Surround – the New Background?

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Abstract

Reproducing colour transparencies on hard copy is a common cross-media reproduction task, in which the original and reproduction have different viewing conditions. Colour appearance models CIECAM97s and CIECAM02 have not been successful at predicting the effect of the different viewing modes, partly as a result of ambiguities over the effects of surround and background.

New values were derived for surround parameters *c* and *Nc*, which gave an improved prediction of the appearance of the transparency. Also evaluated was a function which weights the surround and background luminances by the distance from the stimulus in determining the background luminance factor *Yb*. Although this technique yielded a small improvement in the prediction of the transparency appearance, it was not significantly better than the grey world assumption which sets *Yb* to 20%.

Introduction

In graphic arts colour reproduction, original images are compared with proofs and final reproductions under controlled viewing conditions. In a transparency to print workflow, the transparency is viewed on an illuminator to compare it with a reflective print which is placed in a viewing booth.

It emerges that there is a degree of ambiguity in the way that the surround and background are defined, that makes it difficult to apply CIECAM97s or CIECAM02 to this workflow. The purpose of this paper is to verify the parameters used in models of colour appearance (in particular the surround and background parameters) to predict the effect of the surround in a transparency-to-print workflow, and to attempt to point up where these ambiguities lie.

Viewing transparencies and reflection prints

ISO 3664:2000 [1] specifies the conditions under which prints and transparencies should be viewed. Conditions P1 and T1 are defined for critical appraisal of print and transparency respectively. The illumination of the two media are specified in such a way that the luminance of the clear film of a transparency (with an assumed highlight density of 0.3) is a close match to the luminance of a perfect diffuser viewed by reflection. The luminance and illuminance values given in ISO 3664 thus correspond to approximately 635 cd/m^2 for both transparency highlight and diffuse white reflector.

Table 1 ISO 3664 viewing conditions for viewing prints and transparencies

ISO 3664 viewing condition	T1	P1
Chromaticity	D50	D50
Chromaticity tolerance	0.005	0.005
Luminance /illuminance	1270 cd/m^2	2000 lux
Luminance tolerance (preferred values in parentheses)	± 320 (± 160)	± 500 (± 250)
Surround	5-10%	<60%

Figure 1 illustrates the viewing mode for colour images in the ISO 3664 T1 and P1 conditions for the transparency and print respectively. The transparency is viewed against the black film rebate and an opaque black card used to mask the illuminator, while the print image is viewed against the uniform grey surround of the viewing cabinet. An image on a page of mixed content will typically have an unprinted border around it, and it is common to include such a border in psychophysical experiments to permit the observer to adapt to the media white.

The difference luminances of the viewing fields affects the perceived lightness and colourfulness of the stimuli, This effect has long been known [2, 3, 4] and included in models of colour appearance [5, 6, 7, 8]. Transparencies are exposed and processed so that they have an 'objective gamma' [9] or log luminance relative to log scene luminance of approximately 1.5, so that when they are viewed against a dark background the tone reproduction characteristic compensates for the effect of the viewing condition.

In a cross-media colour reproduction workflow, the aim is typically to produce a print whose appearance matches that of the transparency, and a prediction of the surround effect is required in order to achieve this.

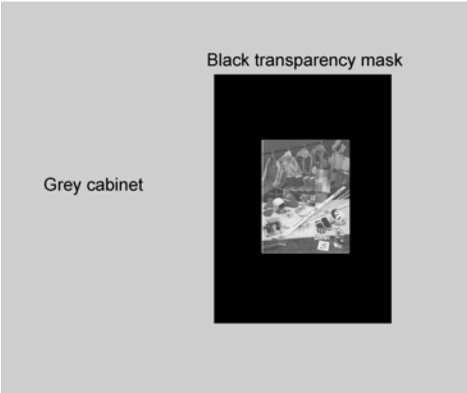

Figure 1a – Viewing fields for transparencies

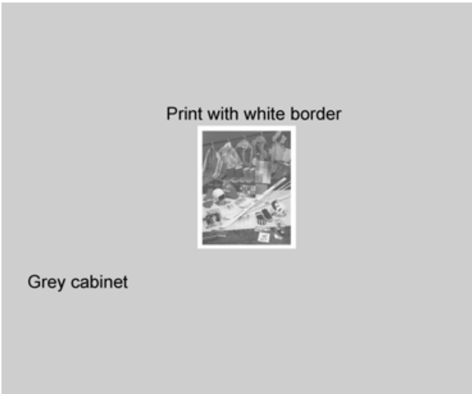

Figure 1b - Viewing fields for prints

Predicting the lightness and colourfulness of the transparency

The colour appearance model CIECAM97s [7] includes a prediction of the appearance of cut-sheet transparencies in the viewing set-up shown in Figure 1. Such a model is used to transform an image between ISO 3664 T1 and P1 viewing conditions by the steps shown in Figure 2. The *XYZ* coordinates of the image are transformed to appearance correlates *JCh* using the appropriate CIECAM97s parameters for the T1 condition, and then the transform is inverted to give the corresponding *XYZ* coordinates using the parameters for the P1 condition.

The principal factors in CIECAM97s that predict the effect of surround and background luminance in cross-media comparisons are *Yb* (relative luminance of the source background in the source conditions); *c* (surround impact constant); and *Nc* (chromatic induction factor). *F* (degree of adaptation factor) is also set according to different surround conditions but has a less significant effect; while F_{LL} (lightness contrast factor) has a larger effect but is normally set to 1 except for large uniform samples with an angular subtense greater than 4°.

The structure of the CIECAM02 model with respect to surround and background is similar to that of CIECAM97s, and both the discussion and experimental results below should apply to both models.

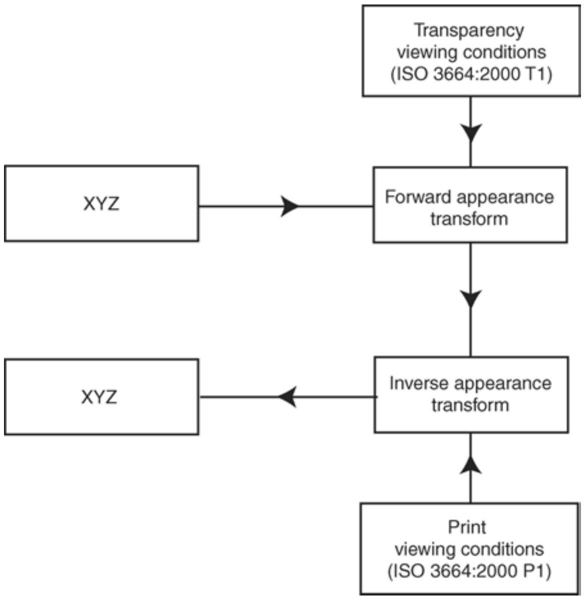

Figure 2 Workflow for transforming an image from XYZ under T1 transparency viewing condition to XYZ under P1 print viewing condition

Since the adoption of CIECAM97s, work has been undertaken by CIE TC 8-01 [10, 11, 12] on the modifications needed to the model to work with complex images as well as uniform samples. One of the changes introduced in the CIECAM02 model [8] is to modify the surround-dependent parameters *c* and *Nc* for dim viewing conditions, and to make both *c* and *Nc* a continuous function rather than a series of discrete values. In CIECAM02 the transparency viewing condition was omitted altogether.

For complex backgrounds, the relative luminance of the background is normally taken to be 20% (corresponding to an *L** lightness of 51.8), which is a form of 'grey world' assumption and is in agreement with the uniform neutral background in ISO 3664. If the pixels within an image are assumed to provide a local background, and the lightness of this equivalent background is predicted by the mean lightness of the image, then *Yb* should be calculated at least in part from the coordinates of the image. If a 'grey world' assumption (i.e. that the average C^*_{ab} chroma and L* lightness of an image are 0 and 50 respectively) is applied to a colour images, this also indicates that background relative luminance Yb is set to 20%.

Previous work on image backgrounds [13, 14, 15] has demonstrated that the integrated lightness of the pixels within an image in effect defines a local background.

Formulation of appearance model parameters for transparency media

Aside from the earlier published work [2, 3, 4], the main source of data for the appearance of colour on transmissive media was obtained as part of the LUTCHI study of colour appearance [16], and this contributed to the formulation of the CIE colour appearance model CIECAM97s.

The LUTCHI phases RVL-1, and LT-4 and LT-10, correspond most closely to the P1 and T1 viewing conditions respectively in ISO 3664. The LT-4 (cut-sheet transparency) and RVL-1 (reflection print) experiments approximate the 'average' surround condition in CIECAM97s, while the LT-10 (cut-sheet transparency) experiment approximates the 'dark' surround condition. The change in perceived lightness with surround can be seen by comparing the ratio of the visual scale lightness (VL) to the measured L* lightness (VC) for different surround conditions. The ratios VL:VC for different conditions are shown in Table 2. Similarly, the ratios of visual colourfulness (VC) to measured C^*_{ab} chroma (CC) were calculated and are given in Table 2.

Table 2 Ratio of visual scale lightness and colourfulness (VL and VC) to colorimetric attribute L* lightness and C^*_{ab} chroma (CL and CC) for the LUTCHI data sets LT-4, LT-10 and RVL-1.

LUTCHI phase	Luminance (cd/m^2)	Y of bkgrnd	Mean ratio VL:CL	Mean ratio VC:CC
LT-4	670	17.4	1.16	1.02
LT-10	658	9.6	1.25	1.04
RVL-1	843	21.5	0.95	1.06

It can be seen from Table 2 that when the visual results for the transparency viewed on a 'dark' surround are compared with those for the 'average' surround (VL:CL of 1.25 and 1.16 respectively), the LUTCHI data are consistent with an increase in perceived lightness, particularly in the darker colours. However, the LUTCHI data do not support a change in perceived colourfulness with dark background, where the VC:CC ratios of 1.04 and 1.02 are very similar.

Other phases of LUTCHI data give similar results. It should, however, be noted that the test stimuli in the LUTCHI experiments were uniform patches rather than complex images.

Surround and background

A study of the literature on colour appearance reveals that there are two usages of the terms 'surround' and 'background', in which the meaning of the terms is opposite. The first usage is found in earlier work on appearance and in ISO 3664, while the second usage appears in the more recent work on colour appearance.

ISO 3664:2000 defines the surround as "The area adjacent to the border of an image which, upon viewing the image, may affect the local state of adaptation of the eye" [1]. The border (the region immediately adjacent to the image) is usually taken as unprinted paper in the case of reflection copy, while for transparencies it corresponds to the unexposed rebate of the reversal media, which in most cases will be white and black respectively.

Before 1991, the terms 'surround' and 'background' were used in most papers in the same sense as the ISO 3664 definition. In 1991, the background was defined as "the environment of the colour element considered, extending typically for about 10° from the edge of the proximal field in all or most directions" [5]. The 'surround' was defined as simply the field beyond the background. This usage continues into the CIECAM97s and CIECAM02 models, but is clearly the reverse of the definitions in ISO 3664 given above. These different usages have been noted elsewhere [17].

If the effects of varying values of surround conditions and *Yb* on the value of CIECAM02 lightness *J* for a cyan ink are plotted (Figures 3 and 4) it can be seen that over the range of field luminances found in P1 and T1 viewing conditions ('average' to 'dark' surround, and background luminances corresponding to the grey cabinet and the black mask), the surround parameters *c* and *Nc* have a greater effect to the background factor *Yb* on *J* lightness, and an opposite effect on *C* chroma. These do not seem to be desirable effects, since it could be expected that the regions closest to the image would have a much more significant effect on its appearance than regions further away.

In Figure 3, Yb has been set to 20, while in Figure 4 the surround condition was chosen to be 'average'.

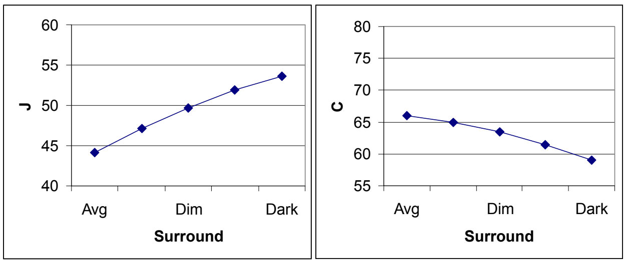

Figure 3 Effect of surround parameters on predicted J and C

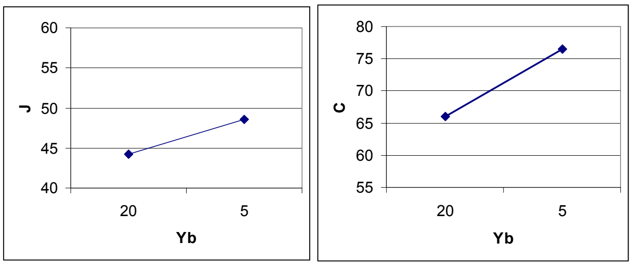

Figure 4 Effect of background Yb on predicted J and C

There are further sources of ambiguity when applying colour appearance models to a P1/T1 viewing condition:

1. The surround condition is defined [6] in terms of the luminance of the surround relative to the average luminance of the viewing field. In a viewing booth, a black transparency surround with a reflectance of 5-10% has a low relative luminance, yet under the lamps of the booth this corresponds to a luminance of about 64 cd/m^2, which is similar to that of the peak white of a CRT under typical office conditions [18]. It is difficult to conceive that the state of adaptation when viewing originals within a brightly-lit viewing booth is the same as 'when viewing film in a darkened room' [6].

2. If the magnitude of the effect is greatest for fields closest to the stimulus, then the image border should be

considered when predicting appearance. A proximal field ('the immediate environment … extending … up to 2° from the edge of the colour element considered') is defined [6], but no terms for this field are included in CIECAM97s or CIECAM02.

Experimental

Since appearance models do not seem to correctly predict the appearance of the transparency in the T1 viewing condition, it is necessary to modify the models in some way. In the experimental work undertaken here, this alteration took the form of testing alternate surround parameters *c* and *Nc*, and background luminance factor *Yb*. Two phases of experimental work were undertaken, with the aim of first deriving values for *c* and *Nc*, and then in the second phase testing these values together with a new method for calculating *Yb*. Aspects of this work have been reported previously [19, 20]. Where the terms 'surround' and 'background' are used below, the CIECAM97s definitions [6] will be adopted.

Phase 1

In the first phase, three original cut-sheet transparencies in 125x100mm format were selected: SKI, SHOOT and TABLE. The transparencies were scanned, colorimetric coordinates calculated by a device model, and after the appearance model transformations printed on an ink jet printer. Scanning was performed on a Crosfield Magnascan, and prints were made on Epson Photo paper using an Epson 980 ink jet printer. The accuracy of the input and output device models are given in Table 3.

Table 3 Accuracy of Phase 1 device models, ΔE^*_{ab}

	Mean	Max	95th percentile
Scanner	3.15	9.98	6.16
Printer	1.88	4.01	3.42

In Phase 1, the aim was to determine values for *c* and *Nc* which produced the best appearance match between the transparency and print when viewed simultaneously under T1 and P1 conditions in a viewing booth.

Reproductions

The images were transformed from *XYZ* to *JCh* using the forward CIECAM97s model, and then back to *XYZ* using the inverse of the model, following the workflow shown in Figure 2. In the forward direction, the *c* and *Nc* parameters were chosen for T1 transparency viewing conditions, while in the inverse transform the print viewing conditions were used. The transformation was repeated with a total of nine of different values of c and *Nc*, ranging between the 'cut-sheet transparency' and the 'dim surround' viewing conditions of CIECAM97s.

A series of test values for *c* and *Nc* were selected, with the aim of providing random points along the continuum of values judged to be plausible alternatives. The nine transformed versions of each image were printed, together with a tenth version in which no appearance transform was applied. The gamut of the original transparencies and the transformed versions was larger than that of the printer in some regions, and so there was a small degree of clipping in the reproductions.

Table 4: Parameters used in the Phase 1 experiment.

CIECAM97s parameters	Transparency	Print
Yb	20	20
L_A	127	127
X_W	96.422	96.422
Y_W	100	100
Z_W	82.521	82.521
Nc	0.41 – 0.56	0.69
c	0.8 – 0.95	1.0
F_{LL}	1.0	1.0
F	1.0	1.0
D	0.984	0.984

Psychophysical

A Verivide proof viewing booth was used to assess the prints and transparencies. The appearance model parameters were as shown in Table 4. The viewing set-up measurements were all within the tolerances in ISO 3664. The measured luminance/illuminance of the booth and the transparency illuminator are those shown in Table 5, where the reflectances given include estimated flare of 5%.

Table 5: Viewing conditions used in Phase 1.

Viewing set-up	Trans.	Print
Luminance of white highlight	696 cd/m^2	613 cd/m^2
Reflectance of background and surround	10%	22%
Width of image border	0	12mm
Reflectance of image border	N/A	93%
Angular subtense of image at viewing plane	13°	13°

A panel of 20 observers, largely experienced graphic arts professionals from pre-press houses and newspaper production departments, compared each print (presented in random sequence) with the original transparency in a viewing booth. Since the experiment sought to determine the effect of *c* and *Nc* parameters on perceived lightness and colourfulness, the observer task was to judge whether each print was lighter or darker than the transparency; and whether each print was more colourful or less colourful than the transparency.

Results

The optimum values for *c* and *Nc* were found by a variation of the method of 'minimizing instrumental wrong decisions'; the optimum value for *c* was the one at which the smallest number of observers judged prints to be too light for higher values of *c* and too dark for lower values of *c*. The optimum value for *c* is located where the total number of samples rejected as being either too light or too dark is minimized, at about 0.46.

The same procedure was used to determine the optimum value for *Nc* in respect to colourfulness. The optimum values found by this method for each image are given in Table 6.

Table 6: Parameters derived for *c* and *Nc* in Phase 1

	SKI	SHOOT	TABLE
c	0.46	0.49	0.46
Nc	0.9	0.9	0.9

Phase 2

The aim of Phase 2 was to verify the results in Phase 1 and to consider the luminance of the background field (image, border and background to 10°) in setting the background luminance *Yb*.

Preparation of test transparencies

For phase 1, a new set of transparencies was made whose colorimetric coordinates were within the gamut of the printer. The three original transparencies were re-scanned on a Dainippon Cezanne (to avoid a dependence on the input device or model). Each image was scanned alongside a test target, and a characterization model built for each image.

After transforming to *XYZ*, the images were compressed to the gamut of the printer by gamut clipping in which the CIELAB ΔE^*_{ab} distance to the surface of the destination media gamut is minimized [21]. This method resulted in a small degree of visible contouring in some high-chroma regions.

The gamut-compressed images were then output onto transparency media by a Kodak LVT transparency recorder. The transparencies were reproduced at a size of 9.5 x 7.5 cm, to give an angular subtense of approximately 10° at a viewing distance of 480mm. The accuracy of the scanner and LVT characterizations is given in Table 7.

Table 7 Accuracy of device models in Phase 2, ΔE^*_{ab}.

	Mean	Max	95th percentile
SKI input	2.62	9.50	5.10
SHOOT input	1.44	10.26	3.22
TABLE input	1.33	7.96	2.86
LVT output	1.88	4.00	3.42

Calculation of Yb

The background field in CIECAM97s extends up to 10° beyond the test stimulus. For a given pixel in a complex image, the background will be made up of the surrounding pixels, the immediate border (if any), and the background beyond, to a total of 10º. Since the density of cones in the retina falls rapidly as perimetric angle from the fovea increases [22], it is likely that the effect of the luminance and colourfulness of the visual field on foveal perception also falls with increasing angular subtense. One possible approach to model this is to assume that the effect decays with the square of the distance from the stimulus:

$$\tau = 1 - d^2 \qquad (1)$$

where τ is the relative magnitude of the effect, and *d* is the fractional distance from stimulus to the limit over which the effect is assumed to apply.

Equation (1) was used to calculate weights for the image, border and background luminances of the fields within the background region, by integrating the weighting function with the relative angular subtense occupied by the fields. As an example, the weight for the black mask is the ratio of the area of the shaded region in Figure 5 to the total area under the curve. This leads to the weights shown in Table 8 for the image, border and background present in the P1 and T1 viewing conditions (where Y_{image} is the mean *Y* value for the image, and all the *Y* values in Table 6 include 5% flare).

Table 8: Weightings for image, border and background in calculating *Yb* background factor.

Field	*Y*	*d*	P1 weight	T1 weight
Black mask	10	0.5-1.0		0.31
Image	Y_{image}	0.0-0.5	0.69	0.69
White border	100	0.5-0.65	0.15	
Grey backgrnd	25	0.65-1.0	0.16	

It should be noted that the flare of 5 cd/m^2 in Tables 4 and 6 was estimated, and is probably higher than that which would have been found if measured.

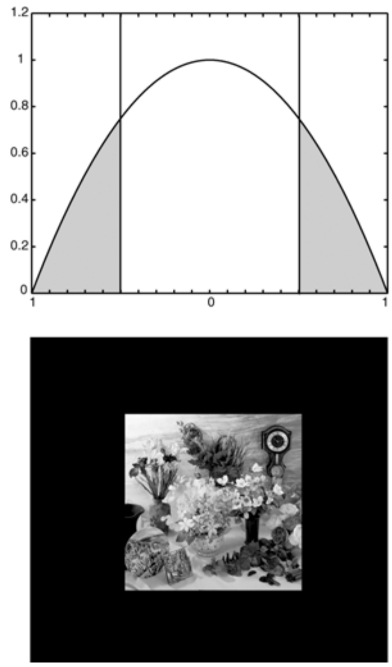

Figure 5 Weight for viewing field determined from area under the function in equation (1)

The weighted value of *Yb* for each viewing condition is then calculated by multiplying each element in the column of weights by the corresponding total luminance for the field, and summing these individual contributions to the total background luminance. Values of *Yb* calculated by this method are shown in Table 9.

Table 9: Values of *Yb* for the test transparencies calculated using the weightings in Table 6

Image	Mean *Y*	*Yb* (T1)	*Yb* (P1)
SKI	10.8	14.0	29.9
SHOOT	11.2	14.3	30.2
TABLE	23.8	23.0	38.9

A similar approach can be taken with the calculation of *c* and *Nc* for the T1 condition. The outer dimensions of the surround region are not defined in CIECAM97s, but if it is assumed that the black mask covering the illuminator extends to 10% of the total surround field, and the weighting function in equation (1) applies, then the mask has a weighting of 0.17 in the T1 condition. Since the adapting field beyond the illuminator corresponds to an ‘average’ surround, then new values for *Nc* and *c* can be calculated by interpolating between the ‘cut-sheet transparency’ and ‘average’ surround parameters using the weightings 0.17: 0.83, resulting in values of 0.64 and 0.96 for *Nc* and *c* respectively.

Reproductions

The gamut-compressed image data were transformed to *JCh* and then back to *XYZ* for a P1 viewing condition, using the same workflow as in Phase 1. This was repeated for four different sets of parameters for *c*, *Nc* and *Yb*, as shown in Table 10. These include the CIECAM97s ‘cut-sheet transparency’ parameters (c=0.41, Nc=0.8) as well as the optimized parameters derived in Phase 1.

Table 10: Parameters for *c, Nc* and *Yb* in Phase 2

	c	Nc	Yb
T	0.41	0.8	20
T1a	0.46	0.9	20
T1b	0.69	1.0	As in Table 7
T1c	0.64	0.96	As in Table 7
T1d	0.41	0.8	As in Table 7

Prints were made by converting the transformed *XYZ* data to printer *RGB* by the same method as in Phase 1. The gamut-compressed *XYZ* data for the original transparencies were also reproduced by the same method, and these prints were designated ‘COL’ as they represent the same colorimetric coordinates as those of the gamut-compressed transparencies, within the limits of the accuracy of the printer characterization. It was observed that the T1 reproduction appeared to be somewhat pale and washed out and that the shadows in all three images were visibly too light in the T1 and T1a prints. In the T1d prints, the predicted lightness increased as a result of the combined effect of the surround parameter *c* and the background luminance *Yb*, and as a result were much too light. The T1d reproductions were not included in the visual evaluation.

Psychophysical

The prints were presented pair-wise in random order in the same viewing set-up as in Phase 1. A panel of 20 observers (mostly graphic arts professionals with substantial experience of comparing originals and proofs in a viewing booth) performed a pair comparison experiment in which the task was to select the most accurate appearance match to the (gamut-compressed) transparency.

Results

The observer data from the pair comparison experiment were analyzed according to Thurstone’s Law of Comparative Judgement, whereby a z-score was calculated from each proportion of choice value by finding the corresponding inverse of the normal cumulative distribution function. The results for the three test images were very similar (correlation 0.996), and the average of the scores over the three images is shown in Figure 6.

The results indicate that the reproductions made using the *Yb, c* and *Nc* parameters calculated from the mean lightness of the image and the luminance of the border and background fields by the distance-weighted function described above were judged to be the most accurate appearance match to the transparency.

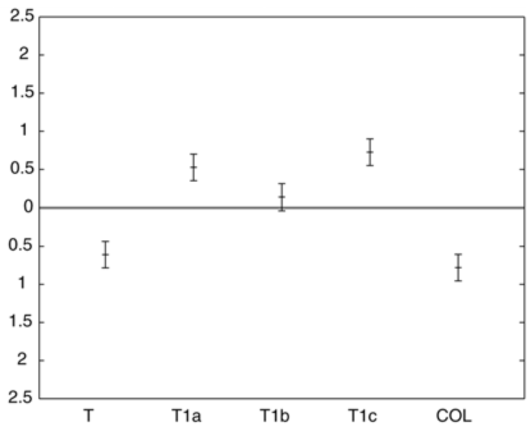

Figure 6. Relative scores of the five different techniques evaluated in Phase 2.

The *c* and *Nc* parameters of 0.46 and 0.9, when used with a *Yb* of 20, gave a very similar performance, and this suggests that when the optimized *c* and *Nc* are used there is no significant advantage in using the weighting function in equation (1) over simply setting Yb to 20. The poor performance of the COL method confirms the need to use an appearance model to predict the surround and background effects, while the similarly poor performance of the T1 model provides support for the claim that CIECAM97s does not provide a good prediction in the cut-sheet transparency surround condition.

Conclusions

The experiments described are a good technique for verifying colour appearance models, particularly in deriving parameters along a single dimension of a colour appearance attribute.

The impression that CIECAM97s over-predicts the effect of the surround in the case of cut-sheet transparencies compared with prints in an ISO 3664 T1 and P1 simultaneous viewing condition is supported by the results of both phases of the work described above. Reproductions made using optimized values for *c* and *Nc* lead to significantly better appearance matches in this viewing set-up.

These results support the omission of the cut-sheet transparency condition from CIECAM02. The definitions and model parameters for surround and background in CIECAM02 need further investigation.

The 'grey world' assumption which leads to the background reflectance factor *Yb* taking the value of 20 for complex images appears to be justified, and no significant improvement was obtained by the alternative approaches tested.

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