The Use of Color in Computer Interfaces: Preliminary Research

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Abstract

This research broadly explores the use of color in computer displays. In particular, the study described here explores issues related to the effective use of color in graphic elements and in text, as well as the more subjective issues related to the use of color.

To design color interfaces effectively, it is important to understand the principles of color interactions: within the properties of color itself, with the medium, with the environment, and most importantly with the viewers.

Color can be used effectively as an attention-getting device, although the choice of an inappropriate color may limit its effectiveness. It is important that highlighting is perceivable enough to be effective, yet not distracting.

The issue of contrast between text and its background is critical to those who spend the majority of the day in front of a computer screen. The contrast should not be so high that it causes fatigue, but it should not be so low that it strains the viewers' eyes. Highly saturated hues should be avoided. In general, color in text should be used sparingly.

Graying unselected windows while leaving the selected window in full color is an effective method of directing the viewers' attention in the context of multiple overlapping windows.

I. Introduction

In the past, computers were viewed as a strictly monochrome medium. Recent advances in display technologies have made color monitors more widely available. However, color adds a complicated dimension to the world of monochrome computers. It creates extra work not only for computer engineers but also for interface designers. There are many different factors which need to be considered when designing applications for use with color monitors. For example, the interface designer must simultaneously consider the inherent properties of color, the medium on which color is being displayed, the environment in which color is being viewed and, most importantly, the perceptual abilities of the viewers.

In trying to incorporate color into any form of visual design, there are basic principles to keep in mind. It is helpful to think of color as being comprised of multiple dimensions. Albert Munsell (1858-1918), a color theorist, described color as being composed of three dimensions; hue, value and saturation. **Hue** is the quality by which we distinguish one color from another, as a red from a yellow, a green, a blue, or a purple. **Value** is the quality by which we distinguish a light color from a dark one. For example "pink" is a light red and "maroon" is a dark red. **Saturation** is the strength or weakness of color, depending on the amount of gray in that color. For example, emeralds and certain green grapes are light green, but they differ in their saturation. Emeralds are strong in color and therefore have a high saturation, while grapes are weaker in color, or grayer, and therefore have a low saturation.

Another important aspect of color is contrast. Colors are able to be perceived because they differ from their surroundings. In other words, colors are better perceived when there is contrast. Johannes Itten (1888-1967) observed that there are seven different kinds of color contrasts[1]; hue, light-dark, cold-warm, complementary, simultaneous, saturation and extension. The most effective of these are hue, light-dark and saturation.

There are many other color theories, each of which add new facets to our understanding of color. For example, human perception is capable of

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[1] Itten (1970). *The Elements of Color*. New York: Van Nostrand Reinhold Company.

discriminating a wide range of colors, although color recognition is limited to a much smaller set. "Some 20,000 colors are accessible to many viewers, with the constraints for practical applications set by the early limits of human visual memory rather than the capacity to discriminate locally between adjacent tints."[2]

In addition, color is an unstable medium: colors take on different appearances when placed in different environments. For example, a certain shade of red will have a different appearance when placed on a yellow background than when placed on a blue background.

Besides the inherent properties of color itself, the designer of the interface must also consider the limitations of the medium on which a given color is displayed. For example, color monitors have many limitations. The color seen on the screen one hour ago may differ significantly from the color being seen now. In addition, screen resolution is an important factor, for without sufficient resolution, the application of color may be limited to garish and inappropriate uses.

The environment is another crucial aspect to consider, specifically the lighting conditions. Color perception is very sensitive to environmental changes. The amount and type of lighting available may influence the perception of color in ways that the designer did not anticipate.

A very important and often forgotten aspect of display design is consideration of the viewer. One factor to be weighed carefully is color deficiency, commonly referred to as color blindness. 8% of the male population and 0.5% of the female population have some degree of color deficiency. The most common type of color deficiency is a reduction in the discrimination of reds and greens.[3] In addition, color vision varies to some extent as a function of the age of the observer. "Rapid improvement has been reported for color discrimination up to approximately 25 years of age, followed by a gradual decline which becomes more pronounced around age 65."[4]

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[2]Tufte, E. R. (1990). *Envisioning Information*. Connecticut: Graphics Press.
[3]Hunt, R. W. G. (1987). *Measuring Color*. Ellis Horwood, Ltd.
[4]Burnham, R. W., Hanes, R. M., & Bartleson, C. J. (1963). *Color: A Guide to Basic Facts and Concepts*. New York: John Wiley.

On the more subjective side, aesthetics is a valid aspect of color design which is often dismissed. Silverstein (1987) found that while color did not necessarily increase performance, users exhibited a general preference for color over monochromatic presentations.[5] Marcus (1988) stated that while people do not learn more from a color display, color is generally considered more enjoyable and color information is easier to remember.[6]

Hopkin (1983), in his paper "Use and Abuse of Colour" wrote that, on the whole, the benefits of color are more apparent than real; users prefer color displays over monochromatic ones because they are more aesthetically satisfying.[7]

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[5]Silverstein (1987). Human Factors for Color Display System: Concepts, Methods, and Research. *Color and the Computer*, pp. 27-61. Ed: J. Durrett. San Diego, CA: Academic Press, Inc.

[6]Marcus, A. (1988). Human Factors of Window Design: *Tutorial Notes ACM SIGGRAPH 1988*. Atlanta, GA.

[7]Hopkin, D. (1983). Use and Abuse of Colour. *'83 Computer Graphics Intl. Conf. Proc.*, pp. 101-10. Middlesex, UK: Pinner Green House.

II. Objective

The research discussed in this report broadly explores the use of color in computer interfaces. The purpose of this preliminary study is to provide some insight into the use of color in the design of computer interfaces. In particular, this study explores issues related to the effective use of color in graphic elements as well as in text. Of equal importance are the more subjective, or aesthetic, issues, which were also a concern of this study.

The primary goal of this research is to help people design color interfaces as effectively as possible. To accomplish this, we explored the ways in which color can be effectively applied to computer interfaces by examining several of the factors which influence users' perceptions of color.

III. Method

1. Materials/Design

Based on our goals and objectives, an experiment was designed to understand the role of color properties and users' perceptions of them in designing effective color displays. Our intent was to discover which parameters affect the way people use color computer applications.

To accomplish this, a simulation of the Andrew "messages" application was used as the setting for this experiment. Andrew is a multimedia computer environment developed for use in educational institutions and industry. The "messages" application is a multimedia electronic mail and bulletin board system. We chose Andrew because it provided us with a usable platform with which we and our subjects, were reasonably familiar.

A typical Andrew screen has multiple overlapping windows. The windows used in this experiment were the "console", "typescript", "twm icon manager", and two "messages" windows. The "console" window is located in the upper left corner of the screen. The "console" keeps track of various kinds of information about the user's workstation. The"typescript" is the window that lets a user to communicate directly with the operating system that recieves, interprets and executes commands. This window is typically located below the "console" window. The "twm icon manager" window provides a mechanism for managing the windows on the screen and is located in the upper right corner of the screen. Users read and send messages using the "messages" windows. The "icon manager" and "messages" windows overlap each other and are located typically to the right of the "console" and "typescript" windows. The snapshots of these windows can be found at the end of this section (Figure 1, page 13).

Users operated the computer using a keyboard and a mouse. While users can have many windows on the screen, they can only work in one window at a time, and they must move the mouse cursor into a window before they can work in it. Throughout this report, the window that the mouse cursor is in is called the "selected" window. The rest of the windows are referred to as the "unselected" windows.

The simulation was created with an interactive hypermedia prototyping system. The hardware included a 13 inch, high resolution (640 x 480 pixels), color monitor, with 256 simultaneously displayable colors. A standard keyboard and mouse were used as input devices for the system.

The experiment was designed to observe the reactions of subjects to the use of color in three specific modes; as an organizational device, as a signalling device and as a focusing device. In addition, we explored different text and background color combinations. Subjects' overall preferences for monochrome or color monitors were also observed.

The subjects were asked to read several electronic mail messages, in a specified order, and to perform the task described within each mail message. Each mail message was displayed using a different color combination. Different signalling, organizational and focusing devices were associated with each of the different tasks.

The simulated screen contained windows commonly used in the Andrew system (see Figure 1). These windows were placed on a textured gray background. The color of these windows were a light beige (RGB 0-0-88). A light beige was chosen because it is slightly dimmer than white. Black text on a light beige background has less contrast than on a white one. In this way, while the contrast is sufficient, the dim quality of the color is soothing.

Organizational devices are ones in which color is used to signify the classification of similar information. Color was used as an organizational device in title bars of the various windows. The "console" and "typescript" title bars used the same reddish brown color (RGB 0-57-74). The same color was chosen for these windows, because they both have similar characters. The red was chosen to reflect the active nature of the windows. Typically both windows remain on the screen during the operation, and they both are related to the operation of the system. Blue (RGB 4-24-54) was chosen for "messages" window title bars to mimic the color of the mail icon described later. The title bar for "twm window manager" window was green (RGB 39-57-53) to differentiate it from the other windows. To avoid great contrast which could create confusion, the value of the colors for the title bars

were chosen within close range of value gradation. The iconified windows in the icon manager used darker versions of the colors that were selected for the title bars of the opened windows to make them appear to recede in the screen so that they would not be distracting.

Signalling devices use color to attract attention to important information. Two types of signalling devices were used in this experiment; attention-getting and highlighting. Attention-getting was applied in two places, in the mail and the warning icons, both of them were in the "console" window. The mail icon (Figure 2) appeared in blue (RGB 13-42-100) and was blinking at the beginning of the experiment. The blue was designated for mail icon because it's contrast with the surrounding elements was high enough that it would attract attention, yet it is not so bright that it becomes intrusive or alarming. In our culture, blue is often used to signify mail services. This attention-getting device was used primarily to convey status information.

The warning icon (Figure 3) appeared in yellow (RGB 100-100-0) and black at a later point in the experiment and was used to convey information about a problem in the system. Yellow and black was chosen because they create high contrast with each other and the surrounding elements on the screen. The brightness of yellow will attract attention immediately. In addition, in the western culture yellow is often used to signify warning.

In addition to attention-getting, color was also used as a highlighting, signalling device. The caption of the message currently being read was highlighted with a blue bar over black, bold letters. A very light blue was used because it was sufficiently different than the background color which was light beige. Besides, because of the low saturation and light-dark contrast between the blue and the background, it would not clutter the screen and would not be distracting.

Finally, color was used as a focusing device, in which color was used to focus viewers' attention to a selected window on the screen. Focusing was achieved by graying unselected windows, leaving the selected window in full color (Figure 4). RGB 59-59-59 was used for the gray. Gray was used to give the illusion of depth. When the mouse was moved to a certain window, that window would be displayed in full color, and the previously selected window would become gray. In this way

the viewers' attention would be directed to the selected window which appeared in full color. The text in all windows remained readable at all times, although the grayed windows exhibited a lower contrast.

To address the issues of text and background contrast, as well as the choices of colors, different color combinations, common and uncommon, were used for different messages. The color combinations used were:

Text	RGB	Background	RGB	Type of contrast
black	0-0-0	white	100-100-100	light-dark
black	0-0-0	light beige	100-100-88	light dark, hue, saturation
saturated blue	0-0-100	bright green	0-69-0	hue, saturation
light gray	83-83-83	light beige	100-100-88	light-dark, saturation
saturated blue	0-0-100	white	100-100-100	saturation
bright green	0-100-58	dark gray	18-21-22	hue, saturation

Table 1. Color combination used for text

These color combinations were used to understand how different color combinations affect subjects as well as to get an idea of what the most effective text-background color combinations are. For the more common color combination, both white and light beige were used as the background for black. For a low contrast effect, light gray text on biege background was used. Saturated color combinations were used for blue text on green background and white background. A similar color combination used for CRT screens, a bright green on a dark gray, was also used here.

To faithfully duplicate the Andrew environment, the typeface used for the text throughout the application was 10 point Times. Bold and italic variations were used for the message captions. For the title bars, Helvetica 10 point bold was used.

Figure 1. Typical screen of Andrew simulation.

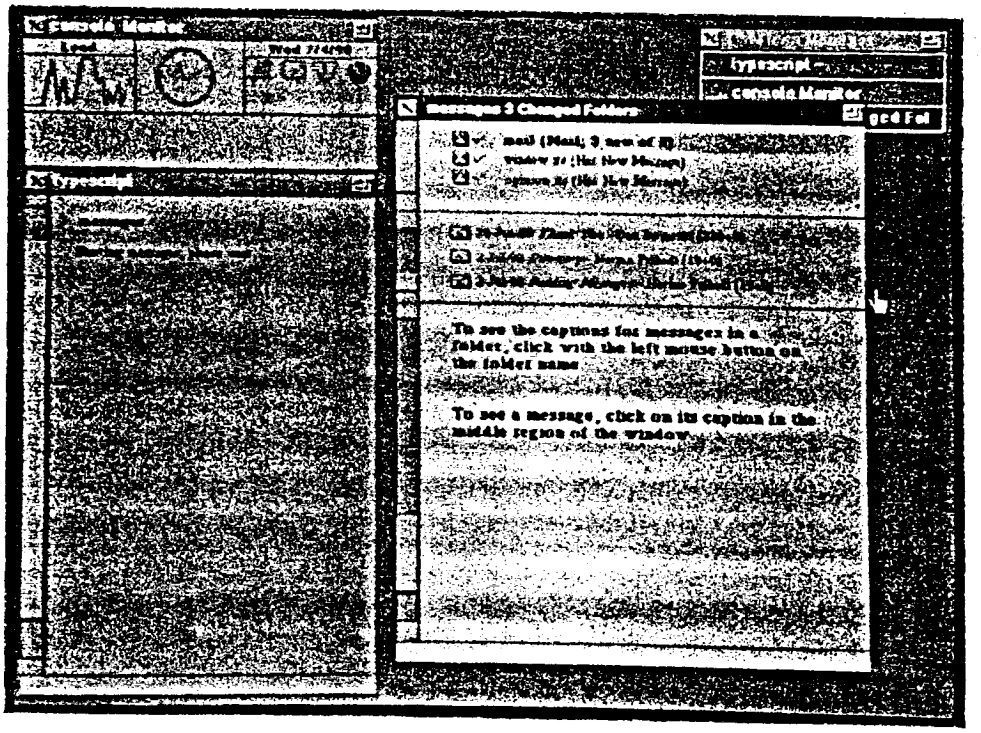


Figure 2. Mail icon.

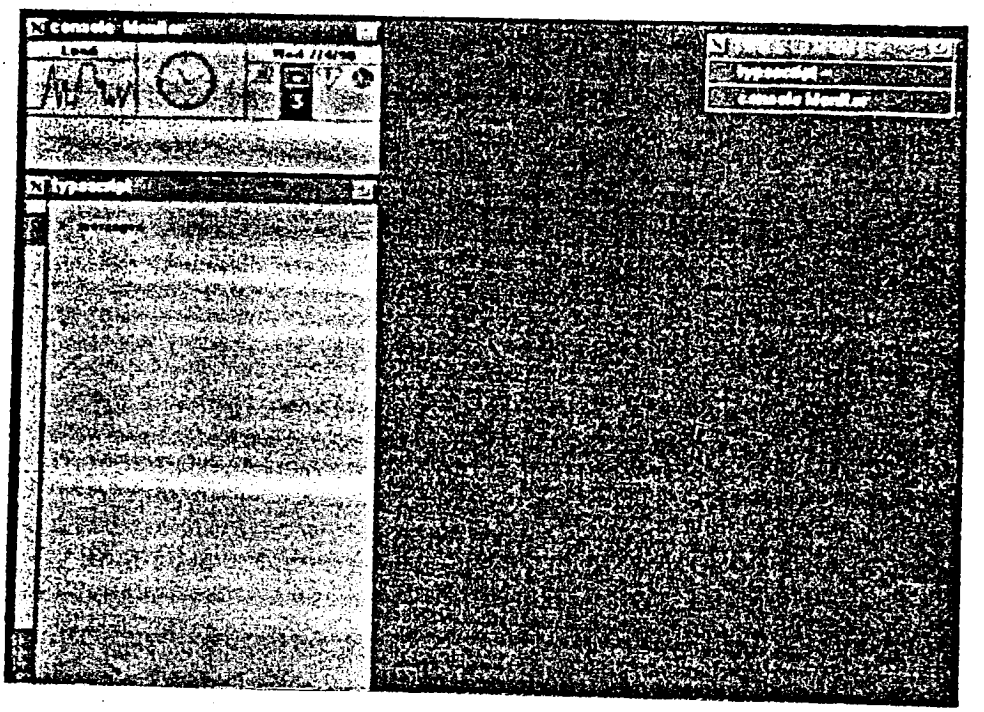


Figure 3. Warnig icon.

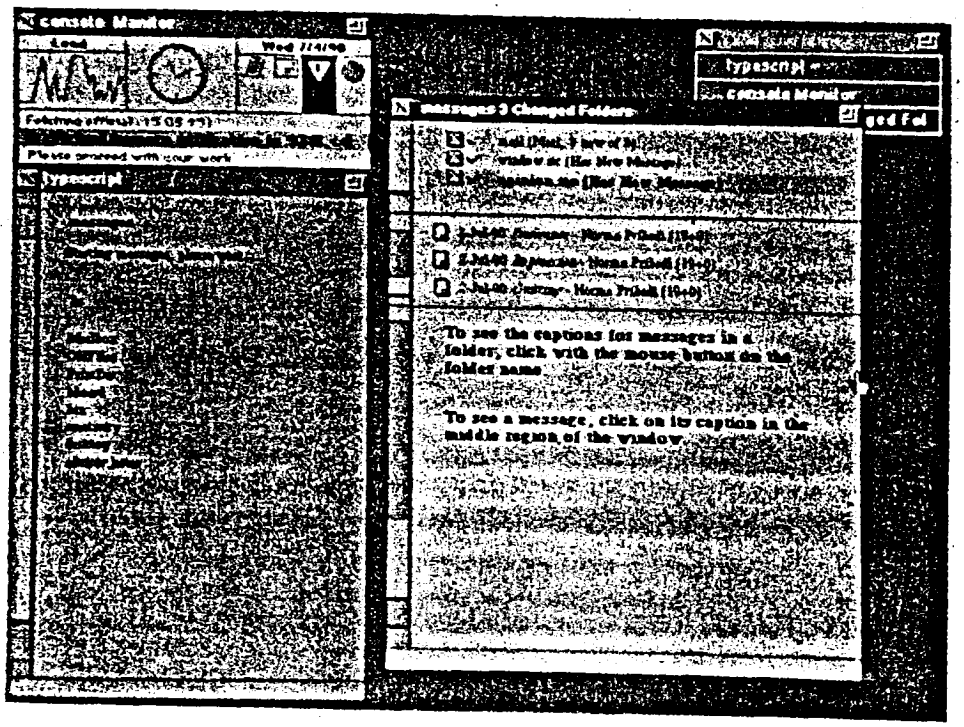
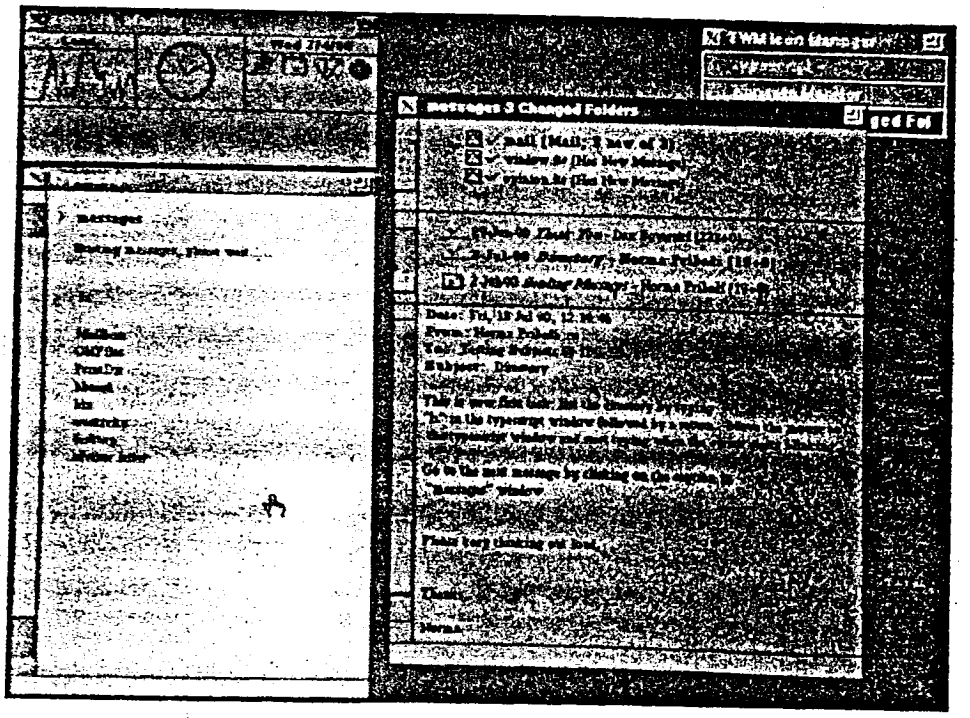


Figure 4. Graying of unselected windows.



2. Subjects

The subjects were students and employees at Carnegie Mellon University. They included five males and three females. They are between the age of age 20 and 40 years. Two of the subjects reported color deficiency, specifically in recognizing certain reds and greens.

Two subjects were affiliated with the English department, while the rest were educated in computer related fields. Two subjects reported education to the Bachelor's level and two to the Master's level. The rest were Ph.D. students.

All of the subjects reported extensive experience with monochrome computers, ranging between three and twelve years. Most of them, at the time of this study, used the computers for programming and for editing text. Most subjects had some experience with Andrew computers, ranging from four months to four years (occasional use for reading mail messages and some editing). Half of the subjects had used color computers moderately to extensively (between two and seven years). The rest had little or no exposure to color computers.

3. Procedure

Subjects were tested independently in an enclosed, windowless and quiet room with fluorescent lighting. The computer screen was approximately 16 inches away from the subjects.

Each one was asked to read electronic mail messages and perform the tasks described within those messages. Each mail message was displayed using a different color combination and described a different task. Different signalling, organizational and focusing devices were associated with each of the different tasks.

Subjects' preferences for monochrome or color monitors were observed. Through their comments and answers to questions during the experiment. To help subjects to see the difference between full color and monochrome screens, the reply screen in which they wrote their replies was monochrome (black, gray and white).

Subjects were asked to speak their thoughts out loud. The subjects were audio- and videotaped, and the results reported here are based on data which was transcribed and encoded from those tapes.

Each subject's testing session was followed by a brief discussion period. During this time the screens were shown again, and the subjects were encouraged to give additional comments.

IV. Results

A table of data was compiled from the transcripts of the experiment. The results are as follows.

1. Reactions to the use of color as organizational device.

Many of the subjects did not respond at all to the title bar colors. One subject wondered if the colors were meant for cueing, while another liked the idea of having different color bars to designate different windows. One subject, who also had color deficiency, merely commented on his preference for a particular combination (white type on blue) for its optimum contrast.

Reactions to the Title Bar's Colors	Number of Subjects
Recognized as organizational device	
Wondered if color was used as organizational device	• •
Commented only on the color	•
No response	• • • • •

Table 2. Reactions to the title bars' colors

Half of the subjects did not respond to the colors of the "twm icon manager" window (see Figure 1 on page 11). The remaining subjects guessed that it was color coded, but were not sure as shown in their responses:

> "You have to remember what that means *(pointing to the smallest green icon).* Actually I am supposed to remember by the color.";
>
> "OK, that's interesting, why is it blue *(pointing to one of the bars in the "twm icon manager" window)* . Let's figure it out. I guess it's blue because that must be the one window there *(pointing to "messages" window).*";
>
> "I want to then, again this is part of the distracting element, figure out what is the significance of that color *(pointing to one of the title bars).* And why is it used in some places and not in others.";
>
> "I guess this is the first I've noticed that the icons are color coded."

Reactions to the Icons' Colors	Number of Subjects
Recognized as organizational device	
Wondered if color was used as organizational device	• • • •
No response	• • • •

Table 3. Reactions to the icons' colors.

2. Reactions to the use of color as signalling device.

a. Attention Getting

• Blinking Blue Mail Icon

Seven out of eight subjects did not react to the first encounter of the blinking blue mail icon. One subject noticed it for the first time during the discussion when the screen, which contained the icon, was brought up again, as shown in her comment during the discussion:

> "That's the first time I've noticed that blue on there *(looking at the blinking blue mail icon).* I can't believe it."

• Yellow Warning Signal

Six of the eight subjects reacted immediately and strongly when the blinking yellow and black warning signal first appeared as shown in some of their comments:

> " I am going to ... it's got a highlighted message over on my console that took my attention away for a minute.";
>
> "So I looked at that before I even bothered with this because that was so compelling.";
>
> "That's interesting. So this yellow message flashes up and it immediately attracts my attention.";
>
> "WOW...uhm, it's kind of hard to miss this warning up here."

One person recognized the combination between the icon and the color as a warning sign:

> "Virtual memory blah blah blah. Is that something I should worry about? Obviously it is, since it has an exclamation point and it's yellow which often is caution."

Another subject, this one with a color deficiency, said that yellow was better than red (red is one of the colors this subject could not detect clearly):

> "See, that, that jumps out at me. That jumps out at me immensely. That is a much better color than a red."

The other two did not make any comments when the warning first came up but elaborated on their thoughts during the discussion. One of them said that it caught his attention during the experiment, but he did not comment on it at the time. During the discussion the subject said

> "That really caught my eye because of the black and yellow."

The other one did not notice it until the discussion. At the discussion the subject was shown the warning signal again and commented

> "Well, that yellow flashing, (this) is the first time I've noticed that too. I don't know if it did that before or not."

On First Encounter	Blue Mail Icon	Yellow Warning Icon
Reacted	•	• • • • • •
Did not react	• • • • • • •	• •

Table 4. Reactions to the blinking blue mail and yellow warning icons.

b. Caption Highlighting

Six of the eight subjects did not comment on the light blue highlighting bar across captions being read when running the program. Of the six, one of them commented favorably without prompting when the screen was shown again during discussion:

> "And I like this blue band as highlighting."

Of the two who showed reactions, one commented unfavorably on it later in the experiment:

> "These being highlighted in color is fine, but I think I would do just as well without the color, with just the boldface."

The other subject said that the color was too faint, that it was hard to see:

> "I think that the shading up here *(pointing to the blue highlight on read captions)* is kind of.., it's just dawned on me that you shaded which of these messages that we are looking at, and it's kind of hard to see. It's kind of hard to see that this is *(pointing to the blue highlight)* a little bluer than this *(pointing to the light beige background)*."

Reactions to Caption Highlighting	Number of Subjects
Positive	
Negative	••
No response	••••••

Table 5. Reactions to blue caption highlighting.

3. The use of color as a focusing device.

The graying of unselected windows was used as a method of directing attention to the window containing the mouse cursor (the selected window). Seven of the eight subjects reacted to the graying of the "unselected" windows at different points during the experiment; five favorably and two unfavorably.

Only one of the eight subjects did not react to it during the experiment. Later on during the discussion this subject said:

> "I think it helps to tell which window is active. Better than just the title bar changing."

Five of eight subjects said that it was helpful. Some of their comments were as follows:

> "I like the way the whole screen goes dim. The focus is very obvious, then you don't start doing things thinking that you are in one window when you are not.";
>
> "I think it helps to tell which window is active. Better than just the title bar changing.";
>
> "..what else do I like..brightness to focus attention so that I don't have to search around the screen so much,...";
>
> "...There are a numbers of things that have always bothered me about the Andrew windows. One of them, seems to be somewhat repaired in this particular application because of the graying of the screen to show which is active and which is not,...";
>
> "..it's helpful for the windows to be lighting up *(in full color)* when they are active, that's helpful. That's something I don't like about my current window manager, it just lights up here *(pointing to the title bar).* It's hard to tell what window you're active in."

One of the subjects was earlier confused by the graying. He said:

> "The graying is a little confusing for some reasons,..."

Later on he stated that he noticed a delay in the focusing:

> "I'd like to have a faster response from the change of focus of where you are. I find there is a sort of hesitation here."

Later on during the discussion the subject responded positively to the graying of the windows:

> "It's a very good way of indicating the focus on the screen. That way you know exactly what window you can type in, what one you can't."

Two other subjects expressed negative reactions to the graying of the windows. One said that it was too dark:

> "It was almost too dark, because at one point I kind of glanced over into the typescript window and try to just see what was typed. You really had to look, you really had to concentrate. You couldn't just sort of glance over there."

The other said that it was distracting:

> "..that's really odd that this changed colors. I think it's really distracting. I mean it does highlight what you are on, but I do think it's distracting."

Reactions to the use of Color as Focusing Device	Number of Subjects
Positive	•••••
Negative	••
No response	•

Table 6. Reactions to the use of color as a focusing device.

4. The use of color for text and background.

There were six different color combinations used for the text of the messages. Subjects responses are described below, and summarized at the end of the section (Table 7).

a. Black type on white background

None of the subjects responded when the black type on white background first appeared.

b. Black type on light beige background

When the message with black type on the light beige background appeared, one subject noticed that the background color was different from the previous message. He responded:

> "This one is, the screen is a little dimmer than the last one. The last one is black and white. This one is black and beige, looks like."

Six others did not respond. Of this six, one noticed the light beige color later in the experiment. She commented:

> "I send that, messages being sent. Now it had odd yellow *(referring to the light beige)* color." *(The reply screen turned light beige when the user's reply was being sent.)*

One of the eight subjects said that at first she did not notice that the message was up on the screen (the message before this one was on a white background creating a contrast with the light beige background in the rest of the window). She remarked:

> "...my attention is on the directory message *(part of the "message" window which contains messages captions)* and I am not noticing the new message coming up. It's all of a sudden there, I haven't actually perceived it coming up, which is something I haven't encountered before."

c. Blue type on green background

Six of eight subjects reacted very strongly on the first encounter to this color combination. Of these six, two of them stated that the color combination was hard to read. They said

> "..but I find the color of the last message hard to read.";

and

> "I also have to say that I thought the blue on green is hard to read,.."

Another two of the six subjects who reacted said that the color combination hurt them physically as shown in their recorded comments:

> "..that neon green color is just so loud that it kind of hurts my eyes or so bright I guess."

She further commented:

> "And I am not sure whether it would hurt them as much if I knew that it was coming. If I knew that it was going to turn green, it might not have bothered my eyes so much."

Another person also reacted strongly:

> "The green is way too bright and it almost gives me a headache."

The last two of the six used the words "abrasive" and "intense" to describe the color combination. The phrases "obnoxious", "jarring" and "the green sort of eats the blue" were also used in their reactions.

One of eight subjects, who also reported color deficiency, did not react on the first encounter. He reacted when the message came up for the second time after he sent his written reply. He said:

> "..I'll have to check why it's green on your message. I never noticed that, but I don't know why...I can't remember whether it was green in the previous message as well."

The first subject in this experiment actually liked this color combination. He said:

"Sending messages, comes up blue and green. Looks nice."

Later on, during the discussion, he said:

"I don't know if I am going to get sick of the lime or whatever green that is. But, I guess it's just kind of fun to see the colors if you are used to just black and white all the time, ... I think I might get tired of that one."

In the same context, he said:

"I don't have the best taste in color, my wife (would) give me a hard time about that."

d. Light gray type on light beige background

This color combination is an example of low saturation and light-dark contrasts. All of the subjects complained that the text was very difficult to read. They used the words "tough," "difficult to read," "hard to read" and "I can't read it." One subject said "This is rather annoying" and another one said "This is almost torture."

e. Blue type on white background

Of eight subjects, four did not respond to this color combination when reading this text. The other two liked the color combination. One said:

"I like blue on white."

Further in the discussion he also said:

"I guess the dark blue on white, vs black on white, somehow it seems to be easier on the eyes and the letters seem to be more alive than black letters."

The other one said:

"This is a good color. I like this color combination."

Another two commented on it somewhat negatively. One said:

"Blue, it's a bit bright."

and the other one said:

"It's readable. I don't particularly care for it. I think it's harder on the eyes than the black on gray. But this is much more readable than the last window was *(light gray text on the light beige background)*."

f. Green type on dark grey

Four subjects out of eight did not express any reaction during the experiment. One of them said that she did not like the colors:

> "I don't care for this either. I think it's difficult to read. But, it might be because I am not used to it. I guess I could get used to it, but I wouldn't be happy about it."

Two subjects responded in favor of this color combination. They said:

> "I like the green highlight on a dark background."

and

> "...this is good too. It's a little hard to read, but not too bad."

Another two subjects made remarks, but their preferences were not obvious. One commented:

> "So, this reminds me of an old style green CRT screen. It's interesting."

The other one said:

> "Oh, green."

Text	Back-ground	Contrast	In Favor	Against	Neutral Response	No Response
Black	White	maximum light-dark				••••••••
Black	Beige	less than maximum light-dark		•	••	•••••
Blue	Green	hue and saturation	•	•••••••		
Light Gray	Beige	minimum light-dark and saturation		••••••••		
Blue	White	light-dark; hue; saturation; close to maximum	••	••		••••
Green	Dark Gray	hue; saturation;	••		••	••••

Table 7. Reactions to the use of color for text and background.

5. Beige vs. White Background

A light beige (RGB 100-100-88) was used for the background color in most ot the windows in this experiment.

During the experiment, only one subject recognized the light beige. He said:

> "This one is, the screen is a little dimmer than the last one. The last one was black and white."

The same subject preferred a bright colored background when asked whether he liked light beige or white for background of black type. His reply was:

> "Those *(black text on white or light beige background)* are pretty standard. I guess I am used to looking at that all the time. Like this is black and white and this, and we get off-white paper as well. It's very easy, very effective. It *(black text on the light beige background)* does not stand out as being as nice as the third message where you get the bright colors on a dark background, ..."

Half of the subjects, during the experiment, did not recognize it as light beige and referred to it as white. One of the three subjects said:

> "I don't know why but I just like the different shades of white *(referring to the white box in the light beige background)*."

While another one said:

> "This is very hard to read, this real light blue here on this white background."

One of the subjects early in the experiment recognized it as white, although later in the discussion she recognized it as off white. During the experiment she said:

> "There is a really light blue, blue gray color on white paper. It's extremely difficult to read."

Another subject said:

> "But, when you had this color on white *(referring to light gray text on light beige)*, that was just horrible ..."

Three subjects preferred light beige background over white background when asked. They said:

> "I like this one *(light beige)* better because the background color seems to make it easier to read.";
>
> "Yeah, I did notice *(the light beige)*, but not until they are in contrast. I'd say I like the black on off-white *(light beige)* the best. It's the easiest on my eyes.";

"I think I actually like the black on yellow *(referring to the light beige)* a little better. I didn't notice that this wasn't white. ..... Because I think this *(light beige)* is easier on my eyes. The white *(referrinf to the light beige)* isn't so glaring I guess..."

One subject preferred white over light beige background. In the discussion she said:

"That's not so bad.. I don't... it's sort of an off white instead of a bright white, I still prefer the white, but I don't mind, I still can use this *(light beige)*."

In the same context she said:

"It *(black text on light beige)* just isn't sharp enough for me."

Reactions to Light Beige Background	Number of Subjects
Recognized it during the experiment	•
Recognized it as white	• • • •
No comments	• • •

Table 8. Reactions to light beige background

Preferences	Number of Subjects
Light beige background	• • •
White background	•
Other	•
No comments	• • •

Table 9. Background preferences for black text.

6. Black and white vs. color monitors.

Six of the subjects stated that they would prefer a color monitor over a black and white one. One of them preferred a color monitor because he felt that color was easier on the eye. Three subjects preferred color for aesthetic reasons as shown in their comments: "nicer to the user"; "I find color more visually pleasing" and "I guess with the color it was prettier." Two of the six who preferred a color monitor said that color monitors have more options or are more flexible. One subject wanted to have the option of using color. Another subject preferred a color monitor, but did not really know if it would bother her eyes if she had to use it for a long time. Another one preferred color as long as the text colors were "readable".

Three of the subjects, who preferred color, specified that they would prefer to use black and white windows for text. One of them said that his preference for black and white windows was related to his color deficiency. He said:

> "But for the windows themselves, I prefer black and white, because there are some color combinations that give me problems."

Two of these three said that they would use color only for the title bars. Besides using color for title bars, one subject wanted to use color for the warning icon and error messages, while two stated that they would like to see color used to highlight important things.

Of the eight subjects, one subject, for various reasons, was not sure whether he wanted a color monitor or not. He said:

> "On the one hand, yes it's worth it, on the other hand no. For what I do, which is programming, it's not like there are usually things that have to attract my attention immediately. And if you are just doing word processing I don't know how useful it is. And I don't know if it helps the readability of the screen at all or anything like that. So, I am not sure I really want a color monitor period, to tell you the truth. Well, on the other a hand color monitor is much more fun to look at. It can certainly be used to convey more information. So, would I like a color monitor? I don't know."

One subject did not want a color monitor because it was distracting, especially while learning to use the system. She said:

> "For learning a system like this, it *(color)* was distracting to me. The use of color touches the kid in me, and I started getting preoccupied with looking at the colors and trying to figure out *(the significance of the colors)*. If it *(the monitor)* were just black and white, there's just that little edge of staying more on task. After I have learned the relationship between different windows and different functioning, then to put the colors on would be OK, slowly, not to just put on this full multi-layers of color..."

Preference	**Number of Subjects**
Color monitor	• • • • • •
Not sure	•
Monochrome	•

Table 10. Preferences between color and monochrome monitors.

Subjects who preferred color	**Number of Subjects**
Preferred black and white text/windows	• • •
Preferred color because it is easier on the eye	•
Preferred color for its flexibility	• • •
Preferred color for aesthetic reasons	• • •
Would use color for title bars only	• •
Would use color for warning icon/messages	• •
Would use color to highlight	• •

Table 11. Specific color preferences.

7. Miscellaneous.

a. Color Deficiency

The two subjects who reported a color deficiency made specific comments related to their condition. One subject, when asked to be more specific about the color combinations he disliked, replied:

> "Uhm, for which colors you mean? Since I am color blind I can't quite remember which messages they are."

The other subject gave comments at different points during the experiment. His comments included:

> "...this is a really hard color combination for me to read and notice, the TWM manager color combination. But this blue and white is optimum for me. Maybe yellow and blue would be better for contrast, but blue and white is pretty darn good.";
>
> "But for the windows themselves, I prefer black and white, because there are some color combinations that give me problems.";
>
> "The screen that's yellow and blue I think I could take. Like yellow writing on blue background or blue writing on yellow background. But anything with red and green... *Because of your color deficiency?* Yes, because of my color deficiency I think. And that's probably why I tend to go for black and white screen, ... because other people tend set up colors that are hard for me to see, like this pink color *(pointing the "console" and "typescript" icons in the "twm icon manager" window)* fades away into the gray and I can't see it. But this blue *(the "message" title bar)* just jumps out at me."

b. Response Time

Delays in response time existed in the experiment material due to the complexity of the simulation. Five subjects responded unfavorably to the delay. One subject commented on things he did not like:

> "Response time moving mouse button slightly sluggish."

Another subject said:

> "I'd like to have a faster response from the change of focus of where you are. I find there is a sort of hesitation here."

Later during the experiment he further said:

> "Also it's very important that, at least to me, that the color change occurs quickly. Any kind of delay is confusing."

Three subjects wished that there was feedback when they clicked on the mouse. One subject said that she would like to see a clock when she had to wait:

> "So, I'll click on that. And I have to wait..I'd like a little clock...very much, so I could see that things are happening."

The other subject thought that the delay was bad:

> "..the blue highlight *(the caption highlight)* doesn't highlight immediately when you choose it. It just waits a while until it actually puts the message up on the screen and I think that's kind of a bad thing, because you don't know whether you have selected it or not."

Further in the experiment she said:

> "I think it's slow and I don't like the fact that it doesn't give you any feedback when you select something. You actually have to wait until it's displayed to know that you've selected something successfully."

The other one said:

> "Hm, what would be good is to have a message that says that it sort of acknowledges your mouse button when I press on the message. Because it's kind of annoying not knowing for a couple of seconds whether you've... It's annoying not getting feedback on that."

c. White Box for Text Entry

In various places in the experiment, subjects were asked to type in a string of commands or messages. Due to the discrepancy in the system used for the simulation, the space where the subjects were to type in text formed a white box on the light beige background. The white box turned light beige as soon as subjects hit the return button to indicate that the input was entered. Six of the subjects, at different points during the experiment, responded positively to this or recognized the white box as a place to type in characters.

One subject recognized it as an entry window:

"..I didn't get the entry window with the blinking cursor that I do now."

Another subject said it look like a white label:

"I am thinking this looks like a piece of paper with an embossed white label on it."

He further said:

"I don't know why but I just like the different shades of white, just like these little highlight areas, I don't know why."

Later on he compared typing input to filling out a form.

One subject even tried to find out why there was a white box as shown in his recorded statement:

"It's interesting, it highlights the area you are typing in. I am not sure what that means to tell you the truth. What happens if I go beyond it, maybe I shouldn't find out. OK, this is sort of your..*(at this point the subject had advanced the cursor beyond the white box)*..so, this sort of says that you can type only in this area here. OK, this makes sense."

Another subject said:

"For example, when you have this highlighted box here that comes up for you to type in. That seems to me a window."

One subject was not sure whether she would like it. She said:

"Now, that's sort of nice *(pointing to the white box in the light beige typescript field)* with the contrast between the two where you see the bar where you are supposed to write. I don't know, I'd have to use it more to really figure out if I like that or not."

d. Ability to Manipulate Colors

Five of eight subjects expressed different degrees of desires to be able to manipulate the colors on the computer, should they own one. Their comments including:

"It's fun to play, to change color combinations around, once a week make a change.";

"I certainly would like a well designed default setting, but certainly want to be able to change the colors myself. I know this from my experience. I've used a color monitor before and I have changed the colors in the window system to suit my taste.";

"I would think that to a certain extent I would want my own colors, just because I think what bothers some people's eyes probably doesn't bother other people's eyes."; "I would probably choose different colors than what I saw on these bar headings."; "I do have a color monitor, and I do have the ability to control the colors, but I don't."

In the same context this subject said:

"It would be good to be able to choose my own colors. Every now and then I think I should probably set up my environment to use various colors in places."

One of eight subjects did not want to have to set his own colors. He said:

"I have no desire to change the colors as long as I find them pleasing to begin with. That's just one more thing to have to worry about. It's cute, something to play with when I'm bored, but I don't see much point in it. If other people want it, fine, but I want something set up ahead of time. I don't want given to me a black and white application that I have to color like a coloring book. I just want it to come with nice colors."

Two subjects, one of which preferred monochrome over color monitors, did not comment on the possibility of manipulation colors.

V. Discussion

Color certainly adds a complicated dimension to the world of monochrome computers. While it is difficult to apply color effectively to computers interfaces, color can be very effective when it is used carefully and thoughtfully.

Color can be used as an organizational device. However users must become acquainted with the coding system, as shown in the results of this study. Half of the subjects did not notice the color and the rest wondered if the title bars were color coded. This supports the findings by Silverstein's (1987) statement that "Adding color to a basically monochromatic presentation in such a way that color is irrelevant or not functionally related to the operator's task performance resulted in inferior search time for a redundant color-coded display with an unknown target color compared to a monochromatic display."[8]

In our study, color was also used as a signalling device. As an attention-getting element, color can be effective, but the choice of color is critical. For example, only one of eight subjects reacted on their first encounter to the blinking blue mail icon, while six of eight subjects reacted very strongly when the flashing yellow and black warning icon first appeared. Both of the icons occupied the same area on the screen and were approximately of the same size. The yellow certainly had higher hue contrast from the other elements on the screen than the blue. Also blue is more soothing than yellow. Yellow is more alarming; it is part of society's collective "language of color," as seen in traffic lights and road signs. This is shown by the reactions of the subjects, for example:

> "Is that something I should worry about? Obviously it is, since it has an exclamation point and it's yellow which often is caution."

The degree of brightness may be related to the degree of the urgency of warning.

While it was shown in the experiment that color could be effective for attention-getting, Christ (1978) said that this property of color is often due to its novelty

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[8]Silverstein, L. D. (1987). Human Factors for Color Display System: Concepts, Methods, and Research. *Color and the Computer*. p. 57. Ed: J. Durrett. San Diego, CA: Academic Press, Inc.

effect.[9] A lengthier investigation on the use of color to attract attention would help us to better understand the parameters involved.

Though color may be used to highlight, again, choice of color is critical. It should be done sparingly so as not to confuse or clutter the screen. Of eight subjects, six did not respond to the light blue highlight of selected captions during the experiment, although one of these six expressed his favor for it later, without prompting, during the discussion. This might be due to its faint color, that it was hardly perceived, or that it highlighted the information successfully without being intrusive.

Only one of eight subjects said that the highlighting, in addition to using boldface on the selected message caption , was redundant. She said during the discussion:

> "But, again, part of it is, to me, it still is overkill. You don't need a blue window here, or, I don't need a blue window. Now, in part, I am very sensitive to type changes, so I notice when something is cued in some way or another."

Marcus (1986) suggested that redundant coding be used when designing color displays.[10] Silverstein (1987) also found that redundant coding methods, where information is available through multiple dimensions or codes (e.g., color and shape) that have zero correlation between them, are beneficial. The benefits include: the preservation of information in the event of partial display or color component failure, minimal impact of color shifts as a function of display instabilities and aging, and color deficiencies in the user population are less of a concern when all displayed information is available through multiple codes.[11]

To direct attention to the selected window, the graying of unselected windows was used, leaving the window in focus in full color. Color is very effective here, but response time must be fast. It's important not to make grayed text too dark or it will be difficult to read. In other words, sufficient light-dark contrast is required.

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[9]Christ, R. E. (1978). Research for Evaluating Visual Display Codes: an Emphasis on Color Coding. *Information Design*. Eds: R. Easterby & H. Zwaga. Chichester: John Wiley and Sons, Ltd.

[10] Marcus, A. (1986). Computer Graphics Today, Tutorial 14: The Ten Commandments of Color. *Tutorial Notes for Visible Language Programming: User Interface Design, Information Graphics, and Documentation*. Berkeley, CA: Aaron Marcus and Associates.

[11]Silverstein, L. D. (1987). Human Factors for Color Display System: Concepts, Methods, and Research. *Color and the Computer*, pp. 27-61. Ed: J. Durrett. San Diego, CA: Academic Press, Inc.

In this study, various color combinations of text and background were used. The findings showed that highly saturated foreground and background colors should be avoided. This finding is in line with Marcus' suggestion to avoid fully saturated hues, because intense colors excessively stimulate the eye causing visual confusion.[12]

Sufficient contrast between text and background is required in order not to strain viewers' eyes. AT&T Color Guidelines and Specifications (1988) suggested that high contrast between text and background should be used, because maximum contrast provides the easiest character recognition.[13] Marcus (1986) suggested that highest contrast in figure-field relationships should be reserved for text type.[14] The question is, "What is the optimum contrast to facilitate reading on the computer screen?" Is it the maximum contrast (e.g, pure black and pure white)? Or is it somewhere between minimum contrast and maximum contrast? From this study, a close to minimum contrast (light gray text on light beige background) made it difficult for viewers to read, especially small text. Three of four subjects, who expressed their opinion, preferred black text on light beige background over black text on white background, which seems to exhibit sufficient, although not maximum contrast.

Most subjects did not show strong responses to the more common color combinations, such as black on white, black on light beige (which half of subjects referred to as white), blue on white and green on dark gray. Perhaps they were accustomed to seeing these combinatons and thus, did not react to them.

Apple Computer, Inc. Human Interface Guidelines suggested that colored text is harder to read than black on white.[15] Our study showed that three of six subjects, who preferred to have color monitors, preferred black and white for text.

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[12]Marcus, A. (1986). Computer Graphics Today, Tutorial 10: Proper Color, Type Use Improve Instruction. *Tutorial Notes for Visible Language Programming: User Interface Design, Information Graphics, and Documentation.* Berkeley, CA: Aaron Marcus and Associates.

[13]AT&T (1988). Color Guidelines and Specifications, *OPEN LOOK (TM) Graphical User Interface Functional Specification,* pp. 12-1 - 12-10. Prerelease Version, July 15.

[14]Marcus, A. (1986). Computer Graphics Today, Tutorial 14: The Ten Commandments of Color. *Tutorial Notes for Visible Language Programming: User Interface Design, Information Graphics, and Documentation.* Berkeley, CA: Aaron Marcus and Associates.

[15]Apple Computer, Inc. (1986). *Human Interface Guidelines: The Apple Desktop Interface.* Massachusetts: Addison-Wesley Publishing Company, Inc.

It seems that the pragmatic aspects of color use in computer interfaces is a current topic of interest and debate. From subjective studies, Silverstein (1987) found that users exhibit a general preference for color over monochromatic screens. It makes users feel more secure and natural, it improves their ability to detect details, it is less monotonous and it produces less eye strain and fatigue. He further says that a satisfactory reconciliation between preference and performance awaits future research, and that, for the present, operator's preferences for color information displays remain a valid criterion.[16] This is supported by our study, which shows that six of eight subjects, for various reasons, prefer a color monitor. Half of the subjects preferred color for aesthetic reasons. Some also felt that color gave them flexibility.

Two of eight subjects reported color deficiency. During the experiment both of them made specific comments related to their condition. Definitely, viewers' ability, or inability in some cases, to perceive color has to be considered when designing color interfaces. As mentioned in the beginning of this paper, a significant number of the population have some degree of color deficiency. In addition, a gradual decline in the ability to discriminate color is reported when a person reaches 25 years of age.[17] To help overcome these problems, redundancy of coding should be used in addition to giving viewers some freedom to manipulate and adjust the colors on the monitors according to their needs.

Five of eight subjects in our study expressed different degrees of a desire to be able to manipulate and adjust the colors to their taste and limitations. One of the subjects did not want to worry about designing his own colors, as long as the colors were well chosen. Given the complexity of the properties of color and the implications of applying them in interface design, it is not a good idea to give users a color monitor set in black and white and let them choose and apply their own colors. Visual interface designers should select an appropriate palette of colors for the application and give the users some degree of freedom to manipulate and adjust the colors according to their needs and/or preferences.

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[16]Silverstein, L. D. (1987). Human Factors for Color Display System: Concepts, Methods, and Research.
Color and the Computer. p. 57. Ed: J. Durrett. San Diego, CA: Academic Press, Inc.
[17]Burnham, R. R., Hanes, R. M., & Bartleson, D. J. (1963). *Color: A Guide to Basic Facts and Concepts*. New York: John Wiley.

Response time is also an important factor to consider when applying color to the computer interfaces. When color is involved, processing time is increased, thereby slowing down system response time. Any such delays can cause confusion on the part of users, who are generally used to "instant" response times.

Most subjects reacted favorably to the white box for text entry. Most of them recognized it as a place to type in text. The white box provided an unintrusive method for focusing the subjects' attention.

VI. Conclusion

This research broadly explored the effects of color in computer interfaces in order to provide basic guidelines to interface designers and system developers on the use of color in interface design.

To design color interfaces effectively, it is important to understand the principles of color interactions: within the properties of color itself, with the medium, with the environment, and most importantly with the viewers.

In this research we used a simulation of the "messages" application on the Andrew network. Color was applied in the simulation based on color theories and previous studies done in similar areas. We observed the reactions of eight subjects as they performed tasks of reading and answering mail messages. The experiment was audio- and videotaped, and the results reported here are based on data which was transcribed from those tapes.

We found that color can be effectively used as an attention-getting element. A further study needs to be done to see whether this is effective in long term use despite novelty effects. We also found that the appropriate selection and application of color are important.

The use of color to highlight important information within text needs to be explored further. It is important that highlighting be not distracting, yet perceivable enough to be effective.

We found that the graying of unselected windows, leaving the selected window in full color, was very helpful. The choice of light-dark contrast between the text and the background within the grayed window is critical. The contrast should be low enough that it does not attract attention, but it should be high enough that the text is easily read without straining the viewers' eyes.

The text and background light-dark contrast within selected windows is also important. It should not be so high that it causes eye strain or fatigue, but it should not be so low that it strains the viewers' ability to read. A topic for further study would be to answer the question: "What is the optimum contrast between text and background to facilitate reading on computer screens?" The choice of hue for text and background is also important. It would be very valuable to find out whether indeed black text on a white background is the best combination, or a faintly tinted background would be better for black text. Highly saturated hues should be avoided. Generally color text should be used sparingly since people are used to reading black text on white paper. This way, color is used as a signalling device and not a decorative one.

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