Color Universal Design
-The Selection of Four Easily Distinguishable Colors for all Color Vision Types-

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ABSTRACT

The objective of this project is to establish a practical application of the concept of Color Universal Design (CUD), the design that is recognizable to all color vision types.
In our research, we looked for a clearly distinguishable combination of hues of four colors – black, red, green, and blue – which are frequently used in these circumstances. Red-green confusion people do not confuse all kinds of red and all kinds of green. By selecting particular hues for each color, the ability to distinguish between the four colors should be greatly improved.
Our study thus concluded that, by carefully selecting hues within the range of each color category, it is possible to establish color-combinations which are easily distinguishable to people of all color-vision types in order to facilitate visual communication.

Keywords: Color Universal Design, color vision, color category, visual communication

1 INTRODUCTION

Most people can see six or seven colors in a rainbow, but some people see fewer. For example, a person who recognizes five colors in the rainbow will see them arranged in a red, orange, yellow, orange, red, cyan, and indigo sequence. Those who perceive red and green as being similar colors are known as 'red-green confusion' people.
In 2004, we established a non-profit organization (NPO) called the Color Universal Design Organization, CUDO, (see figure 1) in Japan. The social aim of this organization is to improve the design of industrial products, signs, publications, and public facilities, e.g. the color-coded sign systems of subway lines, so that people with diverse kinds of color vision can easily interpret information.
There are three major types of color vision: P type (protanope), D type (deuterrnope), and C type (common-type). P and D type people are often negatively regarded as being "colorblind" or of having "color vision deficiency" compared to the "normal" color vision of C type people.
In order to promote more positive attitudes towards P and D vision types, it is important to not use language that is imbued with a negative connotation. As the three color vision types appear because of a genetic polymorphism responsible for the L and M cone cells, none of them should in fact be regarded as "normal." Therefore, we also strive to avoid using the terms "protanomalous" and "deutanomalous."
In today's urban environment, we have to process many color-coded signs, maps, tables, graphs, and control buttons on a daily basis.

2 METHODS

2.1 ANALYSIS OF THE REQUIREMENTS FOR COLOR-CODED TIMETABLES

CUDO received a request from Japan Railways regarding the potential improvement of their color-coded timetables. Following the precepts of Color Universal Design we initially determined that we would have to choose the combinations of colors which could be most easily identified by commuters in the timetables' actual environment, lighting conditions being one such important factor.

2.1 SUBJECTS

The subjects are 9 people, of which four are P type (protans), three are D type (deutans) and two are C type.
All subjects gave their informed consent for the aim of this research.

2.2 THE MEASUREMENT OF THE COLORS CHOSEN FOR THE TIMETABLE

We measured the colors chosen using the Minolta colorimeter, CM-503i.

From the results of the measurements, we displayed the colors on CIE xy color spaces.

2.3 IMPLEMENTATION OF COLOR UNIVERSAL DESIGN IN THE TIMETABLE

We chose four colors for the timetable and created a prototype which included User Guidelines.

3 RESULT

3.1 Challenges Facing Commuters Using Color-Coded Timetables.

In Tokyo, the Odakyu line timetable uses four colors: orange, red, green, and blue (figure 2 and figure 3). Orange signifies the limited express train, red signifies the express train, the green signifies the local express train, and blue signifies the local train.

However, the four colors are not correctly visually communicated to color vision confusion (CVC) people.
Red-green confusion people confuse the kind of red and green generally used on Tokyo train timetables.
According to the timetable guide, red-green confusion people should be able to recognize the four colors shown, but, similarly colored stimuli also appear in the table, and confusion therefore arises about which is the express or local express train.

Therefore, we propose the following kinds of colors for use:

1. Independent colors of which P type, D type and C type people can distinguish from each other;
2. Letter colors which should be able to contrast with the white background;
3. Colors' respective strengths should be used on a 'priority-scale' to correspond with the importance of the information. For example, black should be used to show the times for the local line, which, whilst slower than the express lines, includes all stations on the line.

The four colors we have selected, from primary to lowest important are:

Black CMYK=0,0,0,0

Red CMYK= 0, 77, 100, 0 %

Blue CMYK= 100, 30, 0, 0 %

Green CMYK= 85, 0, 60, 10 %

Where there are two kinds of train service black and red should be used on the same timetable. In the case of three kinds of train service, black, red and blue should be used simultaneously.
In the case of the latter, black, red and green should not be used as this combination would cause confusion of their respective name-categories.

	Dominant Wavelength(nm)	XYZ-Y	Yxy-x	Yxy-y	Hue	Value	Chroma
Black	466.86	6.57	0.3089	0.3144	7.78 PB	3.04	0.07
Red	598.35	32.61	0.5387	0.3634	9.37 R	6.28	14.26
Blue	476.73	17.47	0.1969	0.1979	4.0 PB	4.79	10.42
Green	495.55	31.9	0.1994	0.3585	2.94 BG	6.22	11.77

Table 1. The Four Selected Color-Combinations

In the above table we demonstrate a clear combination of the hues of four colors - black, red, blue, and green.
We show the four selected color combinations in figure 4.

These four colors' stimuli are not positioned on the isochromatic line of protan and deutans (figure 5 and figure 6).
P type and D types do not confuse these four colors with each other.

The figure 7 is the spectral distribution of the selected four colors. As the reflectance of this red to 560nm is 17.63 % and that of the black is 6.69 %, P type people are easily able to recognize the red and the black.
As red appears dark and therefore sometimes similar to black for P type people, the red that is closer to orange is preferable for them in order to avoid this confusion. On the other hand, D type people find difficulty in specifically distinguishing between yellow and orange, so we therefore chose a kind of vermillion to represent this red. A narrowly specific range of yellow was chosen so that it appears brighter than the D type vermillion and is dark enough for people with cataracts to distinguish it from white. As yellowish-green is confused with red for both P and D type people, a bluish-green was selected. However, if the green is too bluish, it appears gray for D types. Only a narrow range of bluish-green was found to be appropriate. Blue was chosen so that it appears distinctly different from greenish-blue for C type people, because C types are blue-greenish-blue confusion people, meaning they often confuse blue and greenish-blue. However, P and D type people always see blue and greenish-blue as being very different colors.

3.2 Usage Guideline

1. Reliance on color alone is discouraged wherever possible. For example, color can be used together with italics, a contrasting background, underling, framing, and footnotes.
2. The inclusion on the timetable of a guide of color names is encouraged names. P type and D type people have different color categories from C type people. In bright-light conditions or when the print has become discolored orange appears as yellow-green or brown, blue appears as purple or pink, and green appears as gray. For example, in a typical traveling situation, passengers look at the color-coded timetable and ask themselves,
   "Which is the limited express train?" "Oh, it's the red one".
   Passengers have to refer to the color's name in this situation. It is important that the timetable guide features the colors' names for this purpose for CVC people.
3. The background of the timetable should only ever be white. When colored backgrounds are used, it becomes immediately difficult to recognize the letters' colors.
4. These guidelines can also apply to other information-signs which use the four-color letter system previously referred to.

4 CONCLUSION

In our research, we looked for a clearly distinguishable combination of hues of four colors – black, red, blue and green – which are frequently used in these circumstances. Red-green confusion people do not confuse all kinds of red and all kinds of green. By selecting particular hues for each color, the ability to distinguish between the four colors should be greatly improved.

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Presently, selected colors have already been practically applied to timetables for the Tokyo subway system map to indicate different train lines. The possible combination of a larger number of colors, to a maximum of six, for use in the zoning of medical facilities, was also examined and consequently applied in a newly built hospital. Our study thus concluded that, by carefully selecting hues within the range of each color category, it is possible to establish color-combinations which are easily distinguishable to people of all color-vision types in order to facilitate visual communication.

REFERENCES

1. Ichihara, Y.G. Color constancy in Japanese Animation, EI2006 Internet Imaging, Color Imaging XI:Processing, Hardcopy, and Application SPIE Vol.6058 pp.60580c-1~8 (2006)

2. Ichihara YG, Nakadomari S,Takeuchi H,Satoru Miyauchi S,Kitahara K, A fMRI Study of Color Related Visual Cortex V4- Retinex processing from the fMRI study on V4 -Artistic Research of coloured Picture Using Functional MRI SPIE The International Society for Optical Engineering EI2002 Internet Imaging, Retinex40 SPIE Vol.4662, 2002

3.Ichihara YG,Nakadomari S,Takeuchi H,Satoru Miyauchi S,Kitahara K, The difference between seeing a random colour dot picture and reading shapes from the same colour dot picture in the Ishihara pseudoisochromatic plates -Artistic research of coloured picture using functional MRI- AIC2001 Rochester Proceeding 2001 SPIE Vol.4421 pp.327-330, 2001

4. Ichihara YG. What do you see in a digital color dot picture such as the Ishihara pseudoisochromatic plates? SPIE The International Society for Optical Engineering EI2001 Internet Imaging vol. 4311 pp.419-426, 2001

5. Ichihara YG. Suitable digital color palette (DPC) for individual human color vision sensitivity, SPIE The International Society for Optical Engineering EI2000 Internet Imaging vol. 3964, pp.168-174, 2000

Fig. 1 The Logo of Color Universal Design (CUDO)

Fig. 2 Odakyu line Timetable at Shinjuku in Tokyo

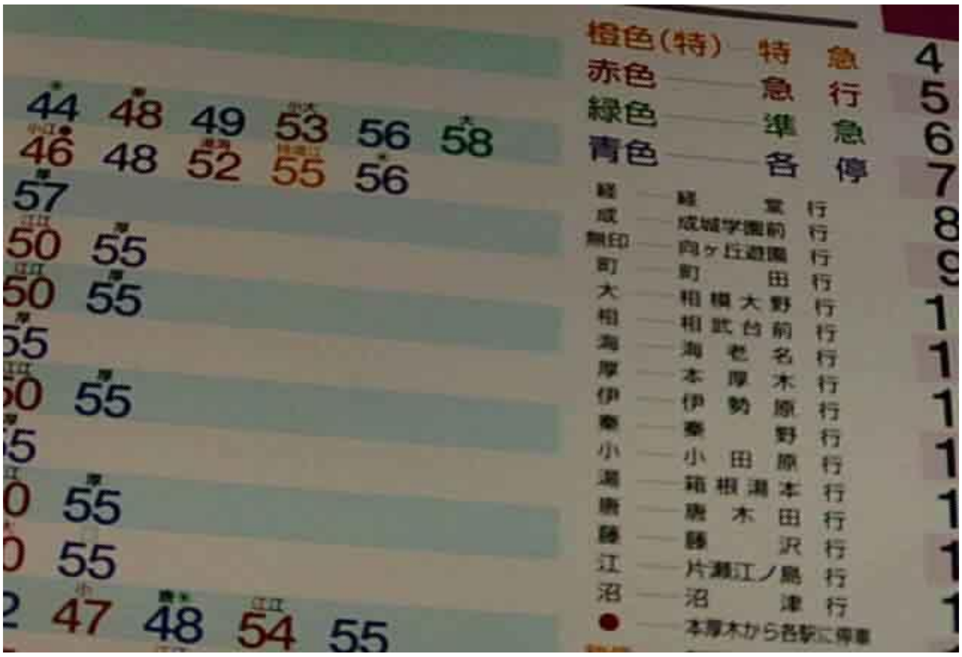

Fig. 3 Odakyu line Timetable Guide

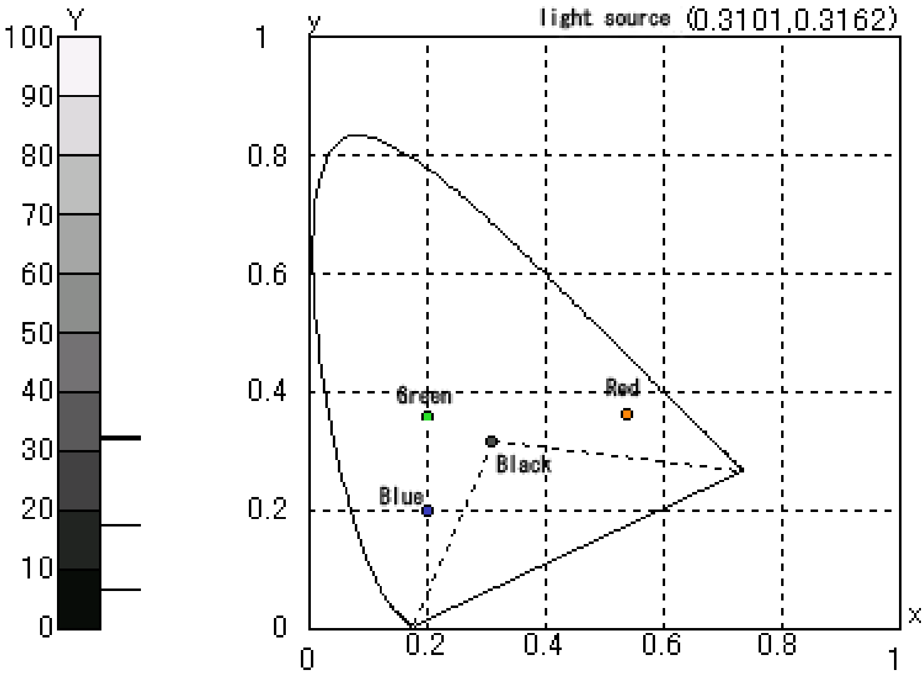

Fig.4 The Four Selected Color-Combinations on CIE xy color spaces

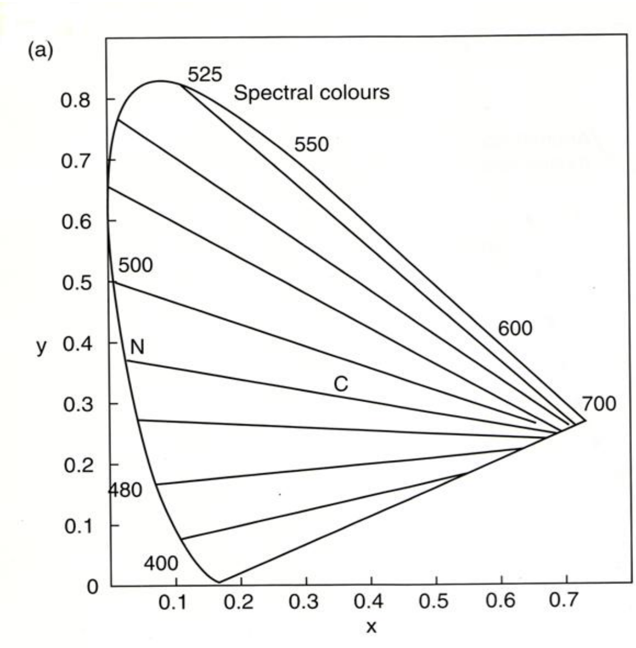

Fig.5 The Isochromatic Line of Protans

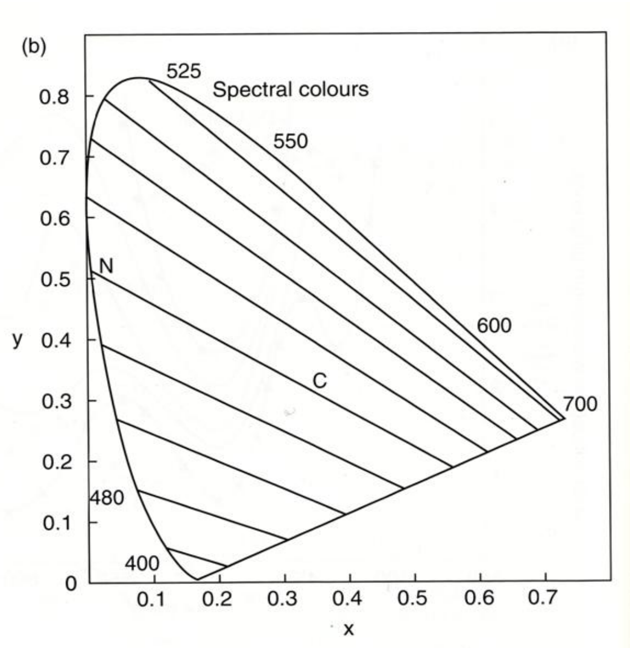

Fig.6 The Isochromatic Line of Deutans

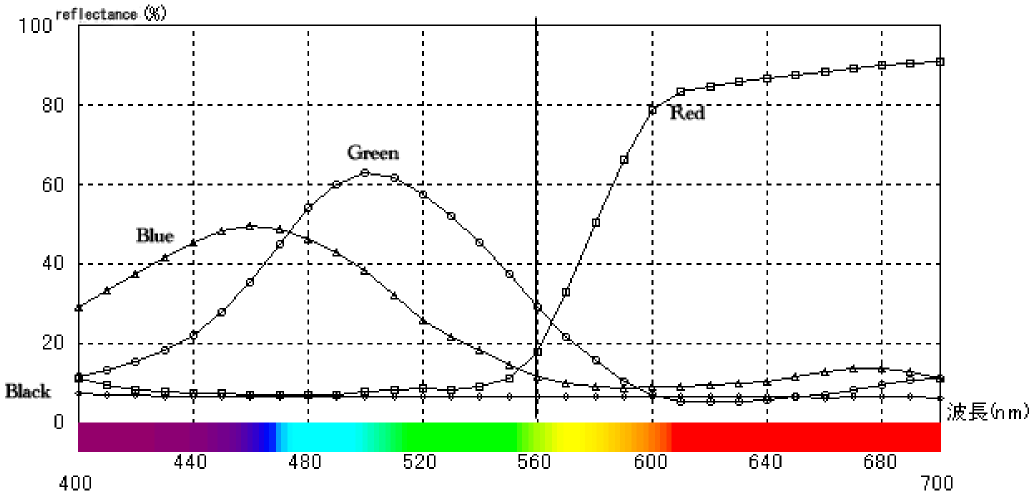

Fig.7 The Spectral Distribution of the Selected Four colors

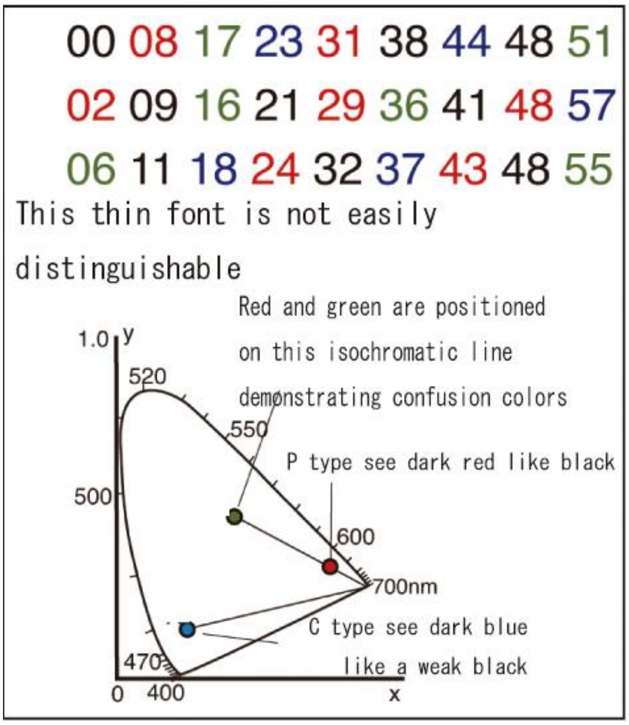

Fig. 8 A Typical Example of a not well Designed Timetable

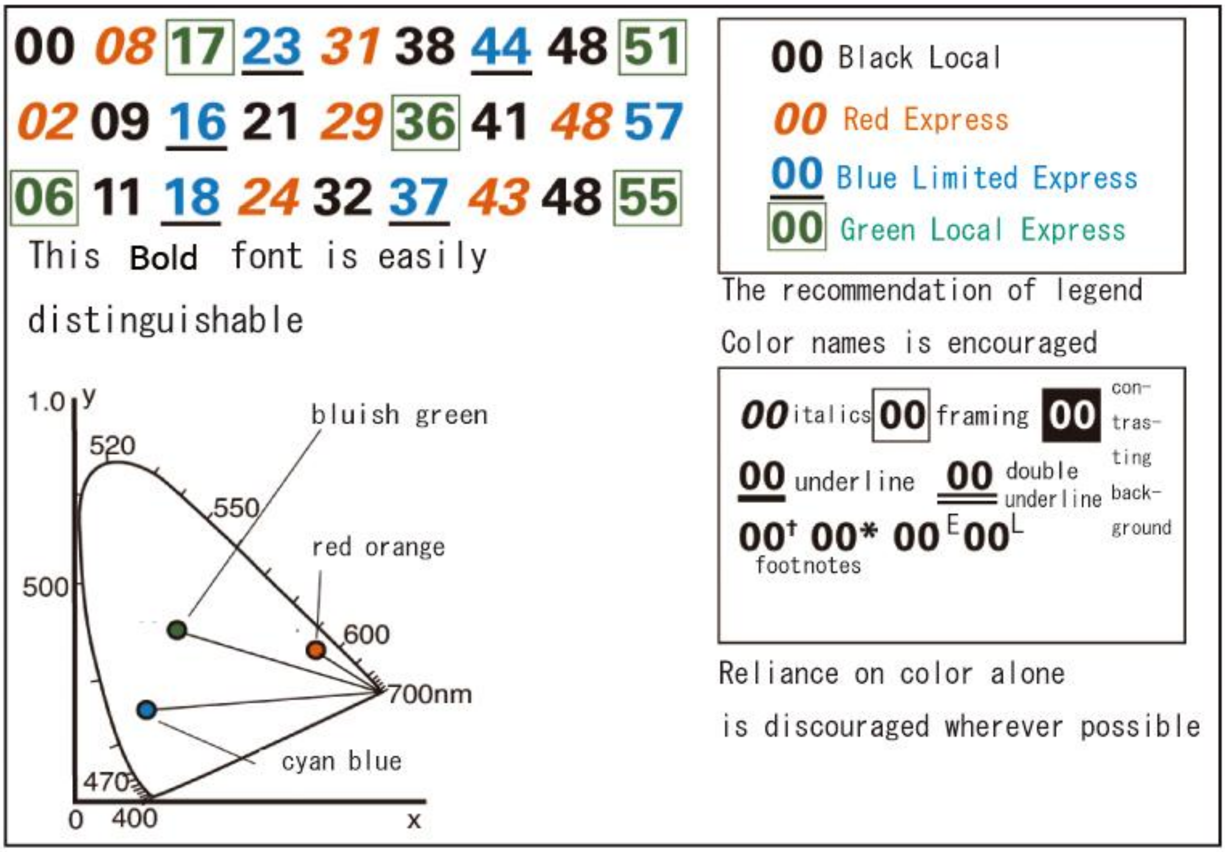

Fig.9 A Recommended Example of a Timetable Featuring the Selected Color Combinations