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A method for constructing an objective eye color chart

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Detailed instructions for constructing an eye-color chart that represents a normal range of human eye colors are provided. The chart is composed of photographic color slides of human irises, magnified to 3.6× life-size. Iris images are sequenced according to their color and measured opacity. This enables researchers to reliably classify subjects' iris pigmentation according to both color and darkness. The eye color chart is easy to use and is highly reliable (between-observers measurements r ≥ .94). The photographic arrangement is also useful for obtaining magnified photographs of irises for documentation and illustration purposes.

Researchers have often speculated that, through its joint association with physiological factors, iris pigmentation may be an easily visible indicator of behavioral responses. Eye color or darkness has been correlated with incidence of schizophrenia (Kent, 1956), pain sensation (Sutton, 1959), perception of critical flicker frequency (Jurenovskis, Jamieson, & Ginsburg, 1980), susceptibility to visual illusions (Coren & Porac, 1978), and motor response times (Hale, Landers, Snyder Bauer, & Goggin, 1980; Landers, Obermeier, & Patterson, 1976; Landers, Obermeier, & Wolf, 1977; Tedford, Hill, & Hensley, 1978; Worthy, 1974b). Few researchers, however, have developed objective scales for measuring eye color and darkness. Investigators have relied, instead, on verbal or numerical categories and observer agreement. Sutton (1959), for example, used nine verbal color categories ranging from blues, through grays, greens, and hazel, to browns to classify his subjects. Worthy (1974b) developed a 5-point scale of eye darkness for rating the darkness of human eyes in black-and-white photographs. Later, he combined color and darkness in a quantitative scale, based on eye color, of animal eye darkness (Worthy, 1975). Blue and green animal eyes were positioned on the extreme light end of this scale; dark brown and black eyes were positioned on the extreme dark end. Recent research relating reaction time to eye color has used Worthy's (1975) animal eye color/darkness scale for measuring the darkness of human eyes (Hale et al., 1980; Landers et al., 1976; Landers et al., 1977). Following Worthy's (1975) suggestion, other researchers have used a simple brown/nonbrown dichotomy for measuring the darkness of human eyes (Tedford et al., 1978; Worthy, 1974a).

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Two eye color scales developed to provide an objective set of comparison stimuli are Kent's (1956) iris pigment scale and the Munsell Eye Color Chart. Kent's iris pigment scale contains nine artificial eyes, ranging from blue to dark brown, arbitrarily chosen "to introduce a spectrum-like continuum of iris pigmentation." The artificiality of the colors of the scale makes its direct use for eye color comparisons difficult; in particular, the intermediate colors of the scale bear little resemblance to naturally occurring iris colors.

The Munsell Eye Color Chart is a subset of color chips from the *Munsell Book of Color* (1973), which contains the range of colors suitable for measuring eye color. The color chips in the *Munsell Book of Color* and the eye color chart progress along three dimensions: hue, darkness, and saturation. All the colors are measured combinations of component color pigments. The chips, however, are fully opaque and uniform in color, a disadvantage in eye color measurement.

A good eye color chart comprises a set of objective stimuli that emulate the visual features of irises and represent a normal range of iris coloration. For ease and accuracy of classification, the chart should generally illustrate three features of the iris: iris color, including color mixtures, iris opacity or darkness, and iris luminosity.

Iris coloration varies along both color and darkness dimensions. At their extremes, the two dimensions are linked: Dark brown eyes are darker than blue eyes. Each eye color group comprises a range of shades or patterns that vary in opacity. Brown eyes, for example, range from light brown, sometimes containing green, to almost black eyes. A single eye is rarely uniform in color or opacity. "Grayness," for example, is characteristic of predominantly blue eyes containing areas of white; the color and opacity of the iris vary across it. Variation in color across the iris makes some iris color combinations particularly difficult to classify. Blue-brown eyes, for example, are sometimes labeled blue, sometimes gray, and sometimes brownish. The color mixtures within this group vary in darkness according to the amount of brown or yellow in the eye and the intensity of the blue. Two distinct forms are common. The first combination is characterized by two concentric rings around the pupil, an inner brown ring that may radiate out and an outer blue or blue-gray ring. The second combination is a speckled eye, containing spots of blue, brown, and yellow. Since these eyes vary considerably in color and opacity across the iris, use of a single chip color comparison is inappropriate in properly classifying the color and darkness of the eye.

Until recently, eye color was thought to be a function only of the concentration and distribution of a single melanin pigment in the eye (Kent, 1956; Weiss & Mann, 1978). The blueness of blue eyes was thought to be caused by the way light was scattered by small, dispersed clusters of melanin granules. Kent, among others, believed that, as the concentration of melanin increased in the superficial layers of the iris, the eye became browner. The artificial eyes in Kent's chart illustrate this hypothesized progression from blue to brown eyes. The actual relationship between color and pigmentation may be more complex. Recent evidence (Menon, Persad, Haberman, Kurian, & Basu, 1982) suggests that there are qualitative pigment differences, as well as differences in pigment distribution, between blue and brown eyes. Menon et al. found pigment isolated from blue eyes to be bluish in color. Blueness, then, may be a function of melanin type, as well as of distribution. In developing our eye color chart, we found that dark blue eyes were measurably almost as dense as medium brown eyes (see densitometer measurements in Table 1). Together with the Menon et al. results, this finding led us to conclude that eye color alone cannot be used to indicate pigment concentration.

In addition to color and darkness features, the iris may be distinguished from other colored objects by its particular luminosity. Looking into an eye has been compared with looking into a marble, or looking through colored glass into a mirror. The eye appears to both transmit and reflect light. The translucence of the eye becomes important in selecting the medium in which iris color stimuli are represented on a chart. Ideally, the medium should be translucent rather than wholly opaque.

In summary, an eye color chart should (1) progress according to both eye color and darkness, (2) represent a normal range of iris coloration, including common color mixtures, and (3) use a medium that mimics the translucence of the eye, thus facilitating classification.

Each of the described iris color/darkness scales has shortcomings that may or may not be evident, depending on the use of the scale. Verbal color categories properly are used to classify irises according to their color. Their accuracy is limited to the precision of the color definitions; the placement of common color mixtures, such as blue-brown and green-brown, are rarely specified. Verbal color categories are misused on human eyes when experimenters use color to measure opacity. The opacity of irises within a single color category may vary greatly.

The use of Munsell color chips for measuring eye coloration permits the observer to measure both the color and darkness of the eye. However, two basic differences between chip color create difficulties in obtaining an accurate standardized measurement. First, the translucence of the iris modifies its coloration sufficiently to make color comparisons with the wholly opaque chips awkward. Second, an iris is rarely uniform in color. Colored rings, speckles, radiations, and textural differences complicate color choices. Common iris color mixtures, such as blue-brown and green-brown combinations, often necessitate specifying more than one color chip for each eye. Consequently, accurate color description using the Munsell color chart is slow and requires trained observers to achieve good reliability.

To deal with the classification problems produced by eye luminosity, color, mixtures within an iris, and variation in eye color and density, we developed a procedure for constructing an eye color chart that uses color slide photographs of human irises as comparison stimuli. There are several advantages to using slides for this type of application. Photographic slide images of human eyes are complex stimuli that allow an observer to make comparisons along several dimensions. In particu-

Table 1
Densitometer Measurements of Iris Darkness on Color Slides of Eye Color Chart

Slide	Eye Color	Iris Darkness*	Slide	Eye Color	Iris Darkness*
1	blue-green	.67	11		.96
2		.89	12		.96
3		1.02	13	blue-brown**	.90
4		1.06	14		.93
5	blue	.74	15		1.05
6		.84	16	brown	1.21
7		.87	17		1.38
8		.89	18		1.41
9		1.13	19		1.68
10	green/hazel	.80	20		1.91

*Log_{10} opacity. **Densitometer measurements were made on the outer blue perimeter of the eye.*

lar, the slides capture variations in iris color and opacity across the iris. With extensive sampling, a full-range representation of eye colors and color mixtures is possible. In addition, color slides are translucent and are capable of capturing the luminous quality of irises. These features enable an observer to make realistic eye color comparisons quickly and with one measurement.

Color slides also permit objective densitometer measurements of iris color and opacity. Density measurements provide a standard base for describing the color and darkness of a slide image and comparing different slide sets. The measurements are also useful for sequencing irises by opacity within the eye color chart.

The eye color chart has enabled a reliable classification of subjects' eye colors in several studies. The irises portrayed were selected to represent a normal, mixed-European range of iris coloration, but the selection can be expanded easily to include additional ethnic racial types. A chart similar to the one we created can be constructed by following the procedures outlined below.

The chart is constructed in three stages. First, a pool of color slides of human eyes is created. From this pool, color slides depicting a representative range of iris colors is selected. Second, the color densities of the representative slides are measured, and the slides are sequenced and packaged. Third, the reliability of the chart is tested.

The photographic method for obtaining magnified images of human irises can be used to record irises in any study involving visible iris features. The method can, for example, be used to document pattern variations in eye color, iris abnormalities, or color changes related to aging.

ACQUIRING EYE PHOTOGRAPHS

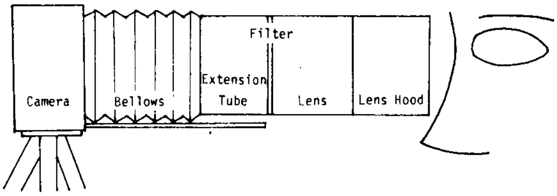
An extensive review of the photographic and biomedical literature failed to disclose a method for giving a greater-than-life-size image of an iris on a 35-mm color slide without a large number of reflections. The usual ring flash arrangements produce a white halo on the iris that obscures the true color and density of the eye. We developed the photographic arrangement detailed below to obtain a saturated 3.6X life-size image with minimal distracting reflections.

Method

Subjects. Using a small, windowless office as a studio, we photographed the right eyes of 100 University of Victoria faculty, students, and staff.

Procedure. An Asahi Pentax Spotmatic camera, on a tripod was fitted with an Asahi Pentax Bellows II. To the bellows, we connected a 30-mm Pentax extension tube and a 55-mm Super Takumar lens (1:1.8) with UV (ultraviolet) filter reversed to magnify the size of the image. A blackened 30-mm Pentax extension tube was threaded to the back of the lens to serve as a lens hood to reduce light scatter (see illustration, Figure 1).

Photographic lighting was provided by a daylight Braun FL300 flash unit operating at full intensity at a standard angle of illumination (55 deg). The flash unit was located 1.25 m from the right side of the subject, at eye level. The flash was directed at a 45-deg angle from full side profile at the right eye. The flash unit was attached by a synch cord to the camera to permit the simultaneous release of flash and camera shutter. Flash duration was 1/700 sec.



Camera: Asahi Pentax Spotmatic with thread mount.
Bellows: Asahi Pentax Bellows II threaded to camera.
Extension Tube: 30mm Pentax extension tube threaded to bellows.
Filter: 49mm UV filter threaded to front of lens; lens and filter taped to extension tube.
Lens: reversed 55mm Super Takumar lens (1:1.8).
Lens Hood: blackened 30mm Pentax extension tube screwed to back of lens.

Figure 1. Camera set-up.

Focused lighting was provided by a 650-W Colortran floodlight directed to cross-light the subject's right side. The floodlight turned off immediately prior to shooting. Initially, we found that the dark interval immediately prior to the flash was sufficient for adaptive pupil dilation. To maintain pupil constriction, auxiliary light was reflected onto the subject's left eye. The reflected light was provided by a 650-W Colortran floodlight. Light from the floodlight was bounced from a Reflectosol umbrella onto the left side of the subject's face at a 45-deg angle from full side profile. Although some light reached the right eye from this source, most of the light was blocked by the bridge of the nose (see illustration of room arrangement, Figure 2).

Kodak Ektachrome 220 ASA daylight color slide film was used to photograph all eyes, with a camera aperture of f8.0. Each subject was photographed seated. A headrest positioned the subject's right eye about 4 cm from the lens hood when the camera was focused.

When the subject was positioned, the focusing light and auxiliary lighting were turned on, and the subject was requested to remain very still. The subject's eye was then brought into focus. The camera aperture was stopped quickly to f8.0. The focusing light was turned off, and the picture was taken.

Results

Ninety-two usable slides were obtained. Two judges jointly reduced the 92 slides to 20, which represented

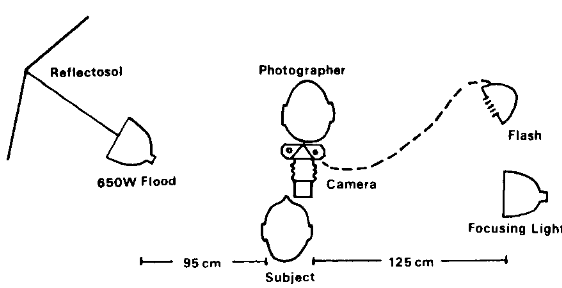


Figure 2. Photographic set-up.

20 distinct eye colorations. The 92 slides were first examined to determine the range and variation in iris coloration obtained, and then were sorted into the basic color categories described below. Within each category, iris images were ordered according to the observers' impressions of overall darkness. Slides that best represented positions along a scale of color/darkness combinations were selected for the chart. Close duplicates and iris images intermediate in color and darkness were discarded.

EYE COLOR CHART

The final 20 slides contained the following color categories:

1. Blue-green mixes. Irises were uniformly aqua in color or were speckled blue and green (slides 1-4).
2. Blue eyes and blue-gray mixes. Irises ranged from light blue to slate blue (slides 5-9).
3. Green to hazel eyes. Green eyes contained some brown, either mixed with the green or as a narrow ring around the pupil. Hazel eyes were characterized by an overall impression of brown that either was light or contained some green (slides 10-12).
4. Blue-brown mixes. Irises either were blue on the outer perimeter, with a yellow or brown ring around the pupil, or were speckled blue, brown, and yellow (slides 13-15).
5. Medium to dark brown eyes. Medium brown irises contained a dark green ring on the outer perimeter of the eye or were uniformly medium brown (slides 16-17). Dark brown irises were uniformly dark brown (slides 18-20).

To confirm the judges' original impressions of darkness, we obtained densitometer readings for each color slide to determine color density and final placement within an eye color category. Total color density was measured using a Macbeth TR924 densitometer. Readings were obtained for three positions on the right lower side of the iris (corresponding to 3 o'clock, 4:30, and 6 o'clock), the regions showing the least lighting glare and the least interference from eyelash shadows. The three readings were averaged to obtain an overall reading for each iris (readings are listed in Table 1). In order to provide a more detailed objective reference for other researchers, additional readings were taken at the 4:30 position to measure the densities of cyan, magenta, and yellow light separately (a table of measurements is available from the second author).

The densitometer readings express the log to the base 10 of the opacity of the slide: density = $\log_{10}$ opacity = $\log_{10}$(total light projected/total light transmitted). As a standard reference, Kodak gelatin color-compensation filters used in color printing are ordered according to density. For example, a CC40Y filter is a yellow filter with a yellow density equal to 0.40.

In the initial category placements, the two judges placed slides into each color category and ordered them according to overall impression of darkness. The densitometer readings pointed to some errors in judging the relative darkness of the slides. Three slide pairs on the chart were reversed to order the slides in accordance with the densitometer readings (slides 5 and 6, 10 and 11, and 16 and 17).

Notably, our chart does not progress along a smooth opacity continuum. Although eyes have been ordered within each color according to their overall density, the categories overlap in darkness. For example, a dark blue iris (slide 9) has almost the same opacity or darkness as a medium brown eye (slide 16).

PACKAGING OF THE CHART

The slides are stored in a 20-pocket clear plastic slide sheet with an opaque backing, readily available from photographic supply stores. The opaque backing serves to diffuse the backlighting used in viewing. Backlighting is provided by a cycling flashlight originally designed to be worn around the head. This light is modified to diffuse and filter the bulb light. The glass is covered with opaque tape and fitted with a short, angled white cylinder to diffuse the light. A light blue Kenko 82C tungsten-to-daylight filter is attached to the top of the cylinder to give a more appropriate color balance to the tungsten light. Using this light, an observer can backlight and view one slide at a time. When the backlight is used in illumination other than daylight, appropriate correction filters may be inserted to balance the backlight to the ambient light.

Use of the Chart

The following procedure is used to measure eye color with the chart.

1. The subject is asked to look toward sufficient illumination.
2. The observer notes the rough color of the subject's eyes.
3. The observer presents the chart to the subject's right eye.
4. The observer backlights the slides and moves the light behind the chart to the appropriate eye color region.
5. The observer chooses the slide most closely corresponding to the color and darkness of the subject's eye.

CORRESPONDENCE BETWEEN EYE COLOR CHART AND KENT'S IRIS PIGMENT SCALE

A direct comparison between the color plate of Kent's (1956) iris pigment scale and the chart described here provides reliable correspondences in the blue and brown regions of the scales; however, four observers were inconsistent in making matches in the regions in which eye colors were mixed. Observers agreed that the first three artificial eyes on Kent's scale corresponded to the blue range on our chart (slides 5-9, opacity = 0.76-1.13), and that the last three eyes on the scale corresponded to the browns on our chart (slides 16-20, opacity = 1.21-1.91).

CORRESPONDENCE BETWEEN EYE COLOR CHART AND MUNSELL BOOK OF COLOR

Four independent observers attempted to match the iris colorations on color slides of the eye color chart with the color chips in the *Munsell Book of Color* (1973).

Considerable variability was found along hue, darkness, and saturation dimensions. The four observers tended to pick out different color highlights in the iris and were tempted to pick out more than one color chip for some eyes to deal with the variation in color across the iris. These problems were particularly apparent in attempting to match color chips to irises with mixed colors, such as green-hazel and blue-brown. Observer agreement was also poor in estimating darkness and hue in the brown range of the chart. A table of comparison measurements is available from the second author.

RELIABILITY OF THE EYE COLOR CHART

The reliability of the eye color chart was tested in two separate studies. In the first study, two observers asked 30 students who were outside on a sunny day if they would allow their eye colors to be rated. Each observer independently asked subjects to orient their heads so that their right eyes were well illuminated. The observer then held up the eye color chart to the subject's right eye and compared the subject's eye color against the backlit chart. The observers found that they could rapidly classify eye color according to the chart. The correlation between observers' measurements was 0.97.

The second study involved 50 married couples interviewed in their homes, under different lighting conditions. Each spouse was independently asked to pick his or her eye color from the slides without help from a mirror. The subjects had no problems using the eye color chart. The experimenter also rated the spouses' eye colors. The correlation between the interviewers' and the subjects' ratings was 0.94 (Ham, 1983).

SUMMARY

The photographic color slide eye color chart described above has proved reliable and easy to use in rating the eye color of subjects under different lighting conditions. The sequencing of iris colors on the chart is objectively based on color density measurements. Using the described procedures, such a chart is easily developed and provides a reliable classification of eye colors. The photographic arrangement is also useful for recording and documenting other visible iris features.

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