Measuring Luminance Color Contrast on Products, Including Fitness Equipment, for People with Visual Impairments

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Abstract

A field method for measuring luminance in order to calculate contrast between colors on consumer products and signage is needed. A contrast value of at least 70% for readability by people with visual impairments is generally recommended. An ASTM Accessible Fitness Equipment Standard is currently under development and will include accessibility criteria for people with visual impairments using fitness equipment, which references this 70% color contrast criteria. In order to obtain accurate measurements, spot meter technology was evaluated. An objective method was developed and tested to quickly and accurately calculate color contrast in the field. These data suggest that spot meter technology and this method allow for the precise calculation of color contrast.

Keywords

ASTM standard; fitness equipment; vision impairment; color contrast; universal design

Background

Need

The RERC RecTech is currently working in conjunction with ASTM to develop a Universal Design of Fitness Equipment (UDFE) Standard with the working title, "Standard Specification for Universal Design of Fitness Equipment for Inclusive Use by Persons with Functional Limitations and Impairments." This standard will aid manufacturers in designing universal fitness equipment, guide fitness centers in the selection of universal fitness equipment, and assist individuals with disabilities in choosing appropriate fitness equipment to match their needs.

Beneficial Designs, Inc. developed draft 2007 Universal Design Fitness Equipment Guidelines during an initial NIH Phase I SBIR. The Inclusive Fitness Initiative (IFI) separately developed accessibility guidelines for fitness equipment in the UK. The guidelines from each of these projects are now being incorporated into an ASTM standard.

One element of this project is designing and testing a method to determine color contrast in the field. IFI initially used a scientific algorithm to calculate brightness and color contrast, but this has proved cumbersome to perform in the field. The Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities 2002 (ADAAG) requires that characters and symbols contrast with their background (1):

Research indicates that signs are more legible for persons with low vision when characters contrast with their background by at least 70 percent. Contrast in percent shall be determined by Equation 1.

However, ADAAG does not outline how to measure the light reflectance values (LRVs).

$$\text{Contrast} = [(B1 - B2)/B1] \times 100 \quad [1]$$

where B1 = light reflectance value (LRV) of the lighter area and B2 = light reflectance value (LRV) of the darker area

Equation 1. Light Reflectance Value Contrast Equation

Problem

In order to measure the contrast of color values against their background, the measurement must be of the apparent reflected light from these parts of the surface. Light is electromagnetic radiation of varied wavelengths. However, human vision can only perceive a portion of these wavelengths. Since ADAAG's recommendation of 70% contrast is to increase the legibility of signage for persons with visual impairments, the methodology needs to measure the perceived light and contrast within the visible spectrum.

Different lighting conditions (e.g., natural sunlight, fluorescent lights, tungsten lights, etc.) affect the apparent brightness and color of an object because different lighting conditions produce different incident light. Incident light (e.g., ambient light) is the amount of light that is falling on an object. In a room with no windows and only fluorescent lights, a white box and a black box sitting side by side will have the same incident light because they have the same light source and are placed at the same distance from the light source. An object's reflectivity (material, texture, color, etc.) will produce different reflected light. Reflected light is the amount of light that is reflected off an object. It is different from incident light because the object absorbs some wavelengths of the incident light, while other wavelengths are reflected. Since the goal of this project is to measure the apparent contrast the average human eye perceives for an object or surface, the measurement needs to be of the object or surface's reflected light. However, given that reflected light is a result of both incident light and the object's reflectivity, the methodology will need to reference the incident light (or light source) within the environment of the object to be measured.

The measurement of reflected light is called luminance. Luminance is "the amount of visible light leaving a point on a surface in a given direction… due to reflection," or the perceived or apparent brightness of a surface (2). The standard unit of luminance is candela per square meter (cd/m2), or nits. Luminance is measured using a light meter, a technology that measures light within the visible spectrum.

Initial research focused on existing methods for the measurement of color contrast. ASTM C60907 uses spectophotomectric equipment to determine color contrast on ceramic tile, but this equipment is very expensive (3). Research was conducted by Westat for the Federal Highway Administration to assess the visual detection of detectable warning materials (4). This research confirmed that warnings were more distinguishable to people with vision impairments when "luminance contrast was 70 percent or greater". To measure and calculate luminance contrast, Westat used the Minolta LS-100 Luminance meter, designed to spot measure luminance in cd/m2, using the LRV Contrast Equation [1]. However, this light meter technology is again very expensive. Armor Tile, which produces tactile surface indicator tiles, also uses the LRV Contrast Equation [1] to calculate contrast for these tiles at sidewalk crossings (5). The LRVs are measured in lux using a flat lumisphere light meter, such as the Minolta Flash Meter V, to calculate the contrast between the tile and the surrounding surface(s). In using this technique, the measurement of reflection is calculated based on the averaged amount of reflected light of a large area. This technique cannot accurately measure the LRV contrast of smaller objects or text.

For the purpose of this project, there is a need to be able to measure the LRV of a detailed area, like small objects, text, and symbols and then the LRV of the background. Spot meters are light meters that are capable of measuring this kind of detail and are commonly used in the photography and cinematography industries. These meters are an economical alternative to other expensive meters.

Methodology

There are only a couple spot meters that measure directly in luminance (cd/m2). The Sekonic L758C, designed for the cinematography industry, is reliable and low in cost. There are other spot meters that measure in Exposure Value (EV), a photography value that denotes all combinations of apertures and shutter speeds that will result in the same exposure. However, EV is not a direct measurement of luminance; rather it corresponds to a luminance for a camera set at a given ISO speed for an EV to produce a correctly exposed photograph. EV can be converted to luminance. Ten LRV readings were taken using the Sekonic meter in cd/m2 and the same ten LRV readings were taken using the Sekonic meter in EV and converted to cd/m2. These data show that the measurements were very close with a difference of under 2%.

Measurement Description	White paper	Yellow bin	Navy blue notebook	Red binder
Luminance (L_1) (measurement in nits: cd/m^2)	**97**	**30**	**6**	**20**
Exposure Value (EV)	9.6	7.9	5.6	7.3
EV Converted to Luminance (L_2) (cd/m^2) $L_2=2^{(EV-3)}$	**97.01**	**29.86**	**6.06**	**19.70**
Percent (%) Difference $[(L_1-L_2)/L_1]*100$	**-0.01%**	**0.48%**	**-1.05%**	**1.51%**
Gray Card Measurement (cd/m^2)	**28**	**9.8**	**20**	**17**

Table 1. Sample Data Accuracy of Converting Exposure Value (EV) to Luminance (cd/m^2) (Data collected using Sekonic L-758C)

Since the incident light affects the apparent reflected light, it is important to make note of the lighting conditions during the measurements. Contrasts will be higher in a well-lit room, as opposed to a dimly lit room. Accurately recording the lighting conditions is commonly done by taking a reading of a gray card placed flush against the surface to be measured. A gray card is a middle gray reference with an 18% reflectance across the visible spectrum, used with reflected meters to measure incident light. The standard information that should be recorded for calculating contrast measurements include: date; time; location; incident light/lighting conditions (description, gray card measurement, and photograph); LRV measurement of object, text, or symbol; description of object, text or symbol; LRV measurement of background; description of the background; and a photograph of the object and surface.

The procedure followed for obtaining an LRV measurement using the Sekonic meter was: 1.) Press the <power> button; 2.) Turn the Incident/Reflected Selector Dial to Reflected Spot operation, and verify that the lumisphere is in the retracted position; 3.) Set the device to measure in nits (cd/m2), press and hold the <mode> button while rotating the jog wheel until the LCD displays <cd/m2>; 4.) Remove the lens cap on the spot lens; 5.) Stand or sit in the expected position of the user of the equipment; 6.) Hold the device up to the eye and look through the finder, aligning the subject (e.g., the gray card, object/text/symbol, or background) completely within the inside of the circle in the eyepiece; 7.) Press and release the measuring button; and 8.) Record the value seen in the screen of the device.

The methodology we followed to collect measurements on signage was: 1.) Record all information other than measurements (e.g., date, time, descriptions); 2.) Take photographs of light sources and of object/equipment; 3.) Measure the LRV of the gray card by having an assistant hold the gray card flush against the surface; 4.) Measure the LRV of the object, text, or symbols; 5.) Measure the LRV of the background; and 6.) Calculate the contrast using the LRV Contrast Equation [1]. Readings should be repeated in the intended environment at a few different times of the day to ensure 70% contrast is visible under various expected lighting conditions. Color contrast should meet or exceed 70% in the dimmest lighting conditions that are expected to exist within that fitness environment during use of the equipment.

RESULTS

In theory, contrast of absolute white and absolute black under perfect white light would be 100%. However, in the field, a contrast value for white and black will never be 100% because white and black will never reach absolutes and the incident light will never be perfect white light. Therefore, an expected contrast for white on black would be between 80 to 100% under bright incident light. The data for readings taken with the Sekonic spot light meter of white on black under fluorescent lighting produced a contrast value of 84%, see Table 2 for other values collected. These data demonstrate that a spot meter, such as the Sekonic L-758C, which measures in cd/m2 and spot meters that measure in EV with data converted to cd/m2, can accurately measure the LRV values to calculate contrast.

DISCUSSION

This study demonstrates an accurate and easy method for calculating color contrast of small objects or text in the field using existing spot meter technologies. The methodology to collect data and calculate color contrast for universally designed fitness equipment will be further developed. Additional research

Object Description	Sign: white text on black	Seated Leg Press	Seated Leg Press	Seated Leg Press
LRV_1 Description	White text	Red handle	Red numbers	Red weight pin
LRV_1 (cd/m^2)	60	13	9.8	8.6
LRV_2 Description	Black background	Black handle	White background	Black weights
LRV_2 (cd/m^2)	9.8	5	15	1.2
Contrast (cd/m^2) [$(LVR_1-LVR_2)/LVR_1$]*100	84%	62%	-53%	86%
Light Source(s) Description	Fluorescent lights	Fluorescent lights and sunlight	Fluorescent lights and sunlight	Fluorescent lights and sunlight
Gray Card Measurement (cd/m^2)	28	17	3.5	8

Table 2. Sample Data for Calculating Color Contrast (Data collected using Sekonic L-758C)

is needed to demonstrate that this methodology is reliable and repeatable. The methodology will be tested to confirm that similar data can easily be produced across and within multiple labs. This method could be used to determine the contrast of text or symbols in both indoor and outdoor environments. Once the percentage of contrast is known, compliance with ADAAG signage guidelines can be determined. The percentage of contrast will have applications for other industries as well. This color contrast measurement can be used to evaluate all types of consumer products that would be used in the home or work environment.

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