Color Universal Design Handbook

About this document

This document is based on material issued by the Color Universal Design Organization (CUDO), a nonprofit organization, with some additions and revisions made under the supervision of CUDO. For the information about CUDO and the material, see the following web sites:

http://www.cudo.jp

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1. What is Color Universal Design?

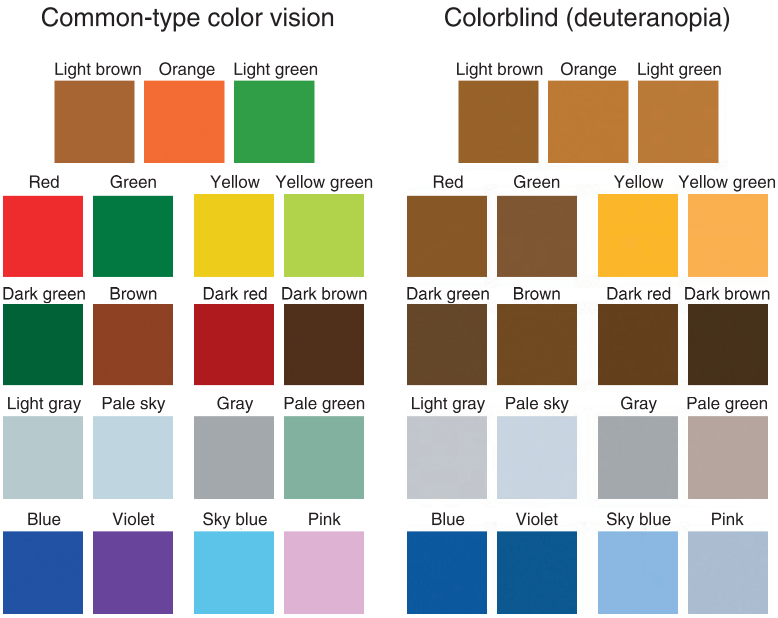
People see color with significant variations. In Japan, there are more than 5 million people in total who see color differently from ordinary people, due to their genetic types or eye diseases. Color Universal Design is a user-oriented design system, which has been developed in consideration of people with various types of color vision, to allow information to be accurately conveyed to as many individuals as possible.

3 (+1) Principles

1	Choose color schemes that can be easily identified by people with all types of color vision, in consideration with the actual lighting conditions and usage environment.
2	Use not only different colors but also a combination of different shapes, positions, line types and coloring patterns, to ensure that information is conveyed to all users including those who cannot distinguish differences in color.
3	Clearly state color names where users are expected to use color names in communication.
+1	Moreover, aim for visually friendly and beautiful designs.

Who is it for?

So-called "colorblind people" (also known as Daltonian, color-weak people, or people with color-vision defects, color-vision deficiencies, or dyschromatopsia) account for the largest proportion of those who have different color vision from ordinary people. In Europe and the US, one out of every 10-12 males and 200 females is believed to be colorblind[1], with a total of over 10 million in the US and around 2 million in the UK. In Japan, one out of every 20 males and 500 females is believed to be colorblind with a total of over 3 million nationwide[2]. And globally, more than 200 million people are believed to be colorblind, and this figure is equivalent of the number of males with type AB blood1. Colorblind people have normal eyesight (resolving power of the eye) and can also see small objects clearly. For some particular combinations of colors, however, they have different vision from the common-type vision (see the following picture and also page 9 for details).



In addition, there are several tens of thousands of people who cannot distinguish any colors and can tell differences in color only by their brightness or darkness. Most of these people also have weakened eyesight.

Age-related illnesses such as glaucoma and cataract can affect how we see color as our eyesight weakens. In Japan, there are over 1.4 million cataract patients in total and approximately 5.6% of the population aged 65 or older suffer from the disease. As society ages, the number of such patients tends to increase. Furthermore, diseases such as diabetic retinopathy and retinitis pigmentosa can also weaken eyesight. A total of several hundreds of thousands of people are so-called "people with low vision[3], with corrected vision of 0.05 or more and below 0.3 in both eyes, who require consideration for not only their weakened eyesight but also simulated views and degrees of contrast.

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1 Reimchen, T.E. (1987) Human Color Vision Deficiencies and Atmospheric Twilight. Soc Biol, 34, 1-11
2 Ota, Y. and Shimizu, K. (1999) Shikikaku to Shikikaku Ijou [Normal and Defective Color Vision]. Tokyo. Kanehara Co., Ltd.
3 Based on the World Health Organization (WHO) definitions.

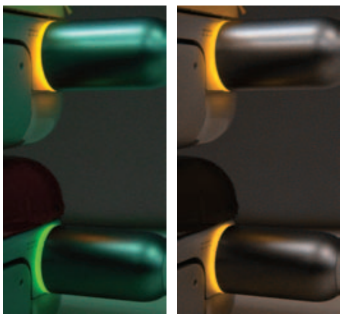
2. How to put Color Universal Design in practice

Why is Color Universal Design so important now?

In 21st century society, use of color is increasingly becoming an important means of information transmission. Several years ago, for example, black and white printing was the norm for newspapers, magazines, textbooks and general publications. But recent development of color printing technology has dramatically turned them into color. These days, even simple guide maps would look rather inadequate unless they were in color. Color has also been introduced to the operation screens of photocopiers, or mobile phones, automatic ticket-vending machines, automatic teller machines (ATMs), etc., and most such screens are now in color. The use of a variety of colors has also become the standard for electronic information boards. Electronic devices and home electric appliances used to have pilot lights with a simple on/off function, but they now commonly come with new types of lights which illuminate in a number of colors to convey information in various different ways. Color-coding is in place in public facilities, museums, exhibition sites, etc., where rooms and areas are divided according to theme colors and full of colorful information displays. At railway stations, train lines are color-coded for direction purposes; route maps and time tables are illustrated with lines and characters in a variety of colors.

As described above, there are so many more scenarios where color is a tool for conveying information, compared with one or two decades ago. However, many color displays are still designed with only common-type color vision in mind. As a result, there are more and more cases like the charging adapter shown in the photograph below, where the information provided is difficult for colorblind people to read, resulting in inconvenience to them. In our current society, life is ironically becoming even harder for the colorblind.

Color Universal Design has been developed to resolve this major issue. Giving consideration to Color Universal Design allows you to use color effectively and create colorful designs that everyone will think beautiful, while still conveying information accurately.



Valuable to everyone regardless of which color vision type

Color Universal Design is not a “peculiar design concept developed only for some colorblind people and rather difficult for people with common-type color vision to see”. The purpose of designing with the colorblind in mind is to completely reexamine the existing inconsistent color-designing procedure that tends to increase the number of colors unnecessarily, establish an order of priority for information elements to be conveyed, and create designs that take into account the impressions and psychological effects they may give to the receiver of the information. Color Universal Design is focused on ease of use from the user’s perspective, rather than only relying on the designer’s aesthetic sense and sensitivity. This will result in “well organized easy-to-see designs” for people with the common-type color vision as well. Therefore, Color Universal Design is valuable not only to the colorblind but also to everyone.

“Color Barrier-free” – The trend of the times

Thoughtful use of color to ensure that the colorblind are not disadvantaged is called a “color barrier-free” presentation. Until recently, vision-related barrier-free activities were designed only in consideration of people who can hardly see. However, the importance of color barrier-free presentations is becoming increasingly recognized at a rapid pace. For example, both Section 508 of the Rehabilitation Act in the US, enacted in 1998, and Phase III of the Disability Discrimination Act in the UK, started from 2004, explicitly call for the consideration to people with disabilities including the colorblind among others.

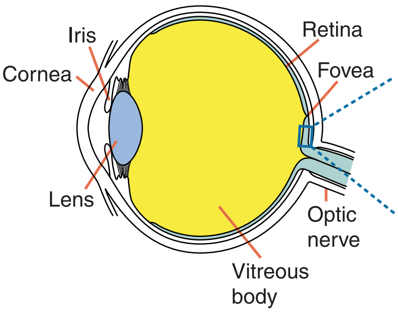
Effective cases of Color Universal Design

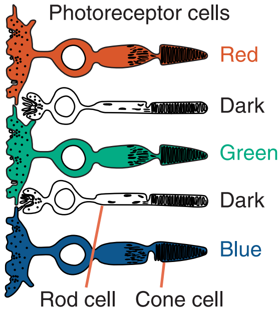
Public facilities	At public facilities such as hospitals and government offices, careful thought must be given to floor directories and warning signs, color schemes for application forms, electric displays in reception areas, color-coding for items to be handed over to the user of the facilities such as medicines, etc. At hospitals, in particular, extreme care must be taken as they are frequented by old people as well as eye patients.
Museums & exhibition sites	In addition to the above, attention must be paid to how to make descriptions of exhibits easy to understand.
Railway stations & airports	Consideration must be given to route maps and directional signs on platforms, electronic information boards to indicate departures and arrivals, etc.
Roads	Attention must be paid to road signs and color tones of lines painted on roads, electronic information boards that indicate road information such as traffic congestion, etc.
Schools & prep schools	Consideration must be given to the colors of chalk and marker pens, the selection of teaching materials, etc.
Newspapers, magazines, text books, reference books, operation manuals, PR magazines for local governments & companies	Careful thought must be given to font coloration, color schemes, line types and color-coding within descriptive figures and graphs, legend indication methods, etc.
Maps, route maps, guide maps, car navigation devices & globes	Attention must be paid to color schemes for color codes, line shapes, legend indication methods, etc.
Ticket-vending machines & ATMs	Consideration must be given to color schemes and designs of operation screens.
Electronic devices	Careful thought must be given to color schemes for charging lights in mobile phones and digital cameras as well as designs for their display screens.
Electronic office equipment	Consideration must be given to operation indicator lights and operation screens of photocopiers, fax machines, PCs, etc.
Home appliances	Consideration must be given to operation indicator lights of electric rice cookers, electric kettles, microwave ovens, etc.
Audiovisual equipment	Careful thought must be given to operation indicator lights and operation screens of TVs, VCRs, etc.
Cars	Consideration must be given to display colors on meters and to designs of operation panels.
Medicines	Attention must be paid to color-coded displays of medicine type and dose, particularly for those prescribed at hospitals and pharmacies.
Stationary	Consideration must be given to color schemes for color-coded filing products such as document folders and binders, ink colors of ball-pointed pens, as well as how to make it easier to distinguish one color tone from another for the colors used in 8 and 12 color sets of marker pens, colored pencils, crayons, paints, etc. The correct color name should also be clearly shown on each item.
Websites	Careful thought must be given to font coloration, color schemes for descriptive figures, and also the selection of background color.
PC software	Attention must be paid to how to display each type of screen.

3. What is colorblindness?

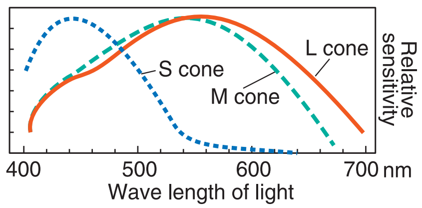
Color vision mechanism and different types of colorblindness

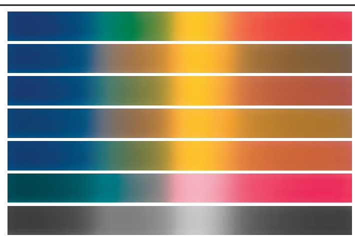
The human retina has two types of photoreceptor cells: rod cells that only work in darkness, and cone cells that only work in light. Cone cells are further divided into three groups depending on which wavelength of light they mainly detect (spectral sensitivity): L (red), M (green) and S (blue).





People with the **common-type color vision** have all of three types of cone cell. In Europe and the US, approximately 90-92% of males and over 99% of females are classified in this category. People with **protanopia** (protanopes) can be divided into two groups: those who don't have L cone cells that mainly detect red light (**strong protanopia**) among the three types of cone cells; and those who have L cone cells with their spectral sensitivity shifted more toward M cone cells (**weak protanopia**). As shown in the following figure, people with strong protanopia have a vision significantly different from the common-type vision, while those with weak protanopia have their vision somewhere between the two vision types. Similarly, people with **deuteranopia** (deuteranopes) can be divided into two groups: those who don't have M cone cells that mainly detect green light (**strong deuteranopia**); and those who have M cone cells with their spectral sensitivity shifted more toward L cone cells (**weak deuteranopia**). Most colorblind people belong to the above four types (strong protanopia, weak protanopia, strong deuteranopia and weak deuteranopia), and about 8-10% of the total male population of Europe and the US belong to one of them (5% of males in Japan, 2-4% in Africa).





Simulated view	Color vision type		Occurence (in males)
	Common-type		(~ 92 %)
	Protanopia	Strong	(~ 2 %)
		Weak	
	Deuteranopia	Strong	(~ 6 %)
		Weak	
	Tritanopia		(~0.001 %)
	Achromatopia		(~0.001 %)

People who don’t have S cone cells that mainly detect blue light have the color vision called **tritanopia** (tritanopes). Those who have only one type of cone cell, or have no cone cells at all but only rod cells, have the color vision called **achromatopia** (achromats). They can only detect differences in color by its lightness or darkness. Less than one out of every 100,000 people are tritanope and about the same number of people are achromatope. While there is no difference in the percentage of tritanopes and achromatopes between men and women, more males have protanopia or deuteranopia than females, with only one out of several hundred women. This is because the protanopia and deuteranopia genes are both on the X chromosome.

Apart from the seven types of vision over the five categories described above, color vision is also affected by eye-related illnesses. A **cataract** is an eye disease that causes the crystalline lenses to become white and cloudy. When the degree of cloudiness is extreme, the lenses do not allow blue to green light of short wavelength to pass through. Furthermore, images become blurry due to the dispersion of light. **Glaucoma**, **diabetic retinopathy** and **retinitis pigmentosa** are diseases that decrease the number of photoreceptor cells in the retina, weakening the eyesight. Weakening eyesight has the most significant effect on the S cone cells, which are the least common of all the three types of cone cell. As a result, the people affected have color vision closer to tritanopia. The severity of these eye diseases differs significantly among the patients. Also, some affect mainly the center of their view, while others mainly the edges. Therefore, one of the characteristics of such eye diseases is significant individual variation, which makes stereotyped simulation difficult.

Notes on use of simulations

Several types of simulation software have been launched to simulate the views experienced by some colorblind people, as shown on pages 5, 6 and 9. Such software can be used to process photographs of products or facilities so as to allow people with common-type color vision to simulate the vision of the colorblind. The simulation applications are highly effective tools for identifying existing problematic color schemes to create new designs. Our system is built on hardware-based simulations that allow the user to control colors displayed on the monitor using the computer. Therefore, it is different from competitors' products, which need to convert images one by one by using software. With our product, the user can convert and view all of the images displayed on the monitor, even movies, in real time.

The user, however, must take note of the following points when viewing images converted through the simulation process.

(1) In the simulation of protanopes and deuteranopes, the vision of the most strongly affected people is reproduced. Approximately one third of colorblind people are estimated to be in this category. The remaining two thirds have their color vision somewhere between that and the common-type color vision, including those who have their vision very similar to the common-type vision. For this reason, please take care not to believe that all colorblind people, including those more weakly affected, have color vision as indicated in the converted images.

(2) When there is a color that is difficult to distinguish, people judge it by using information other than the actual color as a complement. For example, we view an apple as red and paper as white, even when both are lit in red under a red light. The same applies to colorblind people. For them, it is difficult to distinguish some tones of sky blue from some tones of pink. In this case, colorblind people view that the clothes worn by a man should be sky blue (even if pink), and those worn by a woman pink (even if sky blue). This happens because people judge colors by comparing them with their memories and experiences - men often wear sky blue while women wear pink.

In a color vision simulation, a range of colors that are difficult for colorblind people to distinguish are all converted into one color, which is determined by a calculation formula of the colorblind theory. Therefore, the color displayed is not necessarily the color recognized by colorblind people. For example, pink and sky blue, as described above, both appear as sky blue in simulations, but it is incorrect to think that "colorblind people see pink as sky blue".

Simulations do not show you "which color colorblind people see as a certain color". Therefore, they should only be used to understand "which colors on the screen are difficult for them to judge".

Why simulations must be checked by colorblind people

Simulations are effective but not perfect. First, they have limitations such as the inability to reproduce the complete vision of a colorblind person. The color of light-emitting objects such as LEDs cannot be reproduced as the correct color, since these color are beyond the color range that can be handled on digital camera or computer screens. This also results in inaccurate simulations.

In addition, even when some colors are viewed as similar by people with common-type color vision, they may be viewed as completely different by colorblind people. Colorblind people are more sensitive about levels of brightness and saturation than those with the common-type vision, even for the slightest difference. For this reason, some colorblind people may become confused by a slight difference in color that cannot be noticed by people with the common-type vision. Conversely, even when people with common-type vision expect some color scheme to be difficult for colorblind people to view, it may be in fact rather easy for them to distinguish. Therefore, people with common-type color vision cannot perceive how colorblind people exactly see, simply by looking at simulated images on the screen.

Furthermore, colors of the products and displays are also significantly affected by lighting. Therefore, it is very important to evaluate the visibility, readability and design quality of each product or display not on the computer screen, but under the same lighting conditions as for the site at which the product or display will actually be used.

Color Universal Design is a creative process consisting not only of adjusting colors, but also of working out how to use different shapes, line types and coloring patterns and creating designs in a comprehensive manner by using characters and color names without spoiling the beauty of the designs. Neither the beautiful balance of color nor easy-to-see designs can be achieved if the designer simply chooses a confusing color on the computer and simply replace it with a different color.

For this reason, in order to achieve Color Universal Design, it is essential for the designer to work together with colorblind people through discussions to carry out checks and produce ideas. You should however remember that there are different types of color vision, e.g. color is viewed very differently between protanopia and deuteranopia. The same color use may be completely easy for protanopes but extremely difficult for deuteranopes to see, or vice versa. Therefore, it is important during the checking process to verify designs not only with the common-type color vision but also for all four major types of colorblindness (strong protanopia, weak protanopia, strong deuteranopia and weak deuteranopia), rather than selecting only one of them. This gives five types of color vision to be included in the verification process.

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1st Edition-August , 2006
03V22006A1