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AUTHOR Pettersson, Rune
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ABSTRACT

This discussion of factors involved in the presentation of text, numeric data, and/or visuals using video display devices describes in some detail the following types of presentation: (1) visual displays, with attention to additive color combination; measurements, including luminance, radiance, brightness, and lightness; and standards, with specific comparisons between Swedish and U.S. standards for visual display units; (2) color description systems, including the Munsell System, the Natural Colour System (NCS), the hue-lightness-saturation system (HLS), the hue-value-saturation system (HVS), and the red/green/blue (RGB) system; (3) text systems, including characters, design, background, and context; (4) numeric data, with attention to computer graphics hardware and software; and (5) visuals that depend largely on the quality of the screen, e.g., pie charts. The need for additional research in several areas is noted, and a 16-item bibliography is provided. (THC)

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Presentation of Information on Visual Displays

by

Rune Pettersson

Department of Information

Processing Computer Science

The Royal Institute of Technology

The University of Stockholm

and

ESSELTE

Stockholm, Sweden

IR011613

In printed material, such as a book, the table of contents and the index make it easier to find desired information. When a person has read a page in a book s/he can easily proceed to additional information by turning the page. Information stored in a computer system can be accessed in several different ways. Ease of use and the man-machine interaction is vital. Systems should be as user-friendly as possible, e.g. by providing opportunities for complete text searching. Instructions should always be clear, concise and simple. However, further guidelines for ease of use and interaction are not discussed in this paper.

Compared to traditional graphic presentation, presentation of information on visual displays are very limited. Information can still be presented in many different ways. The use of color is obviously important. Different "rules of thumb" probably apply to different types of presentation. The information as such, i.e. the "contents" can be represented as text, numeric data and/or visuals.

1. Visual displays

Visual displays can be devised in many ways. A color television set, an advanced color terminal and a liquid crystal display all have different characteristics. For example, a TV set is designed to be viewed from a distance more than 120 cm. A computer terminal, however, is designed for use at a distance of 60 cm and has a much better image quality. It also costs a great deal more.

1.1 Additive color combination

In technological discussions, color is related to measurable amounts of light. In 1931 an international body, the Commission International de l'Eclairage (International Commission on Illumination, or CIE) defined standards of light and color. In this context primary colors are the basic stimuli used in the synthesis of any color, by addition or subtraction. For color synthesis in a CRT, a cathode ray tube, a range of colors can be produced by the additive combinations of a very limited amount of radiations. A color CRT is a vacuum tube, containing one or three electron guns for generating beams of electrons, a system for focusing the beam to produce a spot of visible light at the point of impact on the phosphor screen and electrodes for electron beam deflection. The thousands of tiny phosphor dots are grouped into threes called triads, one dot emitting radiation that appears red, one emitting radiation that appears green and the third emitting radiation that appears blue. Red, green and blue are called the "three primary colors", RGB. One lumen of white is produced by 0.30 red + 0.59 green + 0.11 blue. Any two primary colors can be mixed to produce any other color. Red plus green can produce a range of yellowish hues. Green and blue produce a range of blue-green hues, while red and blue mixtures produce red-blue colors. The total number of colors that can be produced in a CRT depends on the number of steps or grey levels obtainable for each phosphor dot. Advanced systems are capable of producing up to 256 color stimuli simultaneously from a palette of 16 million. However, only a few color stimuli are needed at the same time in most cases.

Uncertainties in the color coordinates are rather considerable because of the heterogeneous distribution and efficiency of the phosphors over the screen, defects in electron beam convergence and the departures of the relations between the values of the colors signals and the digital counts.

One consequence of additive combinations in color television is that characters presented in white (the three-color combination) are less sharp than e.g. yellow, blue-green or red-blue (all two-color combinations). In a similar way, the latter colors are less sharp than red, green and blue (pure colors). Sometimes color rims can be seen around characters formed from two- or three-color combinations.

The additive combination starts in dark adding light to produce color. Thus, another consequence of additive combinations is that secondary color stimuli always appear to be brighter than the primaries.

1.2 Measurements

Luminance is a photometric measure of the amount of light emitted by a surface (Lumen/steradian/sq.m.). Radiance is a radiometric measure of light emitted by a surface (Watt/steradian/sq.m.). It should be noted that luminance or radiance is not the equivalent of brightness, which is the perceived intensity of light (bright - dull). In color displays it is very difficult to distinguish brightness from lightness (white - black). When the signal to the display is increased, the brightness of the total screen is increased. If a signal to a specific part on the screen is increased the lightness of that area increases compared to the total screen as a whole.

The luminance, hue and saturation of a CRT can usually be adjusted. Like brightness and lightness hue and saturation are also psychological dimensions. Hue is the basic component in color corresponding to different wavelengths. Saturation is most closely related to the number of wavelengths contributing to a color sensation. We should always remember that the production of color, by additive or subtractive methods, has nothing whatever to do with the actual perception of colors.

1.3 Standards

Standards for visual display units, including several detailed specifications, have been agreed upon in different countries. Standards for Sweden and USA are shown as examples in Table 1.

Table 1. Swedish and US standards for VDU.s

	SWEDEN SIS DRAFT 1982	USA US MIL STD 1472B
Polarity	Positive image	Positive or negative for high ambients Negative for low
Refresh rate	Flicker-free, no after images	-
Resolution	-	10 raster lines
Fount design	Dot matrix	-
Character format	14 x 11 (Capitals)	5 x 7 dot matrix (min). 7 x 9 (preferred)
Stroke width	12 - 17 % of character height	1/6 - 1/8 ch. for positive images
Viewing distance	600 mm ± 100 mm	400 mm (min)
Character height	4 mm (min) 20' of arc	18' of arc (min)
Character width	50 - 70 % of ch. height	-
Distance between lines	170 % of character height	One half character height
Distance between characters	20 - 30 % of character height	One stroke width (min)
Distance between words	50 - 70 % of character height	Width of one character (min)
Background luminance	170 cd/m^2; adjustable	
Character contrast	1:8-1:12 (pref) 1:20 max	0.75 (4:1) $(L_H-L_L)/L_H$
Blink rate	-	3 - 5 Hz
Color contrast	-	Color symbols on background of different color, equal luminance shall not be used

2. Color description systems

As seen above, the relationship between hue, lightness, saturation and brightness is very complex. For practical use in art and in industry, several different systems have been developed to provide numerical indexes for color. The most important systems will be described here.

2.1 The Munsell System

The Munsell System was introduced as early as 1905. It has been modified several times. The system consists of fixed arrays of samples which vary in hue, lightness (here called value) and saturation (here called chroma). The value scale ranges from white to black with nine steps of grey. Hue is represented by 40 equal steps in a circle. Value and the hue are related to one another by a maximum of 16 "saturation steps". The Munsell notations are defined by color samples in the Munsell Book of Colors.

2.2 NCS

There are many theories about how the perception of colors actually works. As early as 1807, Young proposed a system for trichromatic color vision. In 1924, Young's theory was formalized by von Helmholtz who proposed hypothetical excitation curves for three kind of cones in the retina cones, sensitive to red, green and blue. In 1925 Hering based his "natural system" on man's natural perception of color and presupposed two pairs of chromatic colors which blocked one another, red/green and blue/yellow. This model is the basic for the Natural Colour System (NCS), developed in the 70's at the Swedish Colour Centre Foundation in Stockholm (Hård & Sivik, 1981). From a perceptual point of view, man perceives six colors as "pure". Black and white are achromatic colors. Yellow, red, blue and green are chromatic colors.

These six colors are called elementary colors. All colors which are not pure elementary colors resemble several elementary colors to varying degrees. Thus every possible color can be described with a specific location in a three-dimensional model, the "NCS Colour Solid", a twin cone (Fig. 1). The chromatic elementary colors, yellow, red, blue and green, are all located on the circumference of the Colour Circle (Fig. 2). Each quadrant can be divided into one hundred steps, thus describing the hue of a color. The Color Triangle is any vertical sector through half of the NCS Colour Solid. It is used to describe the nuance of a colour, i.e. its degree of resemblance to white, black and the pure cromatic color of the hue concerned ("chromaticity").

When we wish to describe a color using the color triangle and the Color Circle, the process is carried out in the following sequence:

blackness, chromaticness, and hue. For example, a color composed of 10 % blackness, 80 % chromaticness and hue of Y70R is designated 1080-Y70R.

The NCS emphasizes qualitative variations in color sensation, whereas the Munsell System is based on equally spaced visual scales. Both systems are based on surface colors.

2.3 HLS

In the hue - lightness - saturation system (HLS), hues are arranged as circles on the exterior of a double cone resembling the NCS Colour Solid (Murch, 1983). Hue specifications start with blue at 0° and then follow the spectral order around the circle. Lightness and saturation are defined as percentages from 0 to 100. The HLS system is easy to use for colors on the surface of the model. However, colors inside the model are difficult to define. As in the Munsell and NCS systems, brightness creates problems.

2.4 HVS

The hue - value - saturation system (HVS) is a model rather similar to the NCS system but it utilizes different coding (Samit, 1983). Value is defined as relative lightness. White has full value. Black has no value at all. Brightness also creates problems here too.

2.5 RGB

In visual displays the color stimuli are specified by red/green/blue (RGB) values as discussed above. People who are specially trained can use RGB proportions as a color description system. However, this is not possible for people in general.

3. Text

The presentation of text on a visual display depends on the type of characters used, the design of the information, the background and even the content.

3.1 Characters

The characters can vary e.g. with respect to fount, size, case, color and contrast to the background. Text legibility depends on the execution of the individual characters and the ability to distinguish them from one another. A great deal of work has been conducted to create legible characters. Knave (1983) drew up guidelines for the creation of characters. A minimum of 10 - 12 raster lines is required per character. When characters are formed by dots in a dot matrix, the dots should be round or square, not elongated. A dot matrix with 7 x 9 dots is often regarded as a minimum. The height of the characters should be at least 4 mm at a viewing distance of 60 cm.

3.2 Design

The design of a visual display can vary with respect to e.g. spatial organization such as headings, line length, justification, spacing, number of columns, number of colors on the same "page" and cues such as color coding, blinking characters or words and text scrolling. Studies (Pettersson et al., 1984 a) of perceived effort in reading texts on a high resolution, high-quality visual display disclosed the following:

° Colors presented on color displays are ranked in about the same order as surface colors in traditional printed media. Blue was the most popular color.

° When text is shown on a visual display there is no color combination which requires very little reading effort and is, thus, very easy to read. About 35 of 132 combinations are acceptable (Table 2). Most combinations are bad.

° The best text color is black. It provides excellent contrast with most background colors (Fig. 3).

° The best combination is black text on a flicker-free white or yellow background (Fig. 3).

° A text can be easy to read in any color, provided the background is carefully selected.

° The best background color is black. It provides good contrast with most text colors (Fig. 3).

° The reading effort caused by different color combinations is independent of the sex of the subjects.

Blank space in printed material increases cost, since more paper is required. Thus, blank space is not used too much. However, as with color, blank space on a visual display is essentially free of charge and can be used to increase readability. Full text screens in several colors are difficult to read and quite annoying. What about e.g. double spacing and/or spacing between colors? As noted above, some rather definite claims can be made with respect to the use of colors. However, it is not as easy to provide guidelines for the other variables. Studies of attitudes to various variables (Pettersson et al., 1984 b) in the presentation of text on visual displays showed that: subjects dislike fast scrolling text. Subjects seem to dislike more than three or four text colors on the same "page". Subjects seem to regard color coding and/or blinking as good ways of indicating that something is especially important. Subjects seem to agree that text in upper case letters is harder to read than normal text. Attitudes were indifferent regarding a few design variables. Thus, text on only every second line was apparently no easier to read than text on every line. Higher characters were not easier to read than standard height characters. Half lines did not appear to be better than full lines. A two-column layout did not appear to be better than a one-column layout.

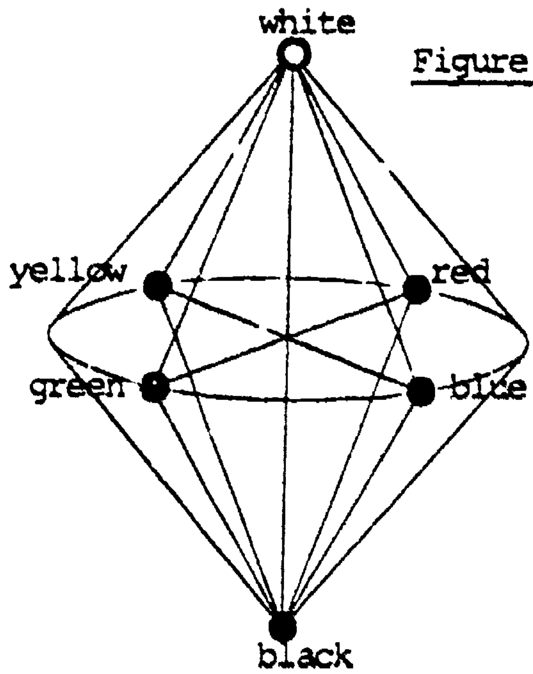
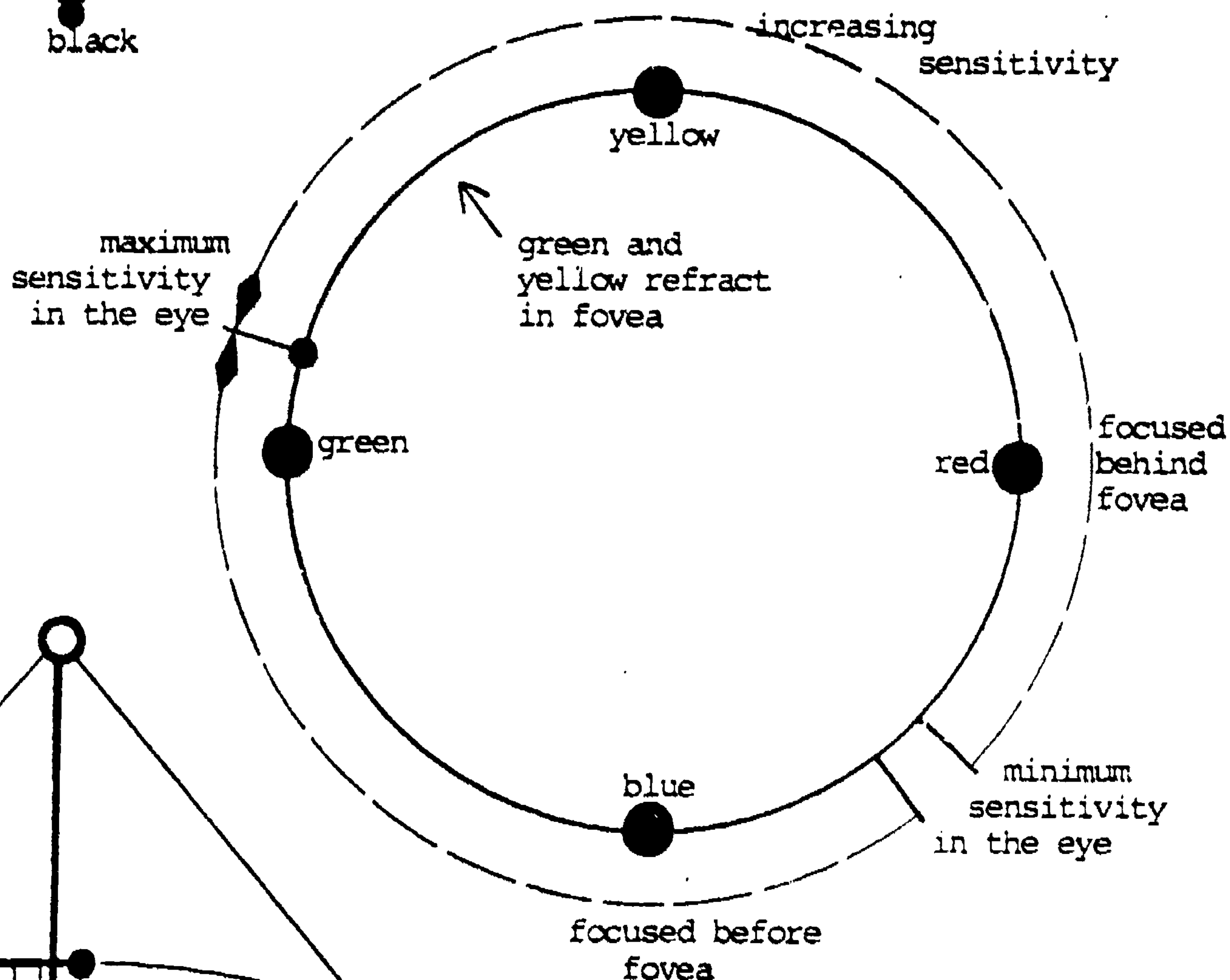


Figure 1: The NCS Color Solid

Figure 2: The NCS Color Circle combined with information on the eye's sensitivity.



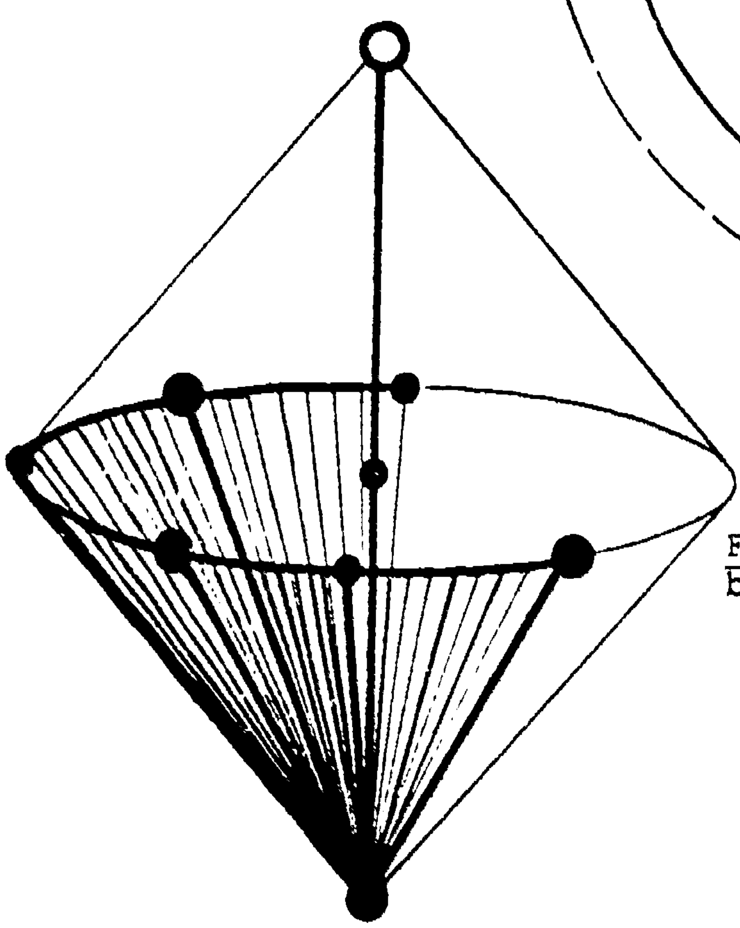


Figure 3: Combinations of text- and background colours that are easy to read.

3.3 Background

The background can vary with respect to e.g. color and brightness. As noted above, good combinations of text and background colors always have good contrast. Optimum contrast is often found to have a ratio of 8:1 - 10:1.

Most subjects prefer positive images i.e. dark text on a light background with a minimum refresh rate of 70 Hz.

3.4 Context

CLEA research (Pettersson, 1984 a), dealing with the perceived effort in reading text on visual displays and altering colors of the display equipment found that the close context is really important to the perceived reading effort. The color of a terminal should be rather discrete. The best of 90 combinations was black text on a white flicker-free screen with a dark grey terminal, closely followed by the surrounding context colors of black, white and light grey. It was also found that having the context color the same as the color of either the color of the text or the background on the screen is an advantage. The combination of surrounding and text/background colors must match. Reading effort increases if they clash.

Further experiments (op. cit.) showed that changing ambient light levels are of no or very limited importance to the perceived reading effort.

4. Numeric data

Numeric data can be presented in different formats, such as text, figures and numerals, tables and graphics (Pettersson, 1984 b). Graphical formats are based on comparisons of numbers, lengths, areas, volumes, positions or comparisons of combinations.

Pettersson (1983) concluded that the different findings regarding comparisons and statistics (mainly in printed media) could be summarized in the following practical guidelines:

° Discriminations are most readily learned when differences between stimuli are maximal. If you wish to be clear, choose clear examples.

° It is easier to distinguish between lines than between areas or volumes.

° It is easier to distinguish between horizontal lines than vertical lines and lines in all other directions.

° It is far too easy to convey misleading information about statistical relationships by using misleading illustrations or scales that are difficult to understand.

4.1 Numeric data on visual displays

Computer graphics hardware and software have become widely available. However, computer generated graphics often tend to be poorly designed and thus fail to improve communications.

These visual presentations often utilize a range of colors to enchance the attractiveness of the material. The use of many colors may be even more noticeable in presentation of numeric data in videotex systems. Around the world different videotex systems are being developed. Regional standards, such as the North American Presentation-Level Protocol Syntax, NAPLPS, (Lax and Olson, 1983), permit videotex communication between different types of microcomputers. In all experiments, field trials and even in the evolving commercial videotex systems, different kinds of business and financial information is among the most utilized information in the data bases.

CLEA-research (Fahlander et. Zwierzak, in print) has shown that the greater the difference is between the colors in a graphic presentation the more distinct is our perception of the border between the color spaces.

Ehlers (1984) discussed problems of legibility in business graphics. Direction and pattern or texture of graphic elements appear to be important factors. For example, diagonal lines are often able to suggest movement. If a static comparison (of e.g. bars in a bar chart) is intended, horizontal or vertical lines should be used. However, dot patterns may be even better.

Studies of attitudes to different variables in the presentation of information on visual displays (Pettersson et al. 1984 b) showed that: Subjects consider it easy to see the difference between vertical bars. Subjects consider it easy to see the difference between horizontal bars.

In a subsequent, comprehensive study (Pettersson et Carlsson, in print) forty subjects worked actively with computer graphics element and made a total of 1400 assessments (Fig. 4). For example, when vertical bars were the stimuli (A and B), subjects had to estimate B as a percentage of A. The data were recorded by pushing a button on a tablet cursor. The stimulus material consisted of vertical bars, horizontal bars, vertical vs. horizontal bars, circles, squares, circle vs. square and pie charts. Each type of stimuli was presented in five different values selected at random by the computer program. All stimuli were also presented to the subjects at random. With the exception of horizontal lines not being better than vertical lines, the results confirmed knowledge from printed media, as previously discussed (Pettersson, 1983). Regardless of over- or underestimates the mean errors amounted to about five percent for vertical and horizontal bars respectively. However, errors in comparisons between vertical and horizontal bars were off by ten percent wrong. Errors in judging circles, squares and pie charts were also about ten percent off.

As expected, the biggest errors concerned comparisons between circles and squares. The mean error here was as high as twelve percent with a standard deviation of 8.3. There were very large differences between individual estimates. These results show clearly that comparisons of areas cannot be recommended for general use in computer graphics, at least not without actual figures to accompany the pictorial information. Numeric data formats using comprisons of lengths were much more accurate, as long as the lines on the bars were parallell.

A great deal of research remains in the field of computer graphics.

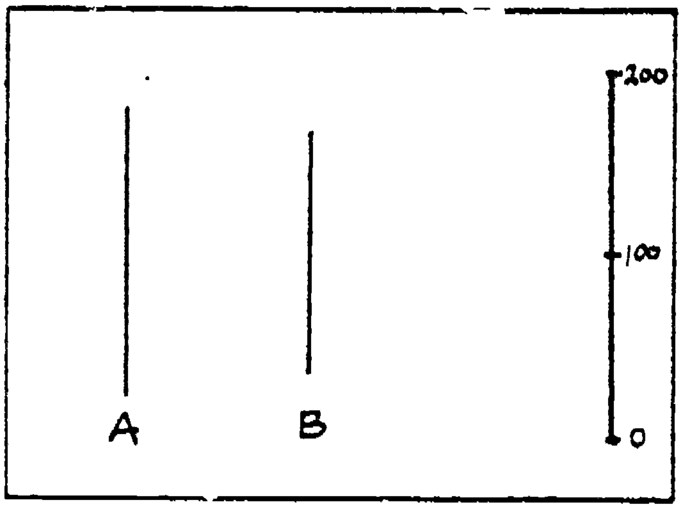
5. Visuals

Our perception of visuals on visual displays largely depends, of course, on the quality of the screen, especially when pie charts are used. E.g. European videotex terminals are simply unable to reproduce a pie chart since their graphics resolution only amounts to about 5000 graphical elements. An ordinary TV image currently consists of about 250,000 image points or picture elements which vary with respect both to grey scale and color information.

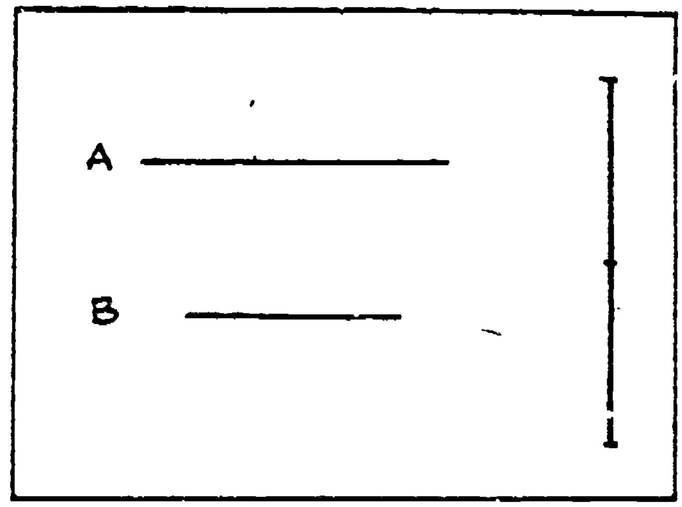
Hayashi (1981) reported on the development of High Definition Television (HDTV) in Japan. HDTV uses 1,125 scanning lines and can hold five to six times more information than the present NTSC standard color TV system with 525 lines. Like HDTV the development of flat plasma screens will also provide better technical opportunities for improved perception of visual information.

A great deal of research remains. One interesting area, for example, is the combination of computergenerated text and visuals stored on video discs.

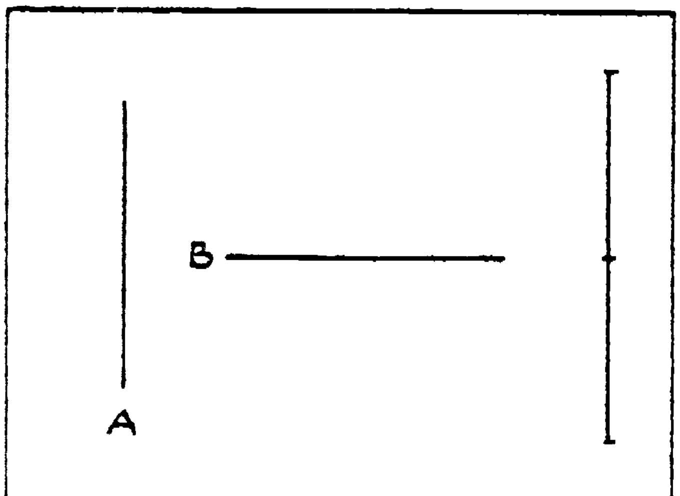
Computer Graphics Experiment: Interpretation of size
(B = X %·A)



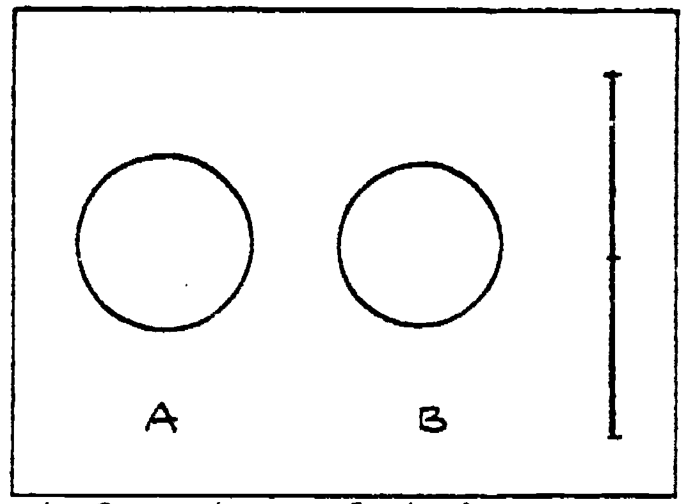
1. Comparisons of vertical lines



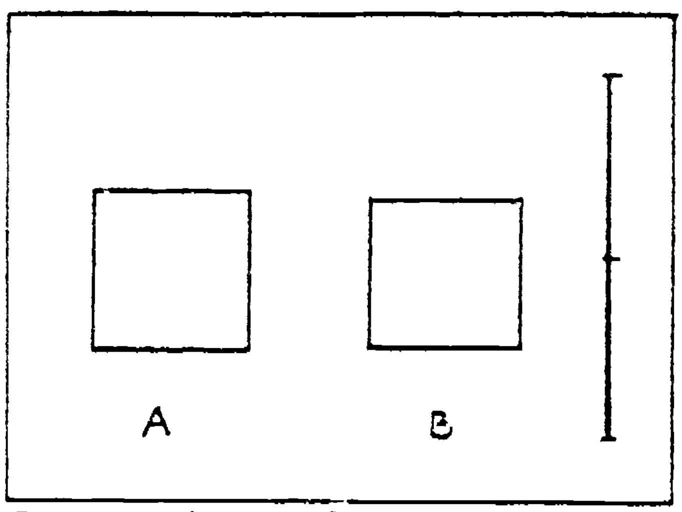
2. Comparisons of horizontal lines



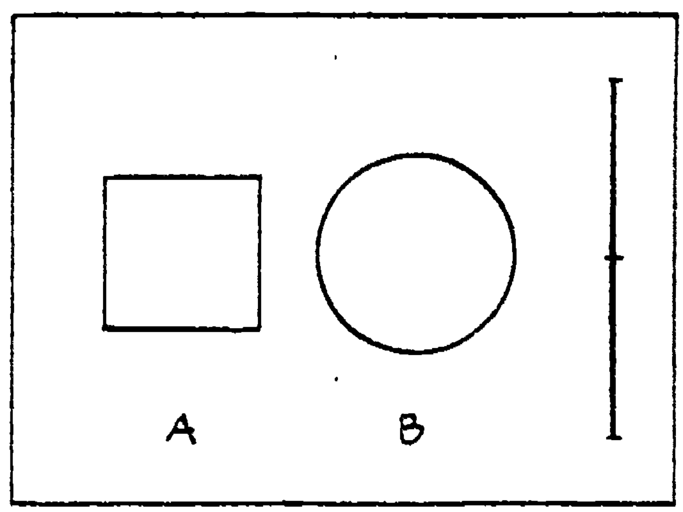
3. Vertical vs. horizontal line



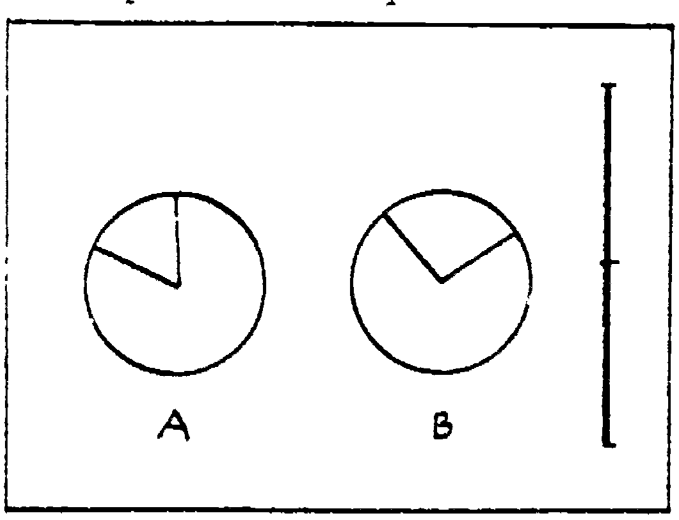
4. Comparisons of circles



5. Comparisons of squares



6. Square vs. circle



7. Comparisons of pie-chart-segments

Mistakes in percent

1. Vertical lines	4.7
2. Horizontal lines	5.0
3. Vertical-horizontal l.	10.2
4. Circles	3.6
5. Squares	9.3
6. Square - circle	12.0
7. Segments	9.6

n = 40 (40x7x5 = 1400 obs)

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