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Colour tolerance for liquid coatings

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Introduction

Ensuring colour consistency between the standard and a batch is a fundamental task in coloured goods manufacturing, which is achieved through the colour matching evaluation[1]. For this purpose, the determination of acceptable tolerances is essential to allow a clear and accurate colour communication and to avoid customer complaints. The study reported in this paper attempted to identify a reliable method to define colour tolerance limits.

One of the limits of every colour representation model is that an Euclidean global colour space cannot be uniform at the same time in term of both hue and chroma differences[2]. Additionally, a tolerance measure based only on the ΔE value does not take into account that this difference could be due to variations along a single or multiple coordinates at once[3]. As a consequence, there is, by necessity, an unsatisfactory correlation between instrumental (ΔE) and visual (ΔV) tolerances.[4]

The most accurate representation of the limits of colour perception in the CIE colour space has the shape of an ellipsoid, defined as: "*the standard deviation of the boundaries around a colour target* (*centre point of the ellipsoids*) *on the CIE colour space, where all the colours within are indistinguishable to the average human eye*"[5]. (Figure 1)

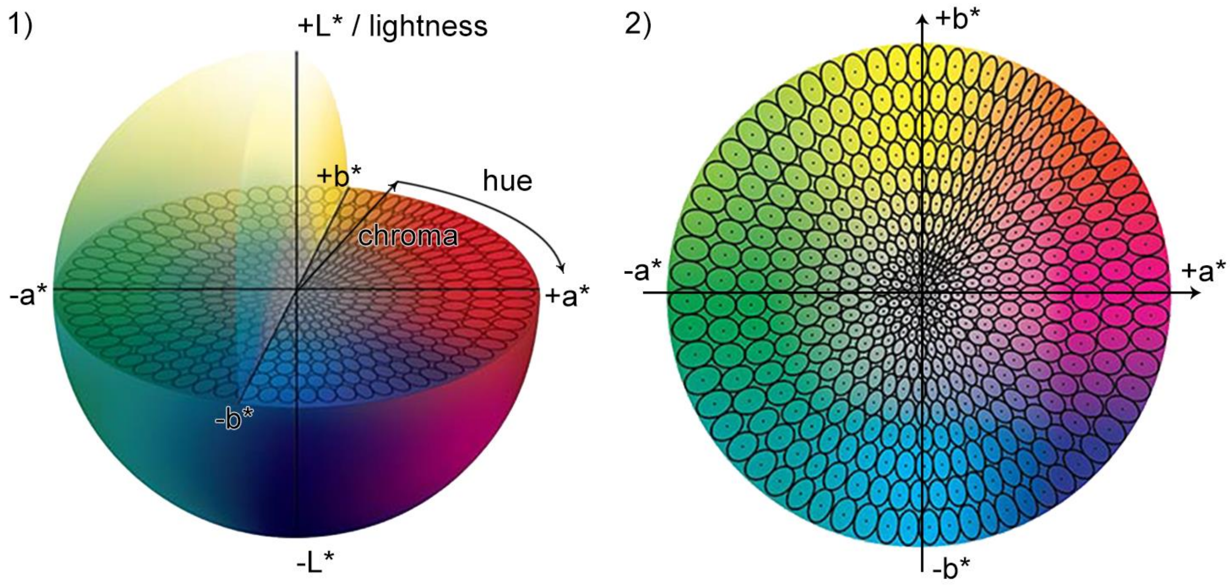

Figure 1 – Tolerance ellipsoids in the CIELab colour space[6]

Studies on the perceptibility and acceptability of colour variations in the CIELab colour space have revealed that changes in hue, chroma and lightness produce variations in the size and shape of the tolerance ellipses according to the following rules:

- human observers tolerate smaller differences in hue;
- human observers perceive variations in chroma as more acceptable than the equal variations in hue;
- the most acceptable differences are those in lightness;
- differences in lightness are less perceptible in bright colours than in darker ones[7].

Nowadays, anyway, it is evident that the most significant influence on the acceptable variability is due to the observers[8]. Genetic variability in the observer panel[9], the presence of visual texture in effect coatings[10], the experience of the observers and psychological aspects can influence the final response. Unfortunately, the mechanisms by which the psychophysical variables influence the observers' perception of colour appearance is still unknown[8].

As a complete agreement between instrumental and visual tolerances is unrealistic, what this work proposes is a method to achieve the closest one.

Materials

For this study, two samples of water based liquid coatings were chosen, a glossy low chroma green sample and a glossy bright orange sample. From these, new standards (G_{Std} and O_{Std}), with increasing white and red percentages, were formulated to allow variation along the negative direction on the L* and a* axes. The content of pigments in the formulations of the two standards, expressed in terms of percentage by weight of the coating sample, are shown in Table I. For each colour centre, the relative batches were prepared to obtain a comparable range of instrumental ΔE along each semi-axis. Relevant formulations are reported in Table II and Table III. Coated panels were prepared on drawdown charts using a number 8 K-hand bar coater (100 μm wet film thickness), which were allowed to completely dry at ambient temperature.

Table I - Pigments content of the standards

	Pigment content			
Colour centre	*Blue*	*Yellow*	*Red*	*White*
Green	2.80%	6.20%	26.10%	38.80%
Orange	0.02%	23.66%	30.65%	91.72%

Table II - Green batches formulations (percentage by weight of the coating sample)

Semi-axis	***Pigment variation***							
+ *L**	% added white	2	5	7	10	15	20	30
- *L**	% subtracted white	2	8	10	12	15	20	30
+ *a**	% added red	1	2	5	8	10	15	23
- *a**	% subtracted red	3	5	8	10	12	15	25
+ *b**	% added yellow	2	5	7	10	12	15	20
- *b**	% added blue	2	3	4	5	8	10	15

Table III - Orange batches formulations (percentage by weight of the coating sample)

Semi-axis	***Pigment variation***							
+ *L**	% added white	5	10	20	30	40	50	60
- *L**	% subtracted white	10	20	30	45	60	75	90
+ *a**	% added red	2	5	7	10	15	20	38
- *a**	% subtracted red	2	5	10	15	20	25	30
+ *b**	% added yellow	2	5	10	15	20	30	45
- *b**	% added blue	4	10	20	30	35	40	50

Methodology

Instrumental measurements

The colour difference between each standard and its related 42 batches were instrumentally assessed with a Datacolor Check 3 portable spectrophotometer. The measurements were repeated three times for each sample and the ΔL^*, Δa^*, Δb^* and ΔE_{Lab} between the standard and each batch of the correspondent relevant set calculated.

Visual assessment

A standard colour-matching light booth was used. The two panels of the sample pair were placed side by side on a 40x60 cm neutral grey background. Below these was placed a standard grey scale supplied by the Society of Dyers and Colourists. A 45/0 viewing geometry was adopted, with the observer positioned at an approximate distance of 40 cm from the panels. The colour difference assessment was carried out under a D65 light source. Within each set of the batches (e.g. green to yellow set, orange to red set), the samples were randomly presented for the evaluation of the colour difference. In order to qualify the perceived colour difference, the observers (in total 10 university students with normal colour vision) were asked to associate each sample pair to a graded pair in the grey scale which they considered of a similar overall colour difference. The observers were then also asked whether they considered that difference commercially acceptable or not acceptable, by assigning either 0 (acceptable) or 1 (not acceptable) to the two responses.

Correlation of the visual assessment results with the instrumental data

A logistic regression model[11] was used to carry out the correlation and the statistical analysis. The instrumental ΔE was used as independent variable, the dependent one, instead, was expressed using the 0 and 1 values. The statistical analysis was performed using the R statistical software (version 3.5.1)[12].

Results and Discussion

Visual and instrumental data correlation

For each analysed colour, six colour centre plots were obtained, each relating to a set of batches representing the colour variations along one of the semi-axes of the colour space (Figures 2 and 3). From the intersection of the horizontal line at y = 0.5 with the logistic regression curve, it was possible to determine the ΔE correspondent to the case in which a sample had a 50% probability to be rejected or accepted by the average observer. This was considered as the acceptable ΔE tolerance for each tested batch.

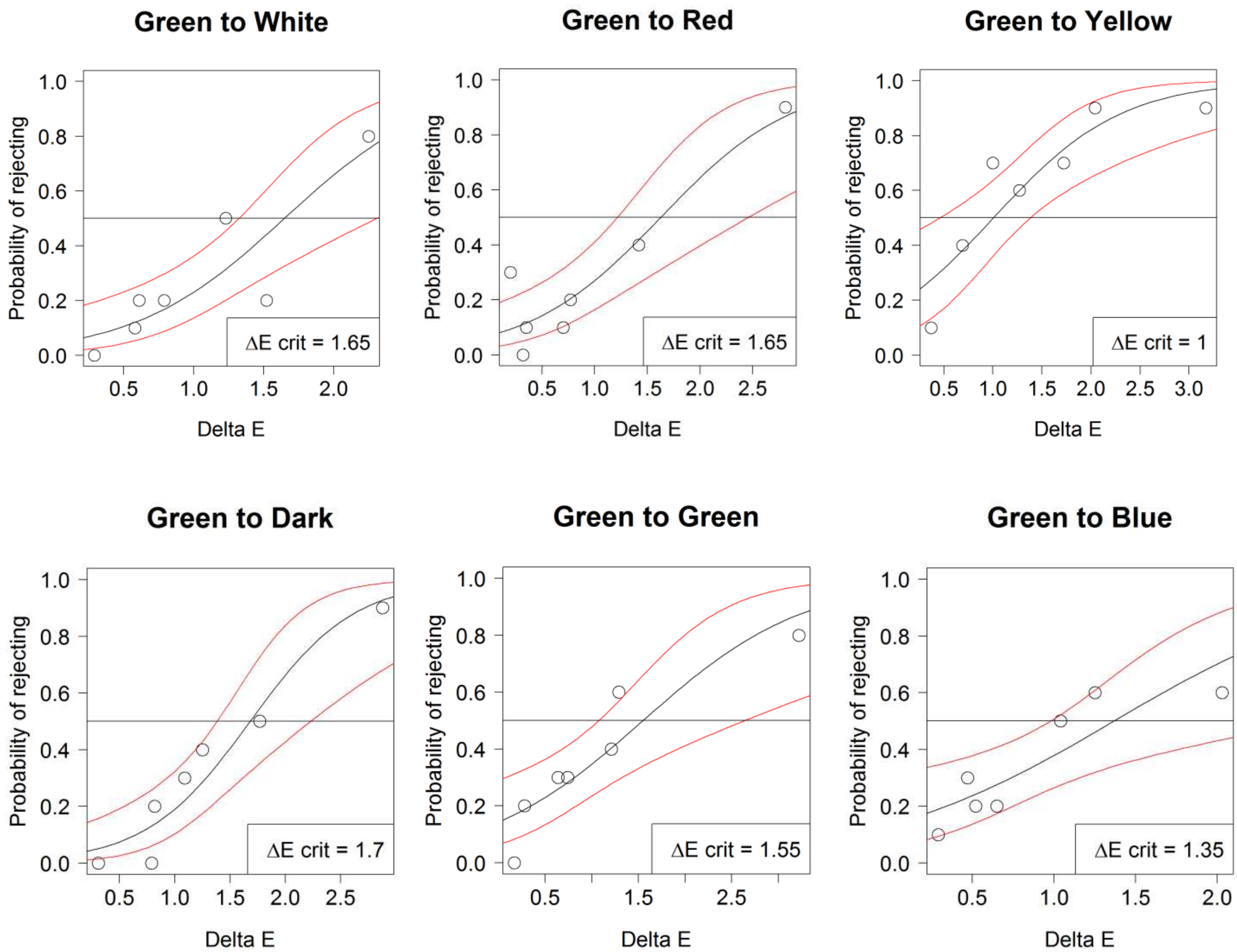

Figure 2 – Colour variations of the green low chroma centre along the axis of the colour space

Looking at the graphs related to the colour variation for the green coating (Figure 2), it can be seen that the scales of the axes of the tolerance ellipsoid for the considered green colour centre increase following the order b* < a * < L*. In particular, the highest tolerance limit can be identified for variation along the negative direction of L* axis and the smallest one for variation along the positive direction of b* axis.

In the case of the orange samples (Figure 3), it is possible to notice a significant variability in the observers' responses.

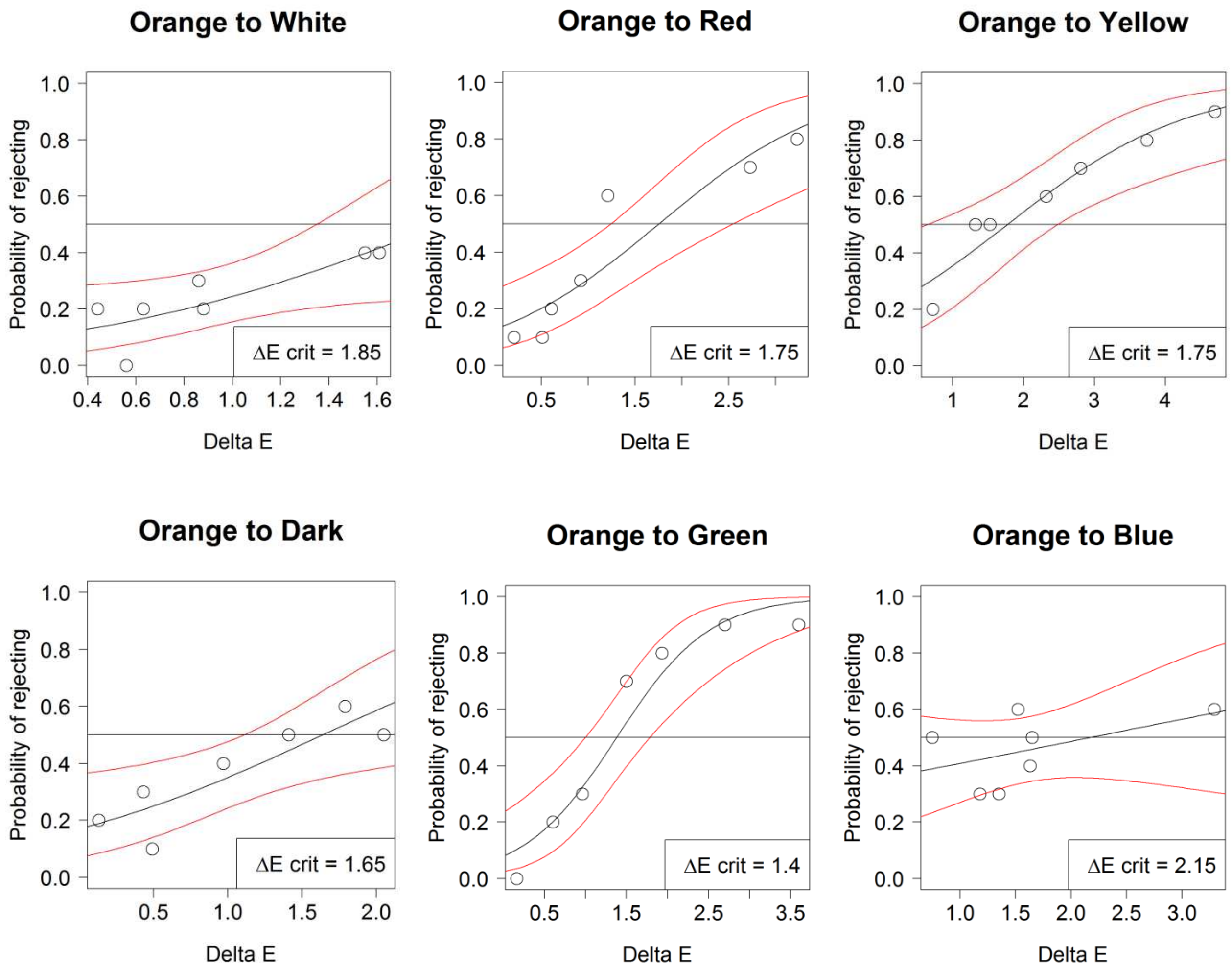

Figure 3 – Colour variations of the bright orange chroma centre along the axis of the colour space

Considering the variation along the positive direction on the L* axis (towards white), it was not possible to identify the ΔE limit because it was higher than the ΔE of the tested batches. Nevertheless, it is possible to identify the smallest tolerance limit for the variation in the negative direction of the a* axis. Moreover, the smallest axis of the tolerance ellipsoid in this case has been identified as the red-green axis.

In light of the statistical analysis, it has to be considered that the estimation of the ΔE values, reported here, cannot be considered entirely reliable. This is probably due to the small number of observers that participated in the psychophysical experiment and to the fact that they had not been trained in the assessment of colour difference. Nevertheless, the methodology established through the study reported here is a valid one that forms a basis for future studies.

Conclusion

The colour space, on which the instrumental calculation of the colour tolerance is based, is not perceptively uniform and so not perfectly correlated with human perception of colours.

From the work reported here, it became clear that size, shape, orientation and distribution of the tolerance ellipsoids for liquid coatings in the colour space are different form theoretical ones. The reliable tolerance limits for the low chroma green, the bright orange and, in general, all liquid coatings need to be set by measuring and assessing the ΔE tolerance separately along each colour coordinate. By doing so, it would be possible to take in to account all possible variations of the tolerance ellipsoids along the different directions of the colour space.

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