30**</td>
<td>.21**</td>
<td>.25**</td>
<td>-.39**</td>
</tr>
<tr>
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<td>.01</td>
<td>.20**</td>
<td>.33**</td>
<td>.04</td>
<td>.17*</td>
<td>.17*</td>
<td>.18*</td>
<td>.07</td>
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<td>-.30**</td>
<td>.13**</td>
<td>.12</td>
<td>.03</td>
<td>.17*</td>
<td>.18*</td>
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<td>.44**</td>
<td>.37**</td>
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<td>.30**</td>
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<td>.43**</td>
<td>.50**</td>
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<td>.56**</td>
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</tr>
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<td>.67**</td>
<td>.48**</td>
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<td>.58**</td>
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<td>Blue</td>
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<tr>
<td>Violet</td>
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</tr>
<tr>
<td>Ishihara</td>
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<td></td>
<td></td>
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* * significant at .05
** ** significant at .01
Table 6

Communality Estimates

<table>
<thead>
<tr>
<th>Variable</th>
<th>R</th>
<th>R square</th>
<th>F</th>
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<tbody>
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<td>Age</td>
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<td>Sex</td>
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<tr>
<td>Brown</td>
<td>.4370</td>
<td>.191</td>
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<tr>
<td>Red</td>
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<tr>
<td>Orange</td>
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<td>.65</td>
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<td>Yellow</td>
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<tr>
<td>Blue</td>
<td>.7473</td>
<td>.558</td>
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<tr>
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<td>.485</td>
<td>.99</td>
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<tr>
<td>Ishihara</td>
<td>-.7576</td>
<td>.574</td>
<td>1.42*</td>
</tr>
</tbody>
</table>

Trace = 5.98

56.7 percent of trace was obtained from one root.

Root 1 = 3.39

* D.F.(148,157)CV = 1.2
variables equaled 5.976. Fifty-six and seven-tenths percent of the trace was obtained from one root. The one root was equal to 3.39. The factor loadings (Table 7) indicate that the results on the Ishihara exam was measuring the same trait that variables on the CCVE were measuring, especially the colors blue, violet, green, yellow, and orange. That trait is deviation in color visual perception.
Table 7

Factor Loadings

<table>
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<tr>
<th>Variable</th>
<th>Loading</th>
<th>Loading Squared</th>
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<td>.11</td>
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<td>Sex</td>
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<td>.15</td>
</tr>
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<td>Brown</td>
<td>.262</td>
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</tr>
<tr>
<td>Red</td>
<td>.110</td>
<td>.01</td>
</tr>
<tr>
<td>Orange</td>
<td>.519</td>
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<tr>
<td>Yellow</td>
<td>.666</td>
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<tr>
<td>Green</td>
<td>.744</td>
<td>.55</td>
</tr>
<tr>
<td>Blue</td>
<td>.782</td>
<td>.61</td>
</tr>
<tr>
<td>Violet</td>
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<td>.55</td>
</tr>
<tr>
<td>Ishihara</td>
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<td>.63</td>
</tr>
<tr>
<td>Root</td>
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<td>3.41</td>
</tr>
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CHAPTER V

DISCUSSION

This chapter presents three general areas in the discussion of conclusions and recommendations. The first areas presented are the methods required by the study for the purpose of completing a reliability and validation study for a computer generated color vision examination. The second areas presented are the general findings of this study related to the Color Computer Vision Exam. Finally, there is a discussion of recommendations for research both in methodology of this model and in the needs of knowledge, application, and further technical advancement which may lead to further answers about color vision.

Methodology

Reliability and validation research provides a vehicle to enhance the process of making a decision as to the usefulness of an examination. The research is initiated through the presentation of a hypothesis which assumes the examination being used as the dependent variable is reliable and measures the same trait for which it is desired that the new testing procedure will measure.

This experimental study was unique in the acquisition of data about color visual perception. Five separate and distinct physical locations allowed for data from different age groups, urban and rural settings, institutional and home settings, and the collection of data from both males and females. This variety of data collection sites was helpful in finding persons with color perception difficulty; without their input to
the study it could not have been completed.

The strength of this study lies in the amount of agreement shown between the two examinations and the intercorrelations between the research variables. The test for agreement chosen for this study is the Cohen K. It was selected because it is the suggested statistic for color vision examinations (Committee on Vision, 1981). The use of this test for agreement should result in the study being most easily communicated to and evaluated by scholars interested in research on color vision examinations.

**Research limitations**

A plan to collect data from Iowans according to their known color perception selected to match the percentage of the population found in the literature was to be implemented at the University of Iowa Clinic of Ophthalmology. Notification that staff was not available to assist as planned led to an alternate data collection plan.

It appeared that the public schools would be a source of data that would be similar to the population except for age. The samples from the school districts involved were quite different. The sample from McCombs Junior High School in Des Moines was from the entire seventh grade class. This sample may have been a good cross section of Iowans but from the class population of 217 only 66 students returned parental permission, twenty-six completed the testing program. Whether this represented the population could be questioned. The portion of the population sample tested in the Cedar Rapids Community Schools were
selected students who had poor performance on another color vision examination paired for this research with students whose performance on the color vision examination had been "normal". This procedure was efficient in finding persons who had deviant color vision but obviously did not meet any criteria toward matching the population percentages.

**Implications of the findings**

Significant association between the Ishihara Plates and the CCVE was found on a preliminary chi-square test. The Cohen K coefficient of agreement was calculated to be .72 on a scale of 0 to 1. The total score on the Ishihara plates correlated significantly with all the scores for each color variable on the CCVE. Referring to Table 5, the coefficients of correlation for the Ishihara Plates are negative, this is due to the Ishihara score being based on the number of plates missed whereas the CCVE scores were a collection of correct responses.

The post hoc factor analysis indicated that a common underlying trait was being measured. It was assumed this trait was color perception.

The results of the study imply that low cost color computers can be useful as a screening device for color perception.

**Recommendations**

The CCVE was developed to find if a low cost color computer could be used in the screening of color vision. This objective is shown to be possible. Several of the control variables have had technological improvements made on them during the time this study was in progress.
Additional technical progress will be made which should continue to enhance the capability for color computers to be used in this manner. New programs, improved color display monitors for the computers, and more familiarization with computers should continue to make computers more desirable for the administration and provide for wider distribution of color vision testing. The new technical developments should be incorporated in future computer color vision instruments.

It was observed while collecting data for this study that persons who were having difficulty with the color matches were also taking longer to make their decisions. Because of this observation, an independent variable of time should be included in a future research model.

It is recommended this study be replicated for test-retest reliability and validity with a stratified population sample. The Nagle anomaloscope is the preferred criterion.

The data collected indicated color vision perception is affected on more colors than red and green. These data raised questions as to the classifications for color vision and the appropriateness of validating this instrument against a red-green standard. There is a continuing need for a color vision examination for young children. Further study and development toward that goal may lead to a valid instrument. A study should be undertaken to determine if the CCVE would be a useful tool for color vision screening of groups. Additional study could be made to find the degree of success the instrument might have as a self administered test.
Summary

The CCVE and the Ishihara tests screened most color viewers in the same manner (Table 2). The CCVE failed to pass .14% of the persons passed by the Ishihara test. These were viewers whose scores indicated they were not perceiving blue and violets as the majority although the other colors were more normal. The Ishihara test was designed as a red green screening instrument. The CCVE also passed 17% of the subjects who failed to pass the Ishihara test. These may be subjects who would be classified as "color weak". These percentages are partially influenced by the choice of cut off score.


Farnsworth, D., Sperling, H. & Kimble, P. F. "A battery of pass-fail tests for detecting the degree of color deficiency." *Medical Research Laboratory Report,* 1949.


Winn, W., & Everett, R. J. Differences in the affective meaning of color of color and black and white pictures. Thesis, ED 160067, April 1978.

ACKNOWLEDGEMENTS

Without the help of several persons this study would not have been completed. Larry Hatch and Warner Smidt patiently took the several color vision examinations and the various designs during the development of the Color Computer Vision Exam. Kevin Lotz and Sian-Lip Tan assisted in the development of the program.

Mr. and Mrs. Edgar Heitshusen and Mr. and Mrs. Richard Sears allowed me to set up the test in their homes and invited the citizens of their townships to participate in the study.

Norman E. Miller, executive director, extended permission to carry out testing in the Des Moines Public Schools. Jerry Stillwell, principal, facilitated the testing carried out at McCombs Junior High School. Dr. George Ross, director of research, granted permission and helped arrange for testing to be carried out in thirteen elementary schools in Cedar Rapids.

Mrs. Mildred Smith, Mrs. Judy Potter, and Mrs. Karline Van Note assisted on the color vision testing teams during the data collection in Cedar Rapids.

The directing committee for the researcher's program of study and research project was composed of Dr. W. G. Miller, chairman, Dr. T. Howe, Dr. R. Gelina, Dr. G. Parks, and Dr. R. Van Iten. Collectively and individually the committee members gave stability and direction toward the completion of this project.

The researcher's family contributed in many ways. Often they were not thanked enough for tolerating a father and husband who didn't want
his attention diverted or who was frustrated by events seemingly with no solution.
APPENDIX A

CCVE PROGRAM LISTING

110 REM\\\\\\\\\\\\\\\\\%
120 REM\
130 REM\ MAIN PROGRAM \%
140 REM\
150 REM\\\\\\\\\\\\\\\\\%
160 V=53248
170 ND=1;NS=1
180 SA=1
190 ROW=1
200 DATA"NORMAL","NORMAL","NEARSIGHTED","UNCORRECTED","FAR-SIGHTED"
210 DATA"CORRECTED","ASTIGMATISM","CORRECTED & TINTED"
220 FOR I=0 TO 3:READ PR$(I),CR$(I):NEXT
230 DATA" RED "," VIOLET "," GREEN "," BLUE "," YELLOW "," ORANGE 
240 DATA" BROWN 
250 FOR I=2 TO 8:READ CL$(I):NEXT
260 DATA"BLACK ","WHITE ","RED ","PURPLE ","GREEN ","BLUE ","YELLOW 
270 DATA"ORANGE ","BROWN 
280 FOR I=0 TO 8:READ BA$(I):NEXT
290 DATA"LEFT","RIGHT","BOTH"
300 FOR I=0 TO 2:READ EYE$(I):NEXT
310 DATA 2,5,4,6,0,1,3
320 FOR I=2 TO 8:READ SE(I):NEXT
330 GOSUB 570:REM TITLE BLOCK
340 POKE V+21,0:POKE 53280,1:POKE 53281,1
350 PRINT"
360 PRINT"3"
370 PRINT SPC(15);"CCVE2":PRINT:PRINT:PRINT
380 PRINT SPC(8);"1) TAKE THE TEST":PRINT
390 PRINT SPC(8);"2) SCORE THE DATA":PRINT
400 PRINT SPC(8);"3) SAVE DATA":PRINT
410 PRINT SPC(8);"4) EXIT THE PROGRAM":PRINT:PRINT:PRINT
420 PRINT"PLEASE ENTER THE NUMBER OF YOUR CHOICE 2"
430 PRINT"
440 GET ANS$:IF ANS$<"1" OR ANS$>"4" THEN430
450 ANS=ASC(ANS$)-ASC("0")
460 ON ANS GOTO 470,490,510,530
470 GOSUB 1050:REM TAKE THE TEST
480 GOTO 340
490 GOSUB 2200:REM SCORE THE DATA
500 GOTO 360
510 GOSUB 1890:REM SAVE THE DATA
520 GOTO 360
530 PRINT"3":END
540 :
550 REM******TITLE BLOCK*****
560 : POKE V+21,0:POKE 53280,1:POKE 53281,1:PRINT":PRINT":PRINT"
570 FOR I=1 TO 40:PRINT":NEXT
580 FOR I=1 TO 20:PRINT":;SPC(38)";: NEXT
590 FOR I=1 TO 40:PRINT":;NEXT
600 FOR I=1 TO 15:PRINT":;NEXT
610 FOR I=1 TO 6:PRINT":;NEXT
620 PRINT SPC(08);"COMPUTER 2":PRINT
630 PRINT SPC(10);"COLOR VISION EXAM 2"
640 PRINT TAB(17)"BY"
650 PRINT TAB(10)"LARRY L. BRADSHAW"
660 FOR I=1 TO 2:PRINT":NEXT
670 PRINT SPC(7);"PRESS RETURN 2 TO CONTINUE"
680 GET A$:IF A$<>CHR$(13) THEN 690
690 RETURN
700 :
710 : REM******TEST INSTRUCTIONS*****
720 : FOR I=1 TO 2:PRINT":NEXT
730 : POKE V+21,0:POKE 53280,1:POKE 53281,1:PRINT":PRINT":PRINT"
740 PRINT SPC(12);"TEST INSTRUCTIONS":PRINT:PRINT
750 PRINT:PRINT"(1) PLACE THE COLOR STRIP ON THE LEFT":PRINT"SIDE OF THE SCREEN.
760 PRINT:PRINT"(2) PRESS THE F1 KEY" 
770 PRINT:PRINT"(3) PRESS THE F7 KEY TO MOVE THE CURSOR DOWN"
780 PRINT:PRINT"(4) PRESS THE F1 KEY TO MOVE THE CURSOR UP"
790 PRINT:PRINT"(5) PRESS THE (M) KEY TO INDICATE A COLOR MATCH"
800 PRINT:PRINT"(6) YOU MAY ENTER MORE THAN ONE MATCH 2"
810 PRINT:PRINT"(7) PRESS (C) TO CONTINUE THE EXAM"
820 PRINT:PRINT TAB(6)"PRESS RETURN 2 TO CONTINUE"
830 GET A$:IF A$<>CHR$(13) THEN 840
840 PRINT SPC(08);"PRESS RETURN 2 TO CONTINUE"
850 POKE 53280,X:POKE 53281,X:POKE V+21,60:IF X=0 THEN PRINT":GOTO 870
860 PRINT"0"
870 PRINT"3":RETURN
880 :
890 REM******SET SPRITE REGISTER*****
900 :
910 X=210:Y=220:PRINT"3"
920 POKE V+21,50
940 FOR N=0 TO 51:READ Q;POKE 832+N,Q:NEXT
950 POKE V+23,12:POKE V+29,12
960 RETURN
970 :
980 :
990 REM******SET LOCATION REGISTERS*****
1000 POKE V+6,250
1010 POKE V+7,120
1020 RETURN
1030 :
1040 REM******TEST*****
1050 IF SA=1 THEN 1120
1060 PRINT"3":PRINT"THE COMPUTER HAS NOT SAVED THE LAST TEST RESULTS YET!"
1070 PRINT"TAKING THE TEST NOW WILL RUIN THE RESULTS"
1080 PRINT"DO YOU WANT TO TAKE THE TEST NOW? (Y=YES N=NO)";
1090 GET ANS$:IF ANS$<>"Y" AND ANS$<>"N"THEN 1090
1100 IF ANS$="Y" THEN 1270
1110 GOTO 1260:REM RETURN TO MENU
1120 PRINT":FOR I=1 TO 11:PRINT:NEXT: PRINT SPC(14);"PLEASE WAIT!"
1130 FOR I=0 TO 8:FOR J=2 TO 8:FOR II=0 TO 6:DAT(I,J,II)=0:NEXT:NEXT:NEXT
1140 PRINT":ND=0:NS=1:SA=0
1150 GOSUB 2580:REM GET USER'S INPUT
1160 GOSUB 740:REM INSTRUCTIONS FOR TEST
1170 GOSUB 910:REM SET SPRITE REGISTERS
1180 GOSUB 1000:REM SET LOCATION REGS
1190 FOR I=0 TO 8:GOSUB 1300
1200 IF I<>0 THEN PRINT":GOTO 1220
1210 PRINT":
1220 FOR J=2 TO 8:GOSUB 1360
1230 IF Y=X THEN 1250
1240 GOSUB 1430
1250 NEXT: NEXT
1260 RETURN
1270 CLR:RESTORE:GOTO 110
1280 REM****CHANGE BACKGROUND*****
1290 :
1300 X=I:IF X>2 THEN X=X+1
1310 POKE 53280,X:POKE 53281,X
1320 RETURN
1330 :
1340 REM****CHANGE SPRITE COLOR*****
1350 :
1360 Y=J:IF Y>2 THEN Y=Y+1
1370 POKE V+42,Y
1380 RETURN
1390 GOSUB 1000:REM SET LOCATION REGS
1400 :
1410 :
1420 REM*****GET CHAR$*****
1430 GET A$
1440 IF A$=CHAR$(133)ANDA$=CHAR$(136)ANDA$<>"M"ANDA$<>"C"ANDA$<>"I" THEN 1430
1450 IF A$=CHR$(133) THEN GOTO 1450
1460 IF A$=CHR$(136) THEN GOTO 1460
1470 IF A$="M" THEN GOSUB 1810
1480 IF A$="C" THEN 1530
1490 IF A$="I" THEN 1510
1500 IF A$="I" THEN 1430
1510 GOSUB 2760
1520 GOTO 1430
1530 ROW=1:RETURN
1540 REM*****MOVE ARROW DOWN*****
1550 :
1560 IF ROW=19 THEN 1610
1570 ROW=ROW+3
1580 FOR I=1 TO 3
1590 PRINT TAB(2);"=_=
1600 NEXT
1610 GOTO 1430
1620:
1630 REM****MOVE ARROW UP****
1640:
1650 IF ROW=1 THEN 1700
1660 ROW=ROW-3
1670 FOR I=1 TO 3
1680 PRINT TAB(2);"=1_=
1690 NEXT
1700 GOTO 1430
1710:
1720 REM****DATA FOR SPRITE*****
1730:
1740 DATA 0,0,0,0,0
1750 DATA 8,0,0,60,0,0,126,0,0,127,0,0,247,23,129,243
1760 DATA 63,255,224,47,255,224,47,255,224,47,255,192
1770 DATA 103,127,192
1780 DATA 78,25,224,24,1,48,24,3,16,20,2,48,20,6,32,22
1790 DATA 63,255,224,47,255,224,47,255,224,47,255,192
1800:
1810 REM***REGISTER CHOICE*****
1820:
1830 POKE 54296,15; POKE 54277,0; POKE 54278,248; POKE 54273,42; POKE 54272,18
1835 POKE 54276,17
1836 FOR T=1 TO 500: NEXT
1840 POKE 54276,0; POKE 54277,0; POKE 54278,0
1850 DAT(I,J,INT(ROW/3))=1
1860 PRINT "YOUR MATCH IS ENTERED"
1870 FOR Z=1 TO 750: NEXT: ROW=1: PRINT "3": RETURN
1880 REM*****SAVE DATA AND SCORES*****
1890 IF ND=0 AND NS=0 THEN 1930
1900 PRINT "THERE IS NOTHING TO SAVE!": PRINT "PRESS <RETURN> TO CONTINUE";
1910 GET X$: IF X$<>CHR$(13) THEN 1910
1920 GOTO 2160
1930 PRINT "3": SA=1: PRINT SPC(14); "SAVE DATA": PRINT "PRINT"
1940 PRINT "AVING DATA FOR CODE NUMBER ": CODE
1945 OPEN 1,1,1
1950 FOR I=0 TO 3
1960 PRINT #1, RES(I): PRINT #1, CR$(I): NEXT
1970 FOR I=2 TO 8
1980 PRINT #1, CL$(I): NEXT
1990 FOR I=0 TO 8
2000 PRINT #1, BA$(I): NEXT
2010 FOR I=0 TO 2
2020 PRINT #1, EXIT$(I): NEXT.
90

2030 FOR I=2 TO 8
2040 PRINT#1,SE(I):NEXT
2050 PRINT#1,CODE
2060 PRINT#1,SEX$
2070 PRINT#1,AGE
2080 PRINT#1,PROB
2090 PRINT#1,CHR
2100 PRINT#1,EYE
2110 FOR I=0 TO 8:FOR J=2 TO 8:FOR K=0 TO 6
2120 PRINT#1,DAT(J,K,L)
2130 NEXT;NEXT:NEXT
2140 FOR K=0 TO 6:PRINT#1,SR(K):NEXT:PRINT#1,S1:PRINT#1,S2
2150 CLOSE1
2160 RETURN
2170 :
2180 REM****SCORING*****
2190 :
2200 IF ND=0 THEN 2250
2210 PRINT"THERE IS NO DATA TO SCORE!"
2220 PRINT"PRESS <RETURN> TO CONTINUE"
2230 GET X$:IF X$<>CHR$(13) THEN 2230
2240 GOTO 2490
2250 IF NS=1 THEN 2270
2260 PRINT"DATA HAS ALREADY BEEN SCORED!":GOTO 2220
2270 NS=0:PRINT"3":FOR I=1 TO 11:PRINT: NEXT:PRINT SPC(14);"PLEASE WAIT!"
2280 GOSUB 2880
2290 PRINT"3"
2300 PRINT"CODE:CODE,"SEX:";SEX$
2310 PRINT"AGE:";AGE
2320 PRINT"PROB:";PROB$(PROB)
2330 PRINT"CORR:";CR$(CE)
2340 PRINT"EYE:";EYE$(E)
2350 I=0
2360 PRINT"BACKGROUND COLOR:";BACK$(I):PRINT" ACTUAL"," OBSERVED"
2370 PRINT" COLOR";" COLOR":PRINT" 1 YEL ORA RED BRO GRE VIO BLU"
2380 GOSUB 2530
2390 PRINT"SCORES : ";FOR K=0 TO 6:PRINT SR(K);" ";:NEXT:PRINT
2400 PRINT"RED, GREEN, BLUE, YELLOW SCORE = ";S1:PRINT:PRINT"TOTAL SCORE = ";S2
2410 PRINT:PRINT"PRESS:<FORWARD, <REVERSE VIEWING,";PRINT"<Q>UIT";
2420 GET A$:IF A$="F" AND A$="R" AND A$="Q" THEN S2<"Q" THEN 2420
2430 IF A$="Q" THEN 2490
2440 IF A$="F" THEN I=I+1
2450 IF A$="R" THEN I=I-1
2460 IF I>8 THEN I=I-1:GOTO 2420
2470 IF I<0 THEN I=I+1:GOTO 2420
2480 PRINT":GOTO 2360
2490 RETURN
2500 :
2510 REM DISPLAY TEST DATA
2520 :
2530 FOR J=2 TO 8:PRINT CL$(J);" ";:FOR K=0 TO 6:PRINT DAT(I,J,K);" ";:NEXT
2540 PRINT:NEXT:PRINT:RETURN
2550 :
2560 REM GET USER'S INPUT
2570 :
2580 PRINT"ENTER YOUR CODE NUMBER ";INPUT CODE:PRINT:PRINT"ENTER YOUR AGE
2590 INPUT AGE:PRINT
2600 INPUT"ENTER YOUR SEX(M/F)";SEX$: IF SEX$<>'M' AND SEX$<>'F' THEN 2600
2610 PRINT
2620 PRINT"WHICH EYE ARE YOU USING? (0=LEFT; 1=RIGHT; 2=BOTH) ";
2630 INPUT E
2640 IF E>2 OR E<0 THEN 2620
2650 PRINT:PRINT"TYPES OF PROBLEMS:", "O=NORMAL, 1=NEAR-SIGHTED, 2=FAR-SIGHTED":PRINT"3=ASTIGMATISM"
2660 INPUT PROB
2670 IF PR>3 OR PR<0 THEN 2660
2680 PRINT:PRINT"CORRECTION TO PROBLEM:", "O=NORMAL, 1=UNCORRECTED, 2=CORRECTED":PRINT"3=CORRECTED AND TINTED"
2690 INPUT CE
2700 IF CE>3 OR CE<0 THEN 2700
2710 PRINT"3":RETURN
2720 :
2730 REM****PROMPT LINE FOR TEST****
2740 PRINT"3"
2750 PRINTSPC(12);"TEST INSTRUCTIONS": PRINT
2760 PRINT"1) PLACE THE COLOR STRIP ON THE LEFT":PRINT"SIDE OF THE SCREEN."
2770 PRINT:PRINT"2) PRESS THE F1 KEY"
2780 PRINT:PRINT"3) PRESS THE F7 KEY TO MOVE THE CURSOR DOWN"
2790 PRINT:PRINT"4) PRESS THE F1 KEY TO MOVE THE CURSOR UP"
2800 PRINT:PRINT"5) PRESS THE (M) KEY TO INDICATE A COLOR MATCH"
2810 PRINT:PRINT"6) YOU MAY ENTER MORE THAN ONE MATCH***"
2820 PRINT:PRINT"7) PRESS (C) TO CONTINUE"
2830 FOR Z=1 TO 2000:NEXT:ROW=1
2840 PRINT"3"
2850 RETURN
2860 FOR I=0 TO 8:FOR J=2 TO 8
2870 IF I<2 THEN 2910
2880 IF I=J THEN 2970
2890 IF DAT(I,J,SE(J))=0 THEN 2970
2900 ER%=0:FOR K=0 TO 6
2910 IF SE(J)=K THEN 2950
2920 IF DAT(I,J,K)=1 THEN ER%=1
2930 NEXT K
2940 IF ER%=0 THEN SR(SE(J))=SR(SE(J))+1
2950 NEXT J
2960 NEXT I
2970 S1=SR(0)+SR(2)+SR(4)+SR(6)
2980 FOR K=0 TO 6:S2=S2+SR(K):NEXT
3000 RETURN
APPENDIX B

CORRESPONDENCE AND FORMS
COMPUTERIZED COLOR VISION STUDY CONSENT FORM

You have been selected to participate in a study to determine if a color computer and television can be used to identify persons who have deviant color vision.

You will be asked to complete an exercise that involves matching the color of a horse to a set of colors on the picture tube. A second measurement of color vision will be taken so that a comparison of the results can be made.

You may choose to stop participating at any time. If you are not feeling well, an alternate time may be set up for participation.

The results from the exercise will be kept confidential.

***************

My consent is given to participate in the computer color vision study.

I understand that my decision to participate may be withdrawn at any time and the results of my exercise will be kept confidential.

Participant's name (print) _______________________

Signature of legal consentor _______________________

If participant is a minor, relationship of consentor _______________________

Date _______________________
Dear Principal

Color surrounds us. Television, textbooks, advertising, and goods are colored for our enjoyment and enhancement. Some persons have confusion rather than enhancement added to their lives when attempting to learn information from educational media which has been color coded. My concern for these persons has led to the preparation of a color vision screening exam for use in schools. This device makes use of a color computer and color television monitor. A pilot study has indicated a high test retest reliability. Further testing is needed to find the test correlation with the Ishahara color vision pseudoisochromatic plates which have been accepted for some time.

Students with color deviant vision in your school have been identified by the Grant Wood AEA. A letter and permission slip would be sent home with students identified to have color perception difficulty and some randomly selected students with normal color perception. These students would be asked to take the Ishahara pseudochromatic color vision plate test, the Farnsworth P2 tritan plate, and the color computer vision exam at your school (approximately 15 minutes per student). A site for examining will be needed which will allow for electrical connections for the computer, television monitor, and lighting source. The testing could be accomplished in any non-distracting environment.

I would be grateful for your consideration of allowing this data collection for completion of my degree program.

Sincerely,

Larry L. Bradshaw
APPENDIX C

PILOT STUDY DATA

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