H36: Instrument Assessment of Colour Difference

Instrument based methods of judging the colour appearance measure the colour co-ordinates of the test and of the standard panel and then determine the total colour difference dE*, and the component differences dL* (lightness) dC* (intensity of colour) and dH* (hue).

CIE L*a*b* Colour difference

Determination of dE*

The CIE L* a* b* system includes an equation for the total colour difference between a trial and standard sample. The total colour difference is the distance between the two points representing those colours in the colour space as illustrated in Figure 1.

The distance, expressed as dE*, is determined using the laws of right angled triangles.

$$dE^* = \sqrt{dL^{*2} + da^{*2} + db^{*2}}$$

Where

$$dL^* = L^*_{Trl} - L^*_{Std}$$
$$da^* = a^*_{Trl} - a^*_{Std}$$
$$db^* = b^*_{Trl} - b^*_{Std}$$

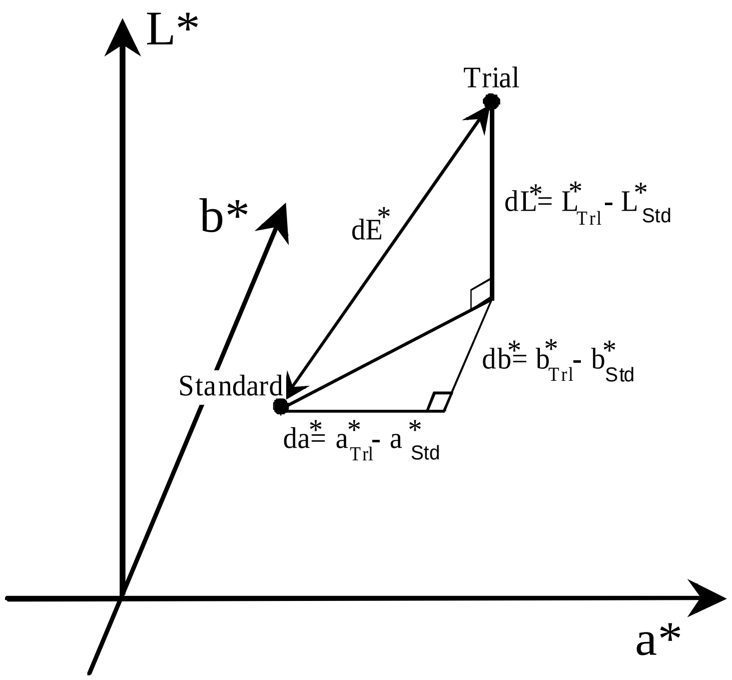

*Figure 1: CIE L*a*b* colour difference*

It is worth remembering that the scaling of the colour space is such that a distance of 1 between the points representing the colour of two samples should be just visually perceptible. This means that if a large number of people were asked to judge two samples with dE* = 1, about 50% of observers would say that there was a difference in colour, the other 50% would say the two colours matched. An example calculation is given later.

Interpretation of dE*

The following is a guide to the interpretation of CIE L* a* b* colour difference values.

$dE^* < 0.8$	the trial is an acceptable colour match to the standard
$0.8 \le dE^* \le 1.2$	the trial is a possible colour match to the standard
$dE^* > 1.2$	the trial is not a colour match to the standard

In practice a customer and a supplier would include a dE* limit as part of the colour specification of the object. The limit could be larger than 1.0 or smaller than 1.0, depending on the type of product and the importance of obtaining an accurate colour match to the standard.

Reliability of a dE* < 1 pass/fail limit

The correct answer as to whether a trial colour matches that of the standard is the majority decision of a group of colourists. An instrumental assessment based on the condition that dE* must be less than 1 for a match, will disagree with the majority about 19% of the time. Instrumental judgements made this way are no more reliable, on average, than judgements made by a colourist.

The instrumental method has the advantage of being repeatable, most instruments and sample pairs can be measured with a repeatability of dE* to better than ± 0.20.

Colour difference splitting dL*, dC* dH*

Splitting the total colour difference (dE*) into differences:
in lightness (dL*);
in chroma (dC*);
in hue (dH*),
as shown in Figure 2, is a great aid to the interpretation of the nature of a colour difference.

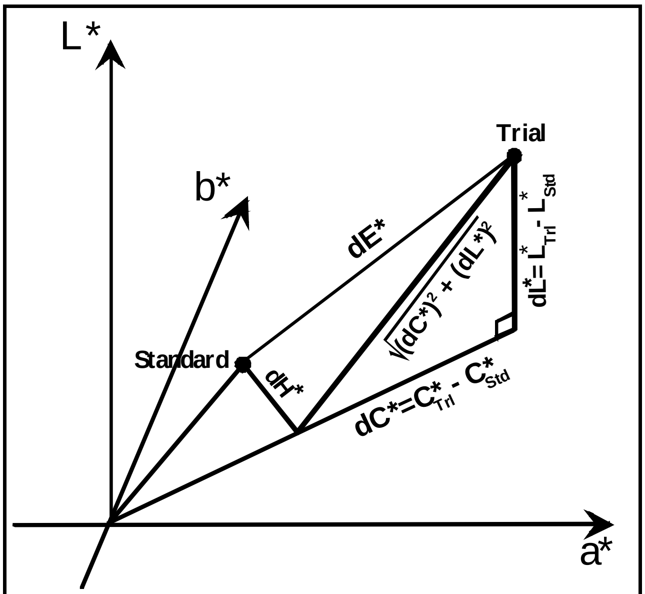

Figure 2: dL dC* dH* Colour difference splitting*

Calculation

Total difference $dE^* = \sqrt{dL^{*2} + da^{*2} + db^{*2}}$

Subtracting the contributions of the lightness (dL*) and chroma (dC*) differences from the total colour difference (dE*) leaves the hue difference (dH*).

Lightness difference	*Chroma difference*	*Hue difference*
$dL^* = L^*_{Trl} - L^*_{Std}$	$dC^* = C^*_{Trl} - C^*_{Std}$	$dH^* = \sqrt{dE^{*2} - \left(dL^{*2} + dC^{*2}\right)}$

The hue difference equation cannot provide a sign for the value of dH*. The convention is that it takes the same sign (±) as the difference between the hue angles of the trial and standard.

If $h^o_{Trl} - h^o_{Std} > 0$ then dH* is positive

If $h^o_{Trl} - h^o_{Std} < 0$ then dH* is negative

Interpretation

dL*, lightness difference

$-0.50 < dL^* < 0.50$	the trial is the same lightness as the standard.
$dL^* \geq 0.50$	the trial is lighter than the standard.
$dL^* \leq -0.50$	the trial is darker than the standard.

dC*, chroma difference

$-0.50 < dC^* < 0.50$	the trial is the same chroma as the standard.
$dC^* \geq 0.50$	the trial is more intense (stronger) than the standard.
$dC^* \leq -0.50$	the trial is less intense (weaker) than the standard.

dH*, hue difference

$-0.50 < dH^* < 0.50$	the trial is the same hue as the standard.
$dH^* \geq 0.50$ or $dH^* \leq -0.50$,	the trial is a different hue to the standard.

Hue difference description

The hue difference is described using one or more of the primary hue names yellower, greener, redder or bluer. For example if an orange coloured standard is considered then the trial will be described as either yellower or redder than the standard.

The CIE L*a*b* system provides a method of obtaining the hue difference description from the positions of the trial and standard on the a* b* plane. An arc is imagined drawn from the position of the standard to the trial and then continued on around the hue circle. The hue associated with the first axis crossed by the arc is quoted followed, enclosed in brackets, by the hue of the second axis crossed. This is illustrated in Figure 3 and Figure 4.

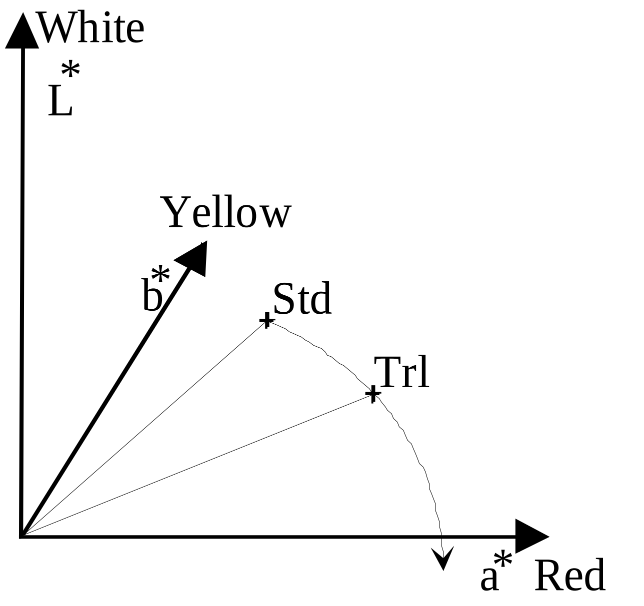

Figure 3: Trial is redder (bluer)

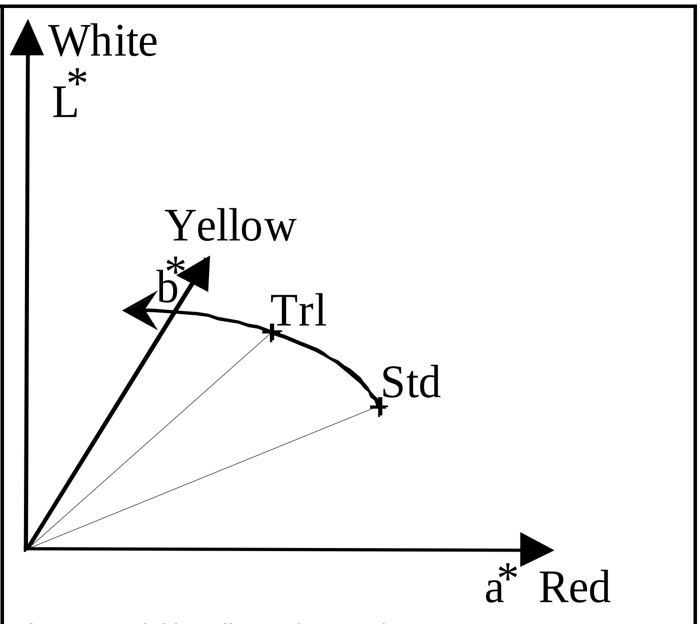

Figure 4: Trial is yellower (greener)

The appropriate hue difference terms are those neighbouring the standard in the hue circle, as shown in Table 1.

Table 1: Hue difference terms

Hue of standard	*Hue difference terms*	*Hue of standard*	*Hue difference terms*
Red	Yellower or bluer	Green	Bluer or yellower
Orange	Yellower or redder	Cyan	Bluer or greener
Yellow	Greener or redder	Blue	Redder or greener
Lime green	Greener or yellower	Magenta	Redder or bluer

Example colour difference calculation

Name	L*	a*	b*	C*	h°
Standard	53.68	-9.20	-36.56	37.70	255.9
Trial	54.90	-10.02	-35.50	36.89	254.2
Difference	1.22	-0.82	1.06	-0.81	-1.7

Total dE* = 1.81, trial does not match the standard
Lightness dL* = 1.22, trial is lighter than the standard
Chroma dC* = -0.81, trial is more intense (stronger) than the standard
Hue dH* = -1.07, trial is greener (yellower) than the standard

Setting pass/fail tolerance values

A reliable method of assessment of colour difference is important for both scientific and economic reasons. The incorrect rejection of a batch of material has the consequence of extra cost and time in unnecessary colour correction. Costs are also incurred if a batch is incorrectly accepted at an early stage in a process and then found unacceptable after further steps in manufacture have been carried out.

Consider the case of a manufacturer making repeated batches of a product based on matching to the same standard colour. The small variations in the manufacturing process will produce batches whose colour co-ordinates in L* a* b* space will lie in a small volume surrounding the standard. Some of these batches will have been judged visually as an acceptable match to the standard colour and others rejected.

It is possible to imagine drawing a smooth, three-dimensional surface around the standard such that the majority of points representing accepted batches lie within the volume enclosed by the surface. This is known as an acceptance ellipsoid since, on average, the shape of the volume is ellipsoidal. Extensive investigation has shown that the shape, size and orientation of the acceptance ellipsoid in CIE L* a* b* space varies with the colour of the standard.

The CIE L*a*b* colour difference equation assumes, irrespective of the colour of the standard, the acceptance volume is a sphere of radius 1 unit. Unfortunately pass/fail decisions based on the CIE L*a*b* (1976) equation with a limit of dE* = 1 are, on average, less reliable than visual judgements made by a single colourist. The simplest method of improvement is to assign individual tolerances either to dL*, da* and db* or to dL*, dC* and dH*.

dL* da* db* acceptance limits

The colour of the standard is measured and plotted in colour space as shown in Figure 5. In this case the standard is a medium lightness, intense, cyan blue colour.

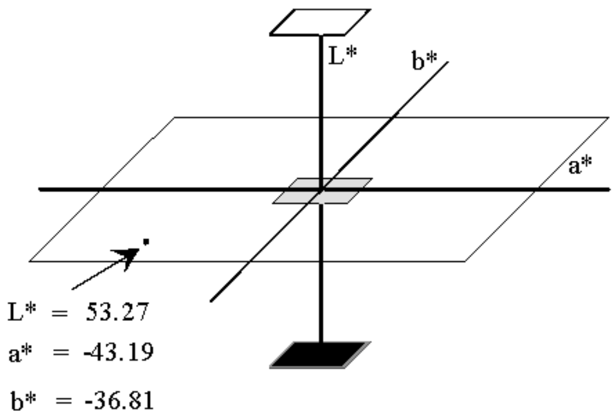

*Figure 5: Standard in CIE L*a*b* colour space*

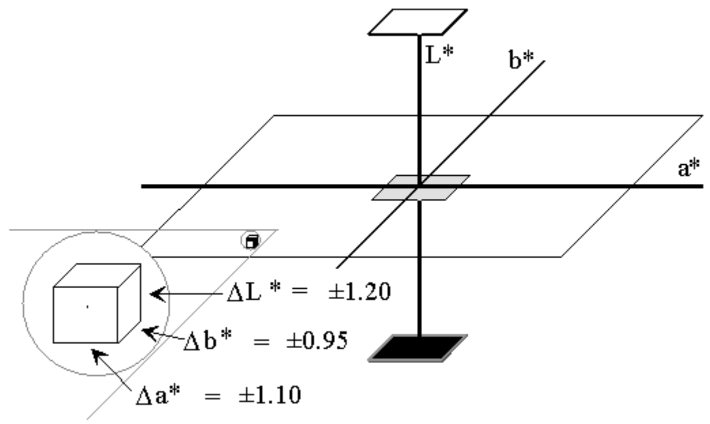

Figure 6. dL, da*, db* acceptance volume*

The assignment of individual tolerances to dL*, da* and db* defines a rectangular box around the standard as illustrated in Figure 6. The orientation of the sides of the box, parallel to the L* a* b* directions, is the same for all positions of a standard in colour space.

If the limits have been set correctly then batches with colour co-ordinates that lie within the box would be judged as acceptable colour matches to the standard. The utility of such a tolerance volume can be assessed by comparing it with the shape of the acceptance ellipsoid.

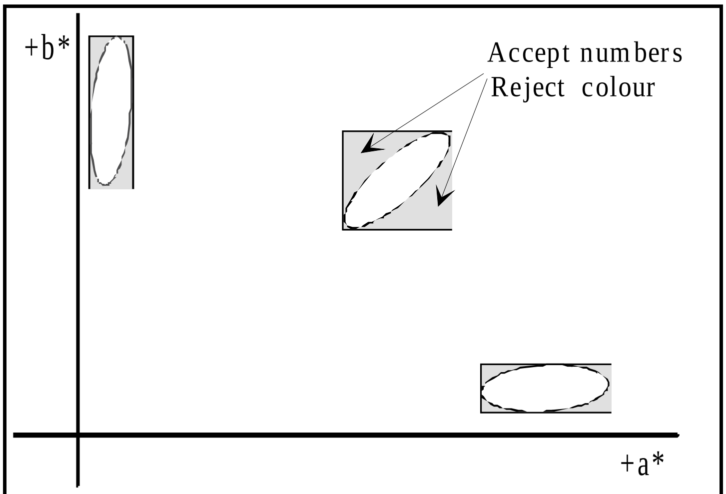

Figure 7: Magnified acceptance ellipsoid areas in the a b* plane superimposed on the da* db* tolerance limits*

Figure 7 illustrates this process by considering just the hue plane, a* b*. In this plane the true acceptance regions are ellipsoid shaped areas roughly oriented towards the neutral point (0, 0). The tolerance limits, da* and db*, define a rectangular area that encloses the area of true acceptance and also a significant region in which colours should be rejected. The reliability of instrumental pass/fail judgements based on setting individual tolerances for dL*, da* db* is better than CIE dE* judgements, but by no means the best that can be obtained.

dL* dC* dH* acceptance limits

The system where individual limits to dL*, dC* and dH* are set is shown in Figure 8. The acceptance volume is similar in shape to that shown in Figure 6, but has a different orientation. The orientation of the dL* dC* dH* acceptance volume relative to the L* a* b* axis changes as the standard moves in colour space, as illustrated in Figure 9.

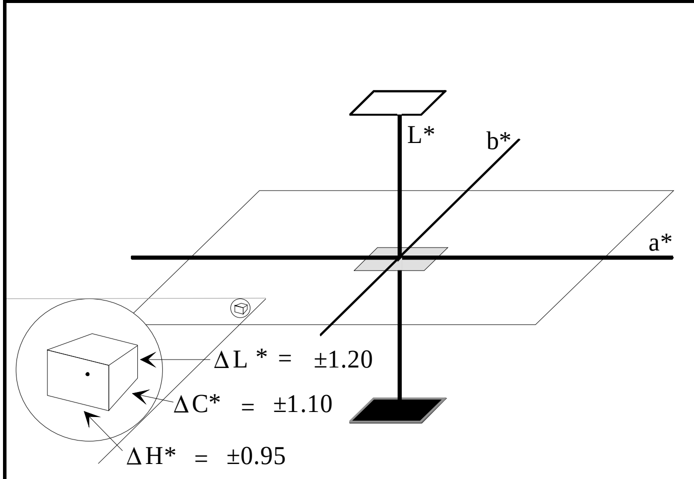

Figure 8: The acceptance volume based on dL, dC*, dH* limits*

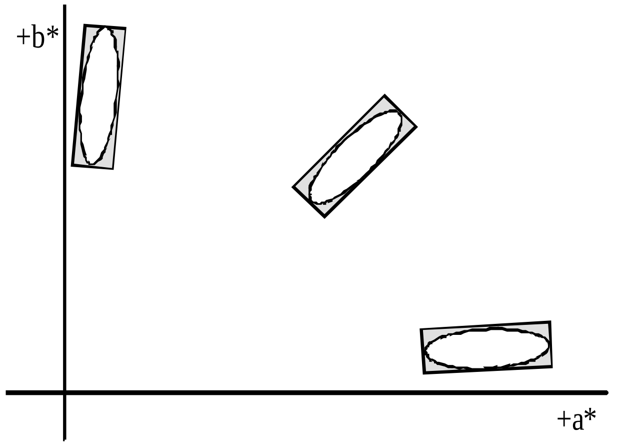

Figure 9: Magnified acceptance ellipsoid areas in the a b* plane superimposed on the dC* dH* tolerance limits*

It is clear from Figure 9 that the tolerance area defined by limits dC* and dH* will still include an area in which colours should be rejected. However, the size of this "incorrect decision" area is less than that when tolerances are based on da* db*, (illustrated in Figure 7). The change in orientation of the dL* dC* dH* tolerance volume with position of the standard is similar to the change in orientation of the acceptance ellipsoid. Therefore pass/fail judgements based on dL*, dC* and dH* tolerance limits are significantly more reliable than those based on dL*, da* and db*.

Colourist terms versus colorimetric terms

The terms used routinely by people working in the colour using industries are often different from the set defined by the CIE. Typically the Lighter-Darker judgement is retained, a second adjective pair is used to describe a coloration strength difference and a third pair is used to describe a difference in the purity of the colour.

It is often possible to associate the use of these terms with particular directions of colour difference on a plot of dC* versus dL*. The position of the standard is at the origin and the trial is represented by the point dC*, dL*. This is illustrated for the paint and the textile industry in Figure 10 and Figure 11 respectively.

The use of the word pair stronger/weaker often leads to confusion. Colourists in the paint and ink industries use the pair to describe an excess or deficit of colorant in the trial compared to the standard, whereas the CIE use the pair to describe a higher or lower chroma of the trial compared to the standard. In some trial-standard comparisons the two judgements would agree while in others they would not.

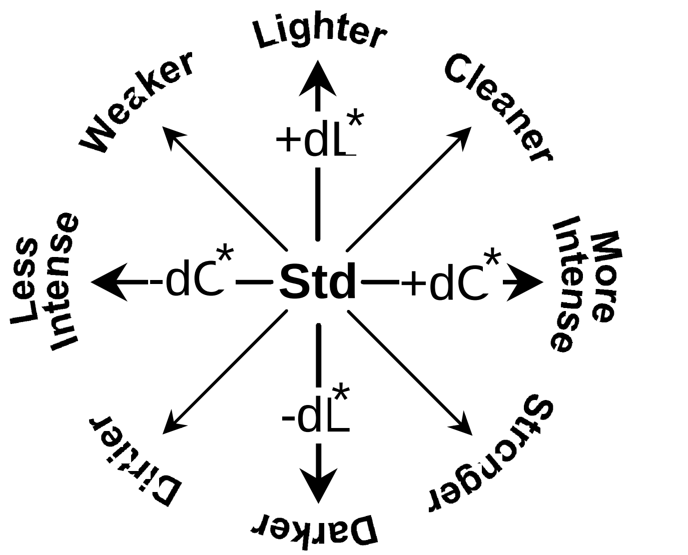

Figure 10: Colour difference terms used in the paint and ink industries

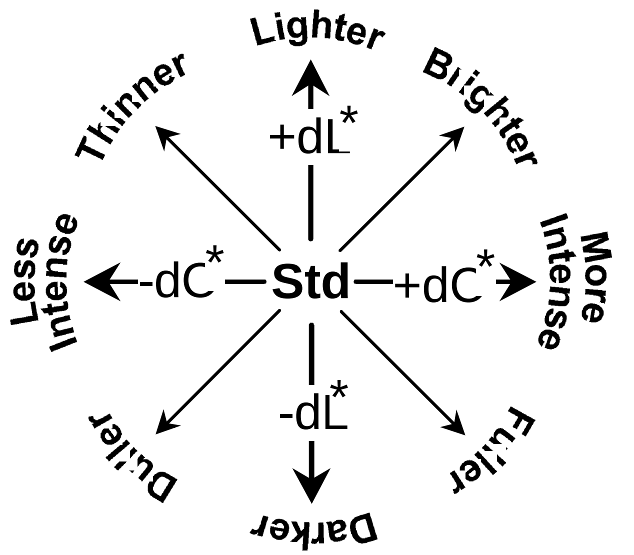

Figure 11: Colour difference terms used in the textile industry

Figure 12 illustrates the changes in L* and C* that occur when either blue colorant is added to a white paint or increasing amounts of blue dye are applied to a fabric.

Initially the value of L* decreases as C* increases (case 1). In this region the colorimetric and the colourist's terms for the difference between the standard and trial shown would agree.

Eventually C* reaches a maximum value and further additions of colorant will decrease both L* and C*, as illustrated by case 2.

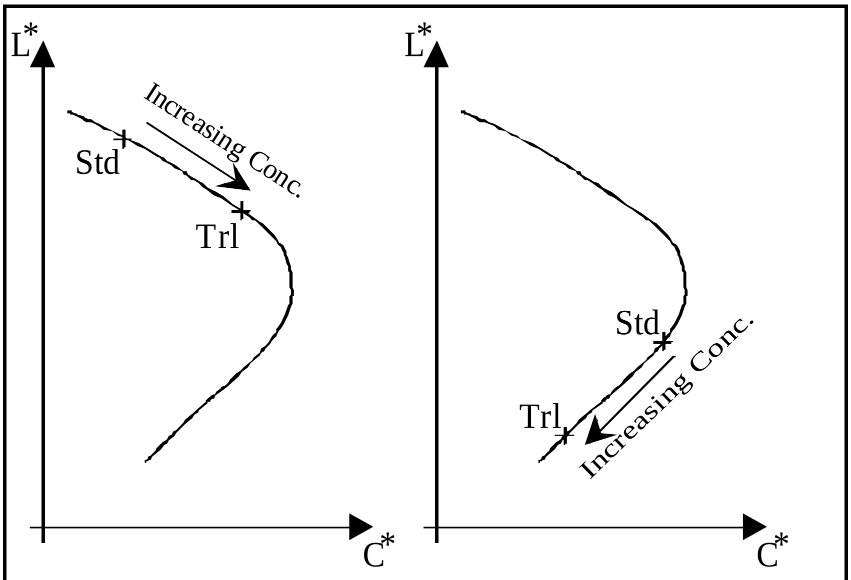

Figure 12: Case 1 (left) colourist's and colorimetric terms agree. Case 2 (right), terms disagree

In case 2, the colourist would still describe the trial as stronger than the standard, however in terms of the numerical chroma difference (dC* < 0), the trial is judged less intense (weaker) than the standard.

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