A Test for color appropriateness and color selections in multimedia design for color deficient observers

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A Test for Color Appropriateness and
Color Selections in Multimedia Design
for Color Deficient Observers

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Abstract

Fifteen color normal and dichromatic observers participated in a CRT image display study conducted via the Internet at the The Rochester Institute of Technology. The groups consisted of three color normal and twelve color deficient observers. All observers were given identical visual tests. The tests, investigated one factor consisting of multi-hued graphics. The graphics were designed to evoke a response from the observers to help the experimenter investigate the difficulties associated with the inability to discriminate colors. Twelve of the observers (eleven males and one female) had been previously classified with dichromatic color vision deficiency, as established by the Ishihara pseudoisochromatic test and/or the Farnsworth-Munsell 100 Hue test. The control (color normal) group consisted of two male and one female observers. The experiment indicated that specialized color deficient-based palettes are beneficial in selecting color schemes to aid the dichromatic consumer. Once multimedia designers become aware of this discrimination process experienced by the color deficient observer, they can respond with appropriate color combinations to minimize these visual challenges in the daily flow of electronic information via CRT image display.

Key words: multimedia; dichromatic; one factor; color schemes; palettes; color deficient; internet; color normal; CRT
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Introduction

Electronic commerce (E-commerce), the way transactions are conducted over the Internet, is the fastest way for businesses to reach potential markets. Today's technology requires multimedia designers to meet these high volume demands by becoming technically proficient in different disciplines. Multimedia designers are responding by relying on their diverse knowledge, particularly about color, to create more dynamic visual solutions to resolve such complex issues.

Designers and their clients are aware that the use of color is a major part of the profit equation. Colors also have a psychological effect on the viewer due to the association people make with them: red is fiery, blue is stable, white is peaceful and yellow is energetic. In the same manner, harmonious color combinations are known to have major impacts on our visual senses. For instance, complementary color schemes offer a significant visual contrast for designing appealing selling environments.

The condition known as color deficiency affects a significant portion of the world population. The article “Color Adaptation for Color Deficient Learners” noted that “one of every 12 (8%) men and one of every 200 (0.5%) women in the US … inherit color defective vision.” \(^1\) There are many classifications of color-associated deficiencies, but the more common deficiencies are dichromats and anomalous trichromats. Common traits associated with these deficiencies have been described as lacking normal responsivity in either two or three of the primary long (L), medium (M) and short (S) wavelength color receptors of our visual system.

Anomalous trichromatism (Tr.) has three distinct noted categories; protanomalous, deuteranomalous and tritanomalous. The anomalous trichromat visual response is slightly different from that of the color normal observer. “Anomalous trichromats can make, with more or less difficulty, the color distinctions that the corresponding dichromat cannot make at all… anomalous trichromats seem to see much the same colors as the normal, but ordinarily they differ significantly from the normal in the mixture ratios \([L:M:S]\) they require for color matches.” \(^2\)
“Protanomalous Tr. are considered to be red weak because, in a red-green mixture, they require more than a normal amount of red to match a given yellow. Deuteranomalous Tr. are described to be green weak because, in a red-green mixture, they require more than a normal amount of green to match a given yellow. Tritanomalous Tr. are considered to be blue weak because, in a blue-green mixture, they require more than a normal amount of blue to match a given blue-green.”

In 1965, Kalmus describes dichromats as, “needing only two primary stimuli to effect all their color matches.”

“Dichromatism is usually divided into three categories: protanopia, deuteranopia and tritanopia.” The characteristics found in each category can provide designers with some helpful insight for possible color solutions for each condition.

“Protanopia, a type of dichromatism, confuses stimuli that are normally seen as red and bluish-green with neutral [gray] and with each other (all three are seen as neutral).

Deuteranopia, a type of dichromatism, confuses stimuli that are normally seen as bluish-red and green with neutral [gray] and with each other (all three are seen as neutral). Tritanopia, a type of dichromatism, confuses stimuli that are normally seen as purplish blue and greenish-yellow with neutral [gray] and with each other (all three are seen as neutral).”

It was found that within these classifications, the first two are identified as red-green color deficiencies. It is this condition that is relevant to this study. There are certain color stimuli that red-green color deficient observers are more receptive to than others. This experiment created a revised color palette so that observers with normal and color deficient color vision can perceive the same color message with similar levels of discrimination.

A challenge facing multimedia designers is a test for color appropriateness in designing for color deficient observers. If designers communicate their client’s messages through electronic media, this means that 8.0% of males and 0.5% of females may not be able to extract critical information from certain hue combinations in CRT messages.
This is because default cathode-ray tube (CRT) software color palettes may not consider the perceptual response patterns of color deficient observers. Unless multimedia design professionals are sensitive to special color combinations that can be seen by the color deficient population, they could potentially lose a significant portion of the viewing population/market share. It is prudent to design with CRT color palettes which have been proven to be discriminally effective with the color deficient population. Such actions would comply with the current federal regulatory statutes to provide appropriate auxiliary aids for color deficiency. The federal statutes were designed to enforce The Americans with Disabilities Act (ADA) of 1990.7

**Research Objectives**
The objectives in this research study are to:

1. Develop an interactive web-site that displays various color patterns and records perceptual responses to these patterns when viewed by both color deficient and color normal observers.
2. Construct appropriate color palettes that reduce color confusion among red-green color deficient observers.
3. Test for perceptual responses with color deficient and color normal observers.
4. Analyze the experimental results to determine if the revised palettes will work with red-green color deficient and color normal populations at the same time.
5. Select revised palette colors for use in real-world design schemes/harmonies as a supplement to current default color palettes.

**Commission on Illumination (CIE)**
The Commission on Illumination, (referred to as Commission Internationale de l'Eclairage), “in 1931, … drew up a system of color specification that has been adopted internationally.” The color system uses a chromaticity diagram that “provides a sort of color map on which the chromaticities of all colors can be plotted [using x, y coordinates].” The chromaticity diagram also makes it possible to locate lines of color confusion for color deficient observers.
Figure 1 shows the lines of confusion for protanopes and deuteranopes plotted on the 1931 CIE chromaticity diagram. "The existence of the confusion colors as represented by the zones [in the chromaticity diagram] are the basis for most tests of defective color vision." Cartographers, Olsen & Brewer, successfully used the 1931 CIE chromaticity diagram in this manner to predict color patterns for reflective print media demographic purposes.

Chromaticity diagram plotting data was calculated from CIE XYZ tristimulus values via a 3x3 RGB matrix transformation. The 3x3 tristimulus matrix values were obtained with colorimetric measurements of maximum R, G, B and white point displays on the monitor used in the experiment. The monitor white point was set at D65. Figure 2 illustrates the RGB to XYZ matrix operation.

\[
\begin{bmatrix}
X_{D65} \\
Y_{D65} \\
Z_{D65}
\end{bmatrix} =
\begin{bmatrix}
36.16 & 25.67 & 12.96 \\
19.9 & 53.3 & 6.2 \\
1.79 & 9.86 & 73.38
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]

FIG.2. Matrix conversions from CRT monitor to CIE tristimulus values.
**Color Palettes and Test Stimuli**
Color flexibility for electronic media is not limited to specific palettes but can include the creation of customized palettes. Such options allow the designer to explore a large variety of color combinations.

The Flash software default palette hues (216 in total) are based on evenly spaced RGB digital count increments. Six default palettes of thirty-six colors each (6x6 color square arrays) were available to the designer. Digital count differences of $\Delta=51$ dc allowed each default palette to display a set of thirty-six different colors by varying the ratio amounts of RGB display primaries. Each of the three display primaries had six set points of 0, 51, 102, 153, 204 and 255 digital counts (8 bit) for color display combinations.

The experimenter eliminated ninety-four default hues due to their lack of distinguishable hue differences in the primarily higher and lower value ranges. This elimination resulted in a set of six 4x6 medium value and chroma hue grids of one hundred and twenty-two color choices to be used in the experiment. The selection choices were made in a manner to simulate the perceptual uniformity found in the Munsell color space, as well as eliminating peripheral colors that both normal and color deficient observers would have difficulty discriminating.
Figure 3 illustrates the movement of the RGB primaries as seen in Adobe’s Photoshop. The six set points digital counts are used to create Flash palettes color display combinations. Photoshop’s Color Picker offers hue (H), saturation (S), and brightness (B) translation notation from RGB digital counts.
The palette of modified hues in Fig. 4. followed the digital count patterns in Fig. 3.: differences of high-low chroma and changes in value. The arrangement of all the modified palette patches, one hundred and twenty-two workable hues, stayed within the original Flash palette arrangement.

FIG. 4. Initial experimenter hue selection to be evaluated in testing.
Observer selection
Observers were selected from the Rochester Institute of Technology student and faculty body. They were previously diagnosed with the Ishihara pseudoisochromatic test or the Farnsworth-Munsell 100 Hue test by their vision care specialist and were classified as either protanope or deuteranope, a criteria described by Fletcher, Voke, Judd & Wyszecki and Kalmus. The control group (color normal) was selected at random from those previously diagnosed by their vision care specialist as color normal. Coincidentally, the majority of all experimental observers were from a multimedia-related background, as seen in Table I.

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Age (years)</th>
<th>Observers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photography</td>
<td>36-45</td>
<td>2</td>
</tr>
<tr>
<td>Printing</td>
<td>27-57</td>
<td>2</td>
</tr>
<tr>
<td>Information Technology</td>
<td>56</td>
<td>1</td>
</tr>
<tr>
<td>Multimedia</td>
<td>25-36</td>
<td>2</td>
</tr>
<tr>
<td>Engineering</td>
<td>57</td>
<td>1</td>
</tr>
<tr>
<td>Computer Images Science</td>
<td>32</td>
<td>1</td>
</tr>
<tr>
<td>Glass Blowing</td>
<td>29</td>
<td>1</td>
</tr>
</tbody>
</table>

Observer adaptation
Prior to the initial testing, each observer received at least a seven minute overview explaining the testing procedure, using the actual screen images. This preparation allowed the observer to adapt to the CRT screen image and room lighting of the testing environment.
Experiment
The experimental design is a one factor study, to identify and remove certain colors within the Flash software default palettes that are confusing for red-green color deficient observers.

The test screens required observers to look at a series of various combinations of color hues in different color harmonies on a CRT display. Observer groups were presented with the same set of color schemes and asked to answer questions by extracting information from the images. The image targets consisted of a fish, stylized logotypes, clowns, clocks and moths. Two sample illustrations are displayed in Fig. 5.
Beginning with the fish image, the observers were asked, "What colors do you see?" This question series related image color and target squares. The instructions directed the observers to view multi-hued images and to match image hues with adjacent target squares. Observer responses were recorded with interactive checkboxes as exhibited in Fig. 6.
The next category asked observers to perform the experiment with an on-screen navigation button that advanced a series of images sequentially (Fig. 7). With the advancement in random order of each screen image, the observers responded to the general question, “What time is it?,” by typing in their observation and pressing a response button to record that answer. This process was repeated until the observers were greeted with a flashing light and text indicating that the cycle was completed. When the light stopped blinking, a phrase appeared that praised the observers (“good job”). This cycle was repeated for the moth images asking the question, “What letters do you see?"

FIG. 7. On screen navigation button allowing observer to interact online.
Observer Decisions
Throughout the experiment, humor was used as a deterrent against any anxiety that the observer might experience. For instance, the removal of the clock hands after the first series of images not only focused the viewer's attention, but it brought smiles to their faces (Fig. 8). Observation notes by the experimenter indicated that these images elicited much laughter in both observer groups (observer relaxation) and piqued curiosity as to what the next image might be.

FIG. 8. Humorous image (no hands at all) used as a deterrent against observer fatigue.
Data Collection
Two methods of interactive data collection were used. In the first method, information was recorded with the color palette squares functioning as checkboxes. The second method recorded responses in a textbox. The information collected from both methods listed answers in the order in which they were given. All response input was fed via Flash software to the experimenter’s e-mail address for sorting and analysis as shown in Fig. 9.

Test Questions
The first question, “What colors do you see?” was used to find out what colors would work as a visual auxiliary aid. In basic color design, it is assumed that a normal observer can identify any hue from its neighboring hue. During the process of examining each hue, it was important for observers to view them against a neutral-gray background. Those hues not identified by the color deficient observers were taken as indicators of color schemes which could cause potential confusion in a design. The second and third questions, “What time is it?” (clock) and “What letters do you see?” (moth graphic image sets) were then used with the type-in textbox to test the visual recognition of the hue sets. The hue selection procedure of CRT screen colors for Flash software followed the reflective color experiment of “Olsen & Brewer” for demographic map presentations.
Preparation

Ergonomics/Safety requirement

As a prerequisite for testing, forms were filed with the Institute’s Review Board on Human Subjects explaining the objectives of the research. This information can be found under policy and procedures in the R.I.T. Policy manual in Appendix A.

Hardware/Software

The computer hardware used in this study was a Macintosh G3 with a nineteen-inch factory issued Macintosh color monitor. All setup and measurements for monitor calibration were done in a semi-darkened room, using a Minolta CA-100 spectrophotometer. Calibration results were tabulated using The MathWorks software MatLab™. The same computer/monitor combination was used throughout the experiment for all observers.

Lighting conditions for the experiment were provided by a vertical torch lamp with a 30 watt 3000k, warm white fluorescent, 8 inch circular bulb pointed at a white ceiling (12ft.). The chair used was a standard office task chair. Tabletop height measured twenty-nine inches, with the monitor center screen at seven inches above the tabletop. Participants were seated at a viewing distance of 24 inches from the monitor as displayed in Fig. 10.

FIG. 10. Observer testing station.
The primary software was Macromedia™ Flash 4.0, an interactive authoring application. The interface design involved creating a screen suitable for multi-task navigation. A combination of neutral gray ranging in values from 55% to 85% in brightness, was applied to the design background as it was non-intrusive to both observer groups. The desktop picture pattern of the computer was also set with a 40% gray brightness created in Photoshop and applied to the background with unrelated icons removed to reduce distractions during testing.

The infrastructure behind the experiment was a combination of Visual Basic, JavaScript, Flash Script Commands (FS Commands)/Action Scripts and a CGI script. When the JavaScript commands were used in Flash, it became possible to view images at the maximum full screen size. This made it more comfortable for the observers to interact for the duration of the experiment. The CGI script made it possible for the data to be delivered directly from the Internet to the experimenter's e-mail address.

A minimalist graphic style was applied to background screen and image graphics to maximize color discrimination rather than compete with the observer's ability to discriminate between colors. "The main reason for using a large field whenever possible is the gain in precision of color-matching.”

**Data Analysis**

Microsoft Excel was used to integrate experimental data from the modified palettes into bar graphs to display relationships between observer responses. A 1931 CIE chromaticity diagram shows the location of where hues fell in relation to lines of color confusion. A 1976 CIELAB chroma diagram was used to provide a more uniform, visually intuitive display of the experimental results. The checkboxes and textboxes were instrumental in providing a means to isolate observer responses for sorting.
Results
The observer selections supported the feasibility for developing color deficient palettes for red-green color deficient observers. This experiment used the confusion lines plotted on the 1931 CIE chromaticity diagram to make color selections for the color deficient palettes that fell across the lines of confusion. The patterns in Fig.11 are the mapped responses made by the red-green color deficient observers.

Figure 11(a)-(f) shows the 1931 CIE chromaticity diagram for all six palettes. The open-circles data points indicated the modified palette hues falling across the lines of color confusion. The plots in these figures are the results of color selections made by both observers in response to the two fish, two clowns and two logotypes.

"In principle, all colors lying along confusion lines are confused." The confusion lines are also referred to as isochromatic lines. However, "two stimuli, although of the same chromaticity for a dichromat (being located on the same isochromatic line of the chromaticity diagram), can be differentiated if they arouse different sensations of brightness or lightness."
FIG. 11. 1931 CIE chromaticity diagram with modified palette hue selections made by color deficient observers falling across lines of color confusion from screen (a) and screen (b).
FIG. 11. 1931 CIE chromaticity diagram with modified palette hue selections made by color deficient observers falling across lines of color confusion from screen (c) and screen (d).
FIG. 11. 1931 CIE chromaticity diagram with modified palette hue selections made by color deficient observers falling across lines of color confusion from screen (e) and screen (f).
Figure 12 (a)-(l) shows the modified palette observer response data in percentages for all six palettes. The data from the modified palettes followed a selection criteria of observers able to see a 60% or greater color match for "I see it/I do not see it" stimuli threshold. The data in each graph was normalized to minimize size disparity between observer pools; color normal (n=3); color deficient (n=12). The numbers along the y axis represents observer response to the targets in percentages. The patches beneath the bar graph are coded numerically to color match each bar set.

The number of usable hues above 60% is represented by a cutoff line which varied per palette. The total number of hues that meet the 60% selection criteria is 40. The numerically coded patches that dipped below the 60% bar graph cutoff line are considered not usable. Although these hues were not as visibly strong, they were able to be discriminated and could be used in moderation.

For multimedia designers sophisticated analytical experiments of this nature could provide more exacting indicators that color deficient observers are able to differentiate these hues. The benefit that designers gain is that even if they have fewer palette choices, they still have options that will not compromise or stifle their creativity.
FIG. 12. Bar graph percentages of observer identified hues (a) with matching numerically coded patches (b).
FIG. 12. Bar graph percentages of observer identified hues (c) with matching numerically coded patches (d).
 FIG. 12. Bar graph percentages of observer identified hues (e) with matching numerically coded patches (f).
FIG. 12. Bar graph percentages of observer identified hues (g) with matching numerically coded patches (h).
FIG. 12. Bar graph percentages of observer identified hues (i) with matching numerically coded patches (j).
FIG. 12. Bar graph percentages of observer identified hues (k) with matching numerically coded patches (l).
As was anticipated, the color normal observers were able to discriminate in most areas of the Flash color palettes. Color deficient observer choices are displayed on the 1976 CIELAB chroma diagram.

Figure 13 (a)-(l) show data from the six modified Flash palettes in Fig. 4. It should be noted that when the default Flash palette patches were plotted in CIELAB space there was a transposition of the software menu orientation. The 1976 CIELAB chroma diagram describes increasing chroma intensities as the hues move away from the center in separated concentric circular bands.17 Hue and chroma shifts of the observer data is displayed in a visually oriented color space display. As colors plot towards the axis center, they become less chromatic (more neutral) in appearance. For multimedia design, it is a means to display color data in a "color space in which equal distances approximately represent equal color[visual] differences."18

When a Flash palette is displayed in CIELAB color space, the overall square palette shape is skewed; this is the result of the evenly spaced digital counts used for the palettes not displaying colors in visually uniform patterns. Although the hues have even mathematical spacing, they show a non-uniform plot in CIELAB color space. An outline is used to define the color space shape of each palette.
FIG. 13. 1976 CIELAB chroma diagram with Fig.4, modified palettes. The hues read right to left in both the default (a) and subset (b) palettes.
FIG. 13. 1976 CIELAB chroma diagram with Fig. 4 modified palettes. The hues read right to left in both the default (c) and subset (d) palettes.
FIG. 13. 1976 CIELAB chroma diagram with Fig. 4. modified palettes. The hues read right to left in both the default (e) and subset (f) palettes.
FIG. 13. 1976 CIELAB chroma diagram with Fig. 4. modified palettes. The hues read right to left in both the default (g) and subset (h) palettes.
FIG. 13. 1976 CIELAB chroma diagram with Fig. 4. modified palettes. The hues read right to left in both the default (i) and subset (j) palettes.
FIG. 13. 1976 CIELAB chroma diagram with Fig. 4 modified palettes. The hues read right to left in both the default (k) and subset (l) palettes.
All the color deficient observers stated that they referenced images by their edges. Some of the areas around the right eye of the clown image in Fig. 14. appeared low in chromatic content and required some effort to define. This was because the edges in that area lacked significant definable hue contrast.

In Fig. 14. the gray neutral background against the bright edge in the multi-hue image was appealing to the color deficient observers because the contrasting edges to discriminate the target were cited as a factor. Daniel Overheim states, "it seems increasingly likely that the [human] visual system primarily uses information from these edges, rather than from the regions within the uniform areas, to produce our visual perception." 

FIG. 14. Palette 3, provided necessary hue contrast.

It was observed during the administration of the test that the participants' anxiety level increased during the checkbox matching phase of the experiment. Several of the participants found that selecting and matching colors presented them with difficulties. Unsolicited comments during testing showed:

1. Realization of their color deficiencies when judging certain colors.
2. Confronting color issues that they wanted to ignore regarding uneasiness at evaluating colors in a testing room environment.
3. Making color choices that might appear questionable to others.
Also noted by the experimenter some of the color spots on the second fish (orange) and the high chromatic background of the fish body presented color discrimination problems for the color deficient observers. This chromatic content tended to overpower the color deficient observers' sorting capabilities. This was a phenomenon that happens according to the laws of simultaneous contrast as documented by chemist M.E.Chevreul.

Chevreul states, “if we look simultaneously upon two stripes of different [value] tones of the same colour, or upon two stripes of the same [value] tone of different colours placed side by side, if the stripes are not too wide, the eye perceives certain modifications which in the first place influence the intensity of colour, and in the second, the optical composition of the two juxtaposed colours respectively.

Now as the modifications make the stripes appear different from what they really are, I give to them the name of simultaneous contrast of colors.”

That was the case when small red shapes were placed against the more vivid large orange background. This orange background for some became a problem after prolonged staring during testing the larger surrounding color begin to influence the smaller color. Therefore the color quality of the smaller shape changed. One observer commented that when he looked away from the screen target and had to refocus his eyes, the bright colors such as orange, vivid in chroma, began to overwhelm him (See Fig. 15).

![Fig. 15. Simultaneous contrast noted in fish background and fish patterns by observer during testing.](image)
Investigator Notes

Investigator observations noted that data sampled from Olsen & Brewer, under the conditions of this experiment resulted in a moment's hesitation for the color deficient observers. Figures 16 (a)-(b) shows the low chroma hue patterns that caused some observer confusion. The low chroma hue patterns lacked in some areas (i.e., combination of numbers, letters and their background) the necessary value contrast even when the color deficient observer relied on the edge of the image components for differentiation. In Figure 16 (c) the hesitation was noticed as a result of a clash between hue combinations high in chromatic intensity.

FIG 16. Hesitation due to a lack of the necessary value contrast.
Final Hue Selections
Some of the color deficient observers' selections, fall within the analogous color scheme, as illustrated in Fig. 17.
Analogous colors consist of any adjacent hue combinations of three or four, hues varying in value that are in consecutive order around an [artist] color wheel. Analogous colors should not be considered an exclusively color deficient palette.

Analogous colors are defined in the words of colorist Faber Birren who quoted from M.E. Chevreul's text, THE PRINCIPLES OF HARMONY AND CONTRAST OF COLORS AND THEIR APPLICATIONS TO THE ARTS. 21 Birren states that, "with analogous color schemes, effects are generally best when the key hue is a primary (red, yellow, blue) or a secondary (orange, green, violet)." 22 Birren discovers through research that, "studies in the field of psychology have verified the observation of Chevreul that colors look best (a) when they are closely related or analogous." 23
This does not mean that designers should be using sets of colors from the analogous color scheme exclusively to design for color deficiency. The author has observed that the testing was helpful in locating new design possibilities after taking into consideration the confusion lines. There are benefits associated with analogous colors states Birren, “when analogy instead of contrast is introduced, colors assume more personality. Red and orange, orange and yellow, blue and green-combinations like these are either warm or cool in feeling [can be used in designs from the brightness between hues]. Emotion is given a chance to operate and the eye and mind a chance to experience a definite and concise response. Analogous hues may be blended without danger of clash.”

![Analogous color scheme diagram](image)

**FIG. 17.** Artist palette showing isolation of an analogous color scheme.
The hue choices made by the color deficient observers reduced the patches from the one hundred twenty-two hue selection modified palettes to the final palettes of sixty-nine hues, as illustrated in Fig. 18.

FIG. 18. Remaining number of final sixty-nine hues recommended for design by the author.
Figure 19 (a) shows selection patches as they populate CIELAB space consistent with abnormal color perception that dichromats are capable of discriminating, “confusion colors.” Figure 19 (b)-(c) shows the bar graphs with various responses in percentages made by the observers to the real world test targets. M.E. Chevreul and Birren’s explanation of analogous colors, blending without danger of clashing, appear to hold true. The analogous color decisions for the final targets were the result of adjusted color combinations from the book, *Color Harmony*.

The graphs indicate which hues were viewed with equal discrimination and a high level of agreement among the observer pool. Selected targets are identified with labels and numbers to match the bar graphs and a letter for palette source.
FIG. 19. Observer reaction bar graph (b) to sixty-nine modified hues used in simulated real-world graphic clock displays (c).
FIG. 19. Observer reaction bar graph (d) to sixty-nine modified hues used in simulated real-world graphic moth displays (e).
Experimental Improvement
From a design perspective, the experiment provided an interesting approach to assist the experimenter in gathering data. It was noticed that the addition of a navigation feature could have made the checkbox experience less cumbersome for observers. This adjustment could allow them to drag-select a palette patch to the target for comparison. Although the study yielded some interesting data, future experimenters might want to even out the size disparity between future observer pools.

Conclusions
This investigation has led to the following conclusions:

There is a need to address the concerns of color deficient consumers who use the internet.

Designing with color deficient palettes can be a useful tool for multimedia designers to market services to customers which include red-green color deficient observers, and provide color design opportunities that will comply with the ADA regulations.

The experimental procedure showed potential as a valid means of gathering data about color deficient observer preferences.

A multipurpose interactive web-site used for analysis and data gathering can be designed to display various color patterns. Using the internet in this capacity has proven to be an effective tool to record perceptual responses of patterns when viewed by both color deficient and color normal observers.

Multimedia designer should strive to do work of an analytical nature to further promote the growth of design education.
The experimental data can pinpoint the colors that were well perceived by both observer groups. The experimenter was able to refine workable color palettes into a subset palette (of a limited nature) that worked as a viable option for both observer groups and reduced color confusion for those with red-green color deficiency.

A revised color palette was created for designers to use as a unique design application. This application could serve as a visual model for opening up new business opportunities and equating to high business yields.

**Future Directions/Applications**

Another area of interest for future investigation was the improvement of target images. The fish had spatial patterns which were too small to discriminate. This size factor prompted questions as to what could be explored by making simultaneous contrast the primary experimental objective. The challenge would be to see how stylized patterns done in a manner similar to 20th century Dutch painter Piet Mondrian abstract approach would fare. This color study also brings into question how many of the traditional artists’ color schemes, such as monochromatic scheme, clash scheme, complementary scheme, secondary scheme and tertiary triad scheme used by color normal artists could be modified to accommodate the color deficient artist.

Also recommended as a future study a sophisticated factorial experiment designed to generate more specific statistical data from combinations of light-dark and size relationships or edge contrast between light-dark values and size relationships.
Create joint advertising and research funded ventures with marketing groups to determine the purchases of goods and services made by the color deficient consumer.

Conduct color deficient evaluation of other existing default palettes in image-making software (i.e., Macromedia Flash™, Adobe Illustrator™, and Adobe PhotoShop™).
POLICY FOR THE PROTECTION OF HUMAN SUBJECTS IN RESEARCH

A. PURPOSE

The purpose of the review of research involving human subjects (in compliance with Part 46 of Title 45 of the Code of Federal Regulations as revised March 8, 1983, and the Notice of the Secretary of Health, Education and Welfare dated May 20, 1975) is to insure the protection of the human subjects in such research. It is the responsibility of the institution to insure this protection by providing:

1. Review and approval of each research project prior to the beginning of that activity by an Institutional Committee on Research Involving Human Subjects to determine that:

   The risks of injury to the subject, if present, are so outweighed by the sum of the benefit to the subject and the importance of the knowledge to be gained as to warrant a decision to allow the subject to accept these risks;

   The rights and welfare of any such subjects will be adequately protected; and

   Informed consent, if required due to risk of injury, will be obtained by adequate and appropriate methods in accordance with the provision of the regulation.

2. For the certification of such review and approval.

3. For a continuing review of all research activities in keeping with the above.

B. INSTITUTIONAL REVIEW BOARD

All research initiated by or conducted at RIT must be approved by the RIT Institutional Review Board if it involves human subjects. [An IRB was established in 1978 by the National Technical Institute for the Deaf due to its extensive research activity with deaf subjects. It is anticipated that the NTID IRB will continue to be maintained as a subordinate committee for review of research in that college, and that it will function in accord with RIT policy and government regulations.]

1. Constitution

   Appendix-A
   RIT Policy Manual

   It is suggested for further detail to visit the web-site at:
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QuarkXpress 3.32, 4.04 and a G4 Power Macintosh were used to construct this publication. This report was set in the Adobe version of Times New Roman and Helvetica families type fonts. Graphs and diagrams were constructed in Microsoft Excel and AppleWorks 6. All interactive programming was done in Flash 4.0. All illustrations were created with Adobe Illustrator 8 and 9. All full color images used to illustrate this report are screen shots acquired from the experiment online web-site.