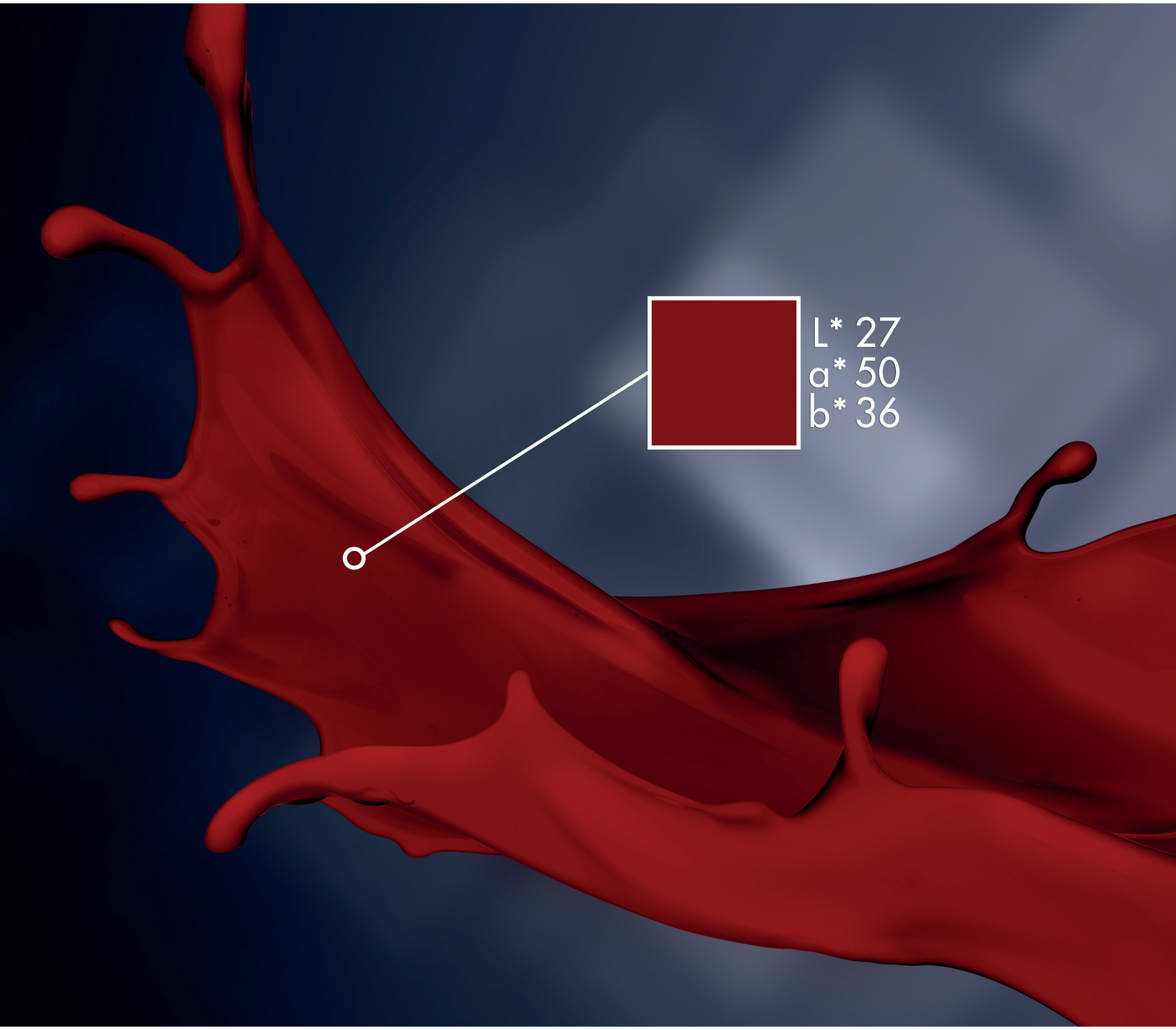
BOOK FIVE OF COLOR MANAGEMENT



Measurement techniques in colorimetry

datacolor

Measurement techniques in colorimetry

In colorimetric applications, color is measured objectively; therefore, visual color perception should be simulated as precisely as possible with the color measurement systems used.

“Color” here always refers to the color specification, that is, the sensation perceived by the eye as the result of a color stimulus. The objective of the measurement is not the (physical, spectral) color stimulus, but the (effect-producing) color specification.

Measurement instruments

Two types of instruments are used for color measurement---the spectrophotometer and the tristimulus colorimeter. They use different equipment and methodology and produce different types of numerical descriptions of a color.

The tristimulus colorimeter

A colorimeter uses filters to record the amount of light reflected in 3 wavelength ranges across the visible spectrum. It includes red, green and blue filters that generally correspond to the 1931 CIE 2° color matching functions x, y and z. These are used to simulate the detectors in the eye. The color matches represented by the filters depend on the physical light used. Because of this, a colorimeter can produce a tristimulus notation only for one light (the measurement light) and for one Observer condition (which is simulated by the filters used the instrument).

Tristimulus colorimeters have very short measurement times, are simple to operate and relatively inexpensive. Tristimulus colorimeters are mainly used in quality control and are reliable for evaluating color differences and color tolerance checks. However, a tristimulus colorimeter cannot detect metamerism, and is not used to calculate color formulas.

The spectrophotometer

Spectrophotometers analyze the light reflected or transmitted by a sample at each wavelength in the visible spectrum, compared to that from a reference sample. They are fitted with a device, typically a diffracting element, which breaks the incident light into individual wavelengths. Spectrophotometers measure the fraction of light reflected/transmitted by the object at each wavelength in the spectrum. This data represents the photometric characteristics of the sample. The resulting data are referred to as spectral data.

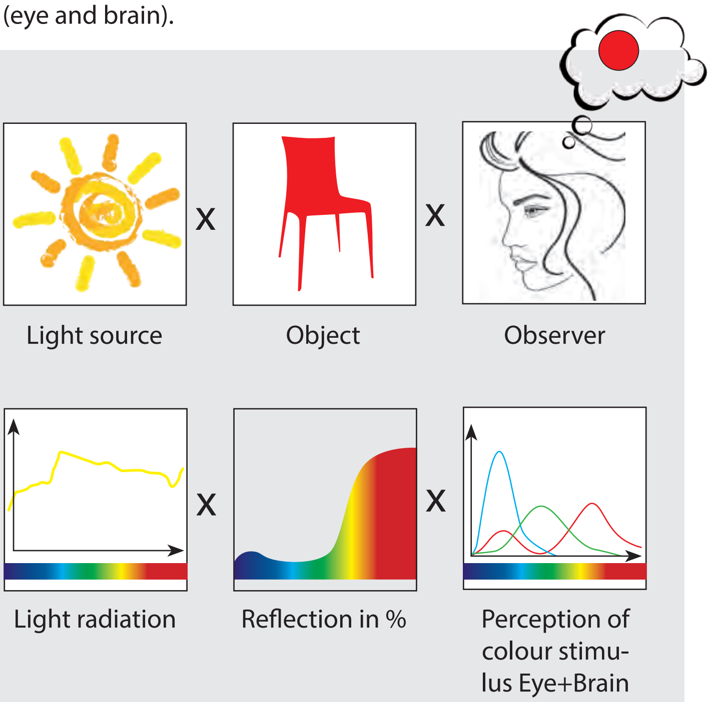
Spectral data are an independent, relative measurement of an object that serves as a fingerprint of the color. This data never changes for the object, and can be used in several different ways.

- A single measurement of the object can be used to calculate the tristimulus values of a color for a variety of Illuminant/Observer conditions.
- Because it can project the tristimulus values for multiple Illuminant/Observer conditions, it can be used to identify whether samples are metameric to one another.
- The data can be used to evaluate color differences between samples and to calculate color recipes for a commercial color matching applications.

Spectrophotometers are simple and fast to operate. Thanks to technological development, these instruments continue to become lighter in weight, making them portable. In addition, prices of industrial spectrophotometers have become quite competitive with traditionally lower-priced tristimulus colorimeters.

The technology of the instruments

Three components are required to generate a numerical description of color: Light, object (sample) and the observer (eye and brain).



The triplet = light source – observer– object

This triplet is found again in the measurement instruments for color measurement. The object remains the same. The light source is implemented with a lamp plus potentially an additional filter. The eye and the observer are simulated by a dispersive system or equipment with a monochromator and connected radiation detector. The object is precisely placed by means of a specimen mount or a sample holder. The measurement geometry specifies how the sample is illuminated and "observed" from the measuring instrument. In a human observer, the brain converts the color stimulus into a color perception. When using a measuring instrument, the task of carrying out the colorimetric calculations is taken over by electronics with signal processing or a computer (microcomputer).

The light source

The light source is located in the instrument. Modern instruments for measuring color generally use one of 3 types of light source –halogen, xenon or LED lamps. They are fitted with a filter to simulate the spectral power output of daylight.

The sensor

The observer is simulated by a light detector. The "eye" of the color measurement instrument depends on the type of instrument. The configuration of the sensor depends on whether a colorimeter or spectrophotometer is used.

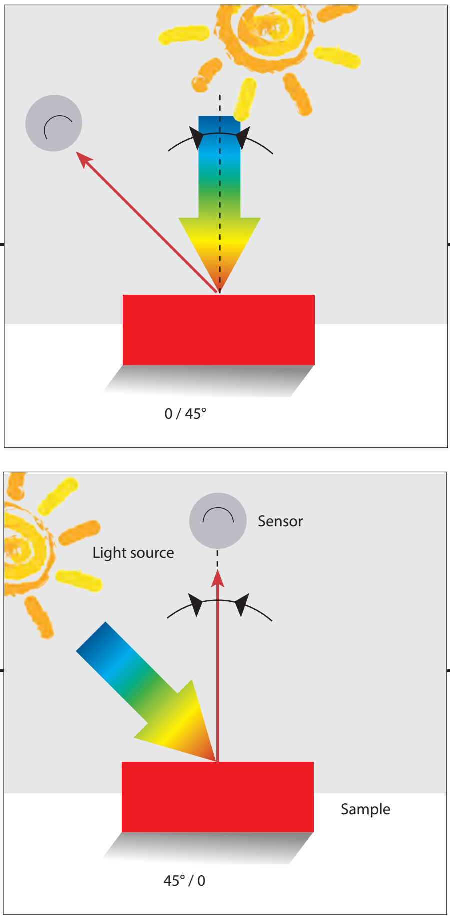
The object (the measurement geometry)

The perceived color of an object depends on the illumination and viewing conditions used. The same object can generate different perceptual experiences of color depending on the angle at which an object is either illuminated or observed. Color measuring instruments are configured to simulate a fixed, specific angle of sample illumination and sample viewing. The measurement geometry defines the angle of illumination and the angle of viewing simulated by the instrument.

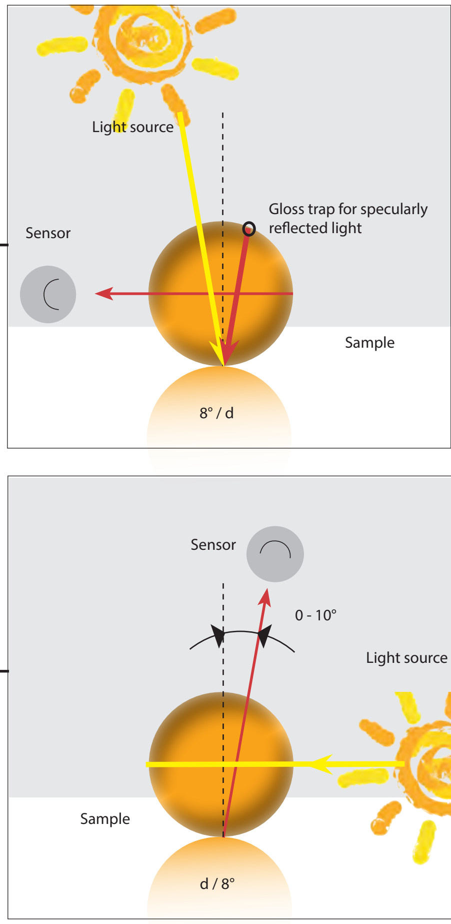
Measurement geometry uses two angles to identify the conditions, for example d/8°. The first angle identifies the angle of illumination and the second angle defines the angle of viewing.

Three measurement geometries are typically used in spectrophotometers:

- Sphere geometry (d/8°). The light reflected /transmitted by the object is collected in a sphere. In this instrument, the object is illuminated by diffuse light (d). This light originates from many different locations around the sphere. The detector is positioned at 8° from the object normal. Some instruments reverse this configuration to 8°/d. In this configuration, the light is located at 8°, and multiple detectors are located around the sphere.
- Angle geometry. The light and the detector are fixed at specific angles in relation to the object. (targeted illumination and observation at fixed angles). The most common geometry used is 0°/45°, or 45°/0° instruments.
  - Measuring instruments using this geometry simulate the natural observation conditions used by humans. This configuration is useful when there are gloss differences between samples. It excludes the gloss component, and often produces an instrumental evaluation that has better agreement with the visual evaluation. This geometry is often used to inspect the color differences between two products that are not made using the same process or materials.
- Multi-angle geometry. There are a category of spectrophotometers that view the sample at variable angles. The angle of illumination is fixed, but the detectors are located at a variety of angles. This measurement geometry is finding its place in procedures used to evaluate effect pigments such as metallic and pearlescent colorants.



Measurement geometry 45° /0°



Measurement geometry d/8°

The area of application determines which measurement geometry is used.

Measurement instruments with angle geometry (45°/0°) use targeted illumination of the sample at an angle of 45° and measure the light reflected by the sample in one direction at 0° (or conversely 0°/45°).

Measurement systems with this measurement geometry observe the sample under conditions similar to those of natural observation by a human. This means that measurements with the angle geometry (45°/0° or 0°/45°) are always taken with the gloss excluded, and therefore result in closer equivalence to the eye's visual impression. This geometry is predominantly used in color control for end products.

Measurement instruments with sphere geometry (d/8°) illuminate the sample diffusely and measure the light reflected by the sample in one direction at an angle of 8° to the vertical position of the sample.

When using a sphere instrument, the specular component may be included or excluded from the measurement. Specular means ‘mirror-like.” Specular reflection is regular; the angle of reflection equals the angle of incidence. The measuring condition you choose depends on your goal regarding differences in sample surfaces. Specular Component Included (SCI) lighting obscures surface differences. Specular Component Excluded (SCE) lighting enhances them.

When an object is measured Specular Component Included, the measurement includes all reflected light regardless of its angle. A pair of samples differing only at their surface yield equal SCI measurements.

A smooth surface reflects more light at specular angles than a rough surface. Excluding the specular component from a measurement of a smooth sample excludes more light than excluding the specular component from a rough surface. Since different amounts of light are excluded, the sample measurements differ. However, surfaces can reflect light regularly or diffusely, so excluding specular reflection does not exclude all surface reflection.

The d/8° geometry is used almost exclusively in applications that require color formula calculations. Most instruments with d/8° geometry also offer the option of measuring the transmission behavior of transparent or translucent samples.

Conclusion

In the last decade, significant advances have been made in the development and production of color measurement systems. In comparison with the instruments available previously, today's modern systems enable reliable measurements with higher accuracy and precision. They are also smaller, lighter and faster. They can be used to measure different sample types, they are more flexible processing data, easy to operate and frequently less expensive than ever before.

The latest color measurement technologies enable communication with digital standards, meaning that the precision of these measuring instruments is so high that virtually no relevant deviation can be detected from one device to another.

Chapter 13

Sample Preparation and Sample Presentation

General

Color measuring instruments are scientific instruments that provide very precise and repeatable results. When you use these instruments you must assure that the sample is prepared correctly, and that it is in pristine condition. If you do not have control of your procedures for sample preparation and sample presentation, you will not realize the benefits of using an instrumental color system.

Sample Preparation

Sample preparation must be consistent. Evaluating color samples instrumentally assumes that every aspect of the samples being evaluated is the same except for the color. The samples must be prepared using standard procedures and equipment. You need to identify all of the variables in the process and make every effort to control each one. Fortunately, you can use the color measuring instrument to evaluate the consistency of your process. The first step is to define both the repeatability and reproducibility limits of your system.

Repeatability refers to the consistency of sample achieved when it is prepared using the same raw materials, the same equipment and the same personnel. It is easy to run a repeatability study. You simply produce the same sample on several different occasions, using the identical raw materials, equipment and personnel. The samples made for the study are then measured and compared. The largest color difference calculated from these samples represents the best performance you can expect from you process. If you are not satisfied with the repeatability, you must analyze each step in the sample making procedure. For example, you may need to increase the batch size used, clean the equipment after each batch, and periodically recalibrate the machines you use.

You must also identify the reproducibility of your process. This identifies the sample consistency achieved when you change an element in the sample processing. It is common practice to change lots of raw materials, the processing equipment or the personnel from one batch to the next. In a reproducibility study, you use the same formula to make a series of samples. For each one, you make a substitution, and evaluate the color differences between the samples. You can substitute a different lot of raw materials, a different piece of equipment or a different technician. This is a practical evaluation because it reflects the day-to-day conditions of your operation. As in the repeatability study, you may find that you need to change your procedures to improve the color consistency from one batch to the next. Throughout both phases of this evaluation, you can use your color measuring instrument to evaluate how any changes you make improve the efficiency of the process.

Sample Presentation

Samples must be uniformly presented to the instrument to ensure quality and consistency. Ideally, the sample should be flat and have a uniform color and texture. You should always carefully inspect the area of the sample that will be viewed by the instrument. Sources of variation can include:

- Impurities on the sample surface. The surface must be free of any contamination. The samples must be cleaned of any dust, grease or film. Fingerprint smudges along often distort the measurement, particularly when working with glossy samples.
- Temperature and moisture. The instrument should be housed in a room that is climate-controlled. Temperature and moisture commonly affect the quality of the measurement. Some pigments and dyestuffs (particularly yellow, orange and red) are thermo-chromatic. These samples change color as the surface temperature changes. When measuring these samples, the temperature must be consistent. Humidity also influences the measurement results, especially for textile samples.









- Pressure, thickness, strain, mechanical factors, etc. Precise sample presentation for the measurement of powders, e.g. calcium carbonate, talc, etc., is especially important. Moisture and pressure have a significant influence on the color achieved when these materials are compressed.

The following recommendations will help you to more closely control the variables in sample preparation and presentation:

- Adopt a sample preparation method that is both repeatable and reproducible.
- Institute a procedure for sample presentation to the instrument.
- Select representative samples. Reject samples that are outliers in terms of visual appearance.
- When working with non-uniform surfaces, you can make several scans and generate an average measurement. Most color measuring instruments can be easily configured to make multiple measurements of a single sample.
- Document a quality assurance procedure for both sample preparation and sample presentation. These procedures should be adopted and referenced by all parties in the supply chain.

Final comments

Machine-based color evaluation systems are widely used to design, manufacture and inspect product color. These systems are based on the fundamental principles of the science of colorimetry. However, because color perception is a psycho-physical experience, these systems have some practical limitations. The eye/brain combination is far superior to any computer-based system when it comes to processing and interpreting all of the data that constitutes the perception of color. A colorist needs to understand the nuances of the science, and the limitations of applying the instrument/machine interface to evaluate color acceptability.

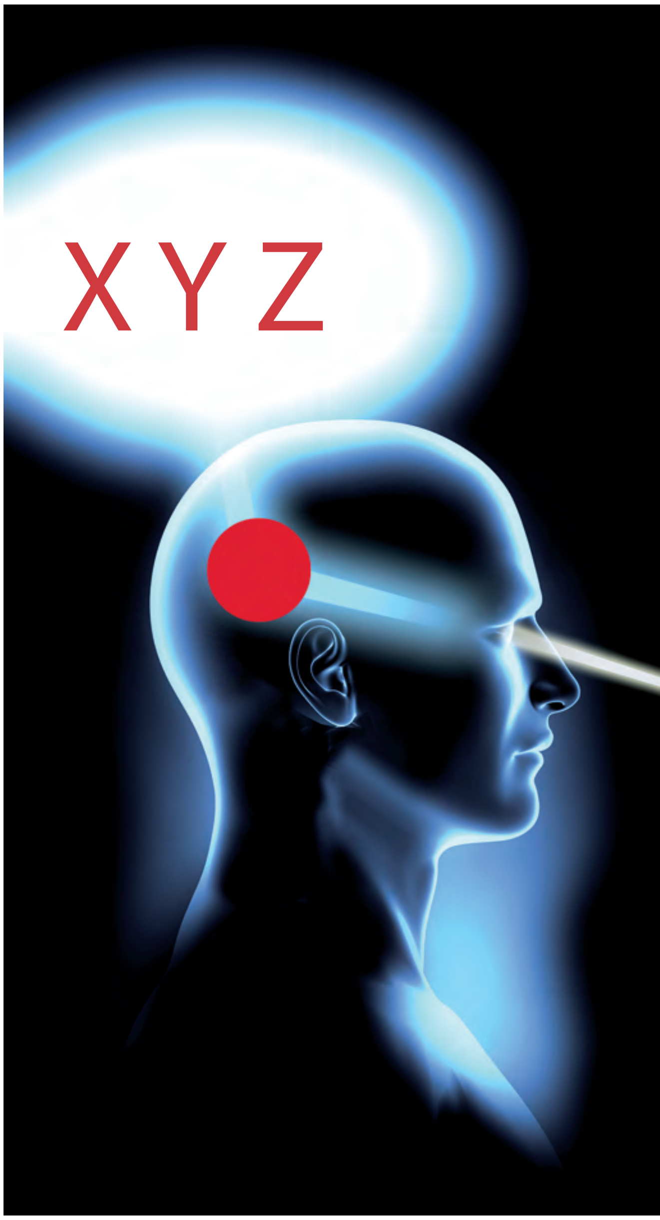
Success with instrumental color control systems requires you to closely control the process you use to prepare and evaluate the samples. You will have limited success until you standardize your tools, processing and measurement methods.

- Tools. Carefully select the hardware (instrument/computer system), color space and color tolerancing systems to use. You may find that you will need to make selections for different products and or different customers.
- Processing. You must be specific about sample size, mixing, processing and curing techniques, and equipment maintenance. The process must be reproducible.
- Measurement. The surface of the sample must be uniform and free of contaminants.

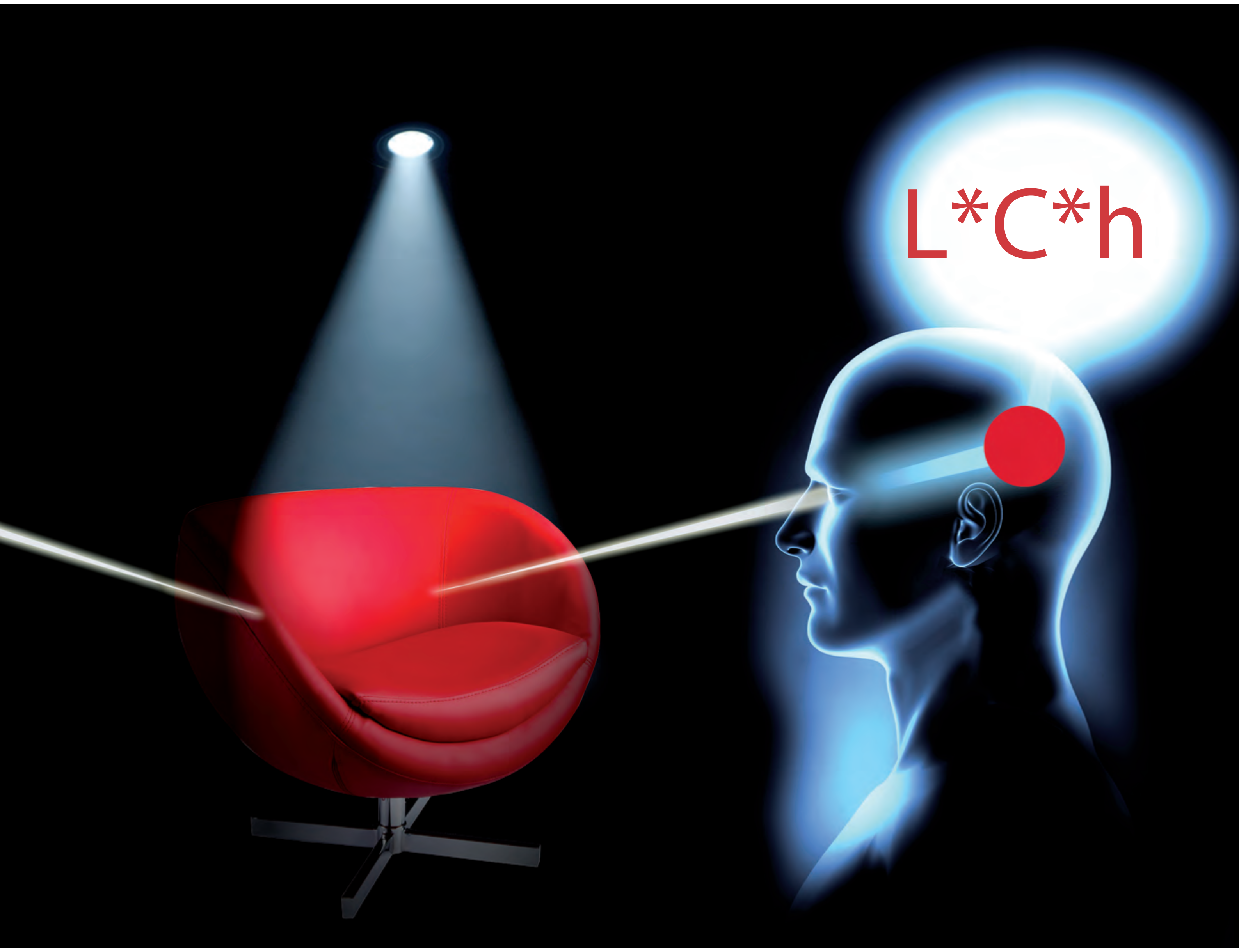
Once you've established these standards, you must use them consistently.

Finally, you must also understand the limitations of this technology. Machines can measure and calculate, but do not rival the power of the eye/brain combination to evaluate a color. Keep these guidelines in mind when you are evaluating colored samples quantitatively:

- Never stop looking at your samples.
- When there is a discrepancy between the numerical and visual evaluations, look beyond DE to try to find an answer. When you look closely at the components of the numerical evaluation, you may find the source of the discrepancy.



- When you are unable to support the visual evaluation with the numerical evaluation, the visual evaluation prevails. The end user does not accept/reject a colored product based on a set of numbers. In the final analysis they look at the samples to decide acceptability.



Color measurement means communication

While the science of colorimetry has transformed the specification, manufacture and evaluation of color from an art to a science, the most successful colorists are constantly trying to better understand the nuances of the science and the limitations of the application. We hope that this document has provided a useful introduction to the fundamental tools of colorimetry, and has provided additional insight into the application of this technology in the evaluation of colored products.

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Telephone: 1-800-982-6497 | Fax: 609-895-7472 | marketing@datacolor.com | www.datacolor.com

Text:
Gabriele Hiller, Hiller Direct Marketing, Stühren 41, 27211 Bassum, Germany
www.hiller-direct-marketing.de

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EUROPE
Datacolor AG Europe
6343 Rotkreuz
Phone: +41 44.835.3800

AMERICA
Datacolor Headquarters
Lawrenceville, NJ
Phone: +1 609.924.2189

ASIA
Datacolor Asia Pacific Limited
Hong Kong
Phone: +852 24208283

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