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Toward perceptolute rendering of media with different amounts of optical brightening agents

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Abstract

The established media relative and ICC-absolute colorimetric intents have been demonstrated to result in unsatisfactory visual matches when comparing prints on substrates with strongly differing amounts of optical brightening agents (OBA). This paper aims to contribute twofold toward the solution of this problem. First, a step toward a colour transformation is taken, which enables the most satisfying reproduction of pictures, printed on substrates with low amounts of optical brightening agents, on substrates with large amounts of OBAs. This is done on the basis of previous findings, which indicate that such a transform should consist of an absolute transform for colours with low lightness and a perceptual transform for colours of medium to high lightness. It is therefore, proposed that a new term be adopted for this colour transformation: perceptolute. In this paper, the previous findings are extended experimentally by investigating the progression of the perceptual part of the transform, via a colour matching experiment for exemplary achromatic colours. Secondly, since the fluorescence of OBA containing substrates strongly depends on the present UV amount, a practical tool to evaluate the UV amount in a given indoor lighting situation will be described. It is called "UV-Checker".

Introduction

The colour specification in most colour related industries is D65 or D50 including the respective UV component. Colour communication, in particular in the printing industry, has achieved excellent consistency between reference and reproduction for years with D50-based ICC [1] colour measurement (M1, ISO 13655 [2]) and D50-based viewing (P1, ISO 3664 [3]). The global switch from fluorescent tubes to UV-free LED technology in general lighting is currently changing the way colour communication is performed in a quality previously unknown. As a result, fluorescent materials, such as many graphic papers with optical brighteners, are significantly less stimulated and therefore appear different indoors than specified. This paper covers intermediate findings from an ongoing research project [4]. It focuses on two main aspects. Firstly, colour matching strategies will be evaluated that achieve the best possible visual matches when OBA-levels and, hence, the corresponding white points differ strongly between source and destination. Secondly, a practical tool to estimate the UV amount of a given indoor lighting environment will be demonstrated. It is called "UV-Checker".

Perceptolute Renderings

Motivation

Currently, print service providers are often required to print on substrates with large amounts of optical brightening agents, which exhibit a bluish tint when viewed under P1 viewing condition. One major problem hereby occurs when they try to reproduce a picture (e.g. contract proof) printed on OBA-free substrates on those with high OBA amount. In that scenario - even if the print service provider follows all colorimetric steps as suggested by ISO [5, 6] and Fogra [7] standards - the resulting print often seems unsatisfying to the customers. Note, that even with a colour match of $\Delta E00 = 0$ between reference and reproduction, a visual match cannot be guaranteed. The reason for this lies in two factors. First, there is a huge gamut mismatch for light colours and second there is mixed chromatic adaptation between the white points of reference (OBA-poor) and the reproduction (OBA-rich) reproduction seen side-by-side via short term colour matching. There are already perceptual colour transforms on the market, which address this problem, however, with current evaluation (and certification) frameworks, reproductions using these transforms will be penalized. Hence, there is a strong necessity for a standardized way to address this issue. To bridge the knowledge gap, a new perceptolute framework is envisioned which will help the print service providers and profile makers to communicate and address these problems. The corresponding transform $T_{perceptolute}$ is described in equation 1.

$$T_{perceptolute}(wp_{ref}, wp_{OBA}, D) = Lab_{ref} \rightarrow Lab_{perceptolute} \quad (1)$$

Here, wp_{ref} and wp_{OBA} refer to the white points of the reference substrate and the OBA-rich substrate respectively. D indicates the degree of adaptation and is expected to be mostly governed by the area of the unprinted substrates in the visual field. Lab_{ref} describes the colours of the reference printing condition (OBA-free or OBA-poor) and $Lab_{perceptolute}$ the colours of the most satisfying colour reproduction for an OBA-rich substrate. First steps toward such a transform have already been undertaken in a previous research project [8], which lead to the understanding that the required transform $T_{perceptolute}$ should consist of an absolute transformation for colours with low lightness (where the unprinted areas having minimal impact in the visual field) and of a perceptual transformation for colours of medium to high lightness; hence the term perceptolute. In the following, an experiment is introduced to get one step closer to $T_{perceptolute}$.

Experimental Details

As the media relative and ICC-absolute colorimetric intents fail to predict colours that lead to a satisfying reproduction on OBA-rich substrates, additional experimental information on which colours are perceived as best suitable on a specific substrate have to be incorporated in the transform. In this section, an experiment is introduced which aims to yield an initial set of best visual colour matches between an OBA-free and an OBA-rich substrate when presented side-by-side and viewed under UV-containing illumination, such as D50 (termed P1 in ISO 3664). Whilst lacking physiological models for such a transform, an experiment was designed to adjust best visual matches for selected colours. Since the visual effect is most dominant for near neutral colours, this experiment is focusing on achromatic colours with medium and high lightness. A follow-up experiment is planned, where chromatic colours will be investigated in the same fashion. In this psychophysical experiment, the observers stand in front of a standard light cabin (Just Normlicht; Virtual Proofing Station in P1 mode) and are presented with different kinds of substrates. Figure 1 shows a sketch of the experimental setup and the reference (OBA-poor) substrate alongside one exemplary test (OBA-rich) substrate as seen by the observer during the experiment.

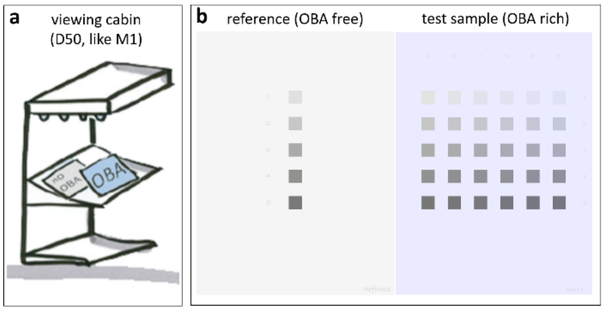

Figure 1. (a) Schematic of a standard light cabin with an OBA-free (Schoeller P22130 TRUST economy Matt OBA free 130) and an OBA-rich substrate. (b) The view on the reference (left) and reproduction substrates as seen by the observer during the experiment (right). Exaggerated blue or lilac tint in the OBA-rich substrate indicates "fluorescent effect".

As seen in Figure 1(b), the reference colours on the left contains grey patches of five different lightness levels and the reproduction sample contains 6 greyish (near neutral) candidate patches having the same lightness as the reference colour. For each row the observers are asked to select the patch from the six candidate patches on the right that give the best visual match. While one specific row on the sample substrate is evaluated, blank sheets of the test substrate cover the other rows on the right to reduce distraction. The candidate patches have been selected to cover the potential yellow-bluish-range by using a linear Bradford model as defined for ICC profiles in Annex E of [1] and different degrees of adaptation. Since CAT transforms also slightly change the lightness, the $CIEL^*$-value was set to the same as the reference. This procedure is done for all six rows on a variety of test substrates, which are listed in Table 1 with their respective white points.

Note, that all $CIELab$-value triplets are measured under M1 condition (2°, D50). The Lab (M1) values of the grey patches (first row) in Figure 1b are shown in Table 2.

This experimental setup is designed to reflect real-world print appraisals. That includes simultaneous assessment, A3 format sheets and patch sizes that cover approximately 2° viewing angle (using a viewing distance of ca. 50 cm).

This experiment was done with 15 persons ranging from professionals of the printing industry to non-professionals. All male observers were tested for colour deficiency by using the Farnsworth Munsell Hue 100 Test. As reliability of judgement for colour differences decreases with increasing visual angle between them, the experimental setup was "inverted". This means that the order of the grey patches was printed with column A now being the right most and column F being the left most column (and all others sorted accordingly). This was done randomly for two substrates namely "ORIS PearlPROOF OBA Matte 140" and "GMG matte OBA 150". Both configurations are illustrated in Figure 2. Note, that the observers were not aware of this and consider these configurations as additional substrates.

Table 1. Test substrates with their respective white points (D50, 2°, M1)

		L^*	a^*	b^*
Ref	Schoeller OBA free	96	0	0
1	ORIS PearlPROOF OBA Matte 140	93	3	-12
2	Sihl TrueColor Paper 140 matt 3333	93	4	-13
3	GMG matte OBA 150	96	3	-10
4	GMG Proofpaper matte 140	95	1	-4

Table 2. Exemplary Lab values for the grey patches shown in the first row of Figure 1b.

	Ref	A	B	C	D	E	F
L^*	90	90	90	90	90	90	90
a^*	0	0	1	1	1	2	2
b^*	0	0	-3	-5	-7	-9	-11

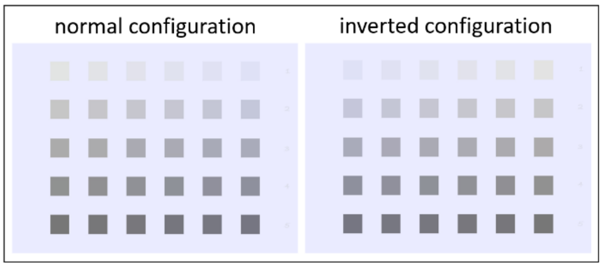

Figure 2. Comparison between the grey patches of the normal and the inverted configuration. The reference sample was always located to their respective left.

Results

The average matching results of this experiment represent the "ideal" perceptolute reproduction, i.e. $Lab_{perceptolute}$. While a full characterisation of the transformation itself exceeds the scope of this paper, the results provide a basis for such a transformation. Since colours on the grey-axis have the greatest visual impact, and since colour shifts predominantly involve yellow-blue changes, the main visual effect can be visualized by plotting the adjustment results in a $CIEb^*$–$CIEL^*$ diagram. Figure 3 shows the average findings and its standard deviation for all 5 colours on 4 different substrates.

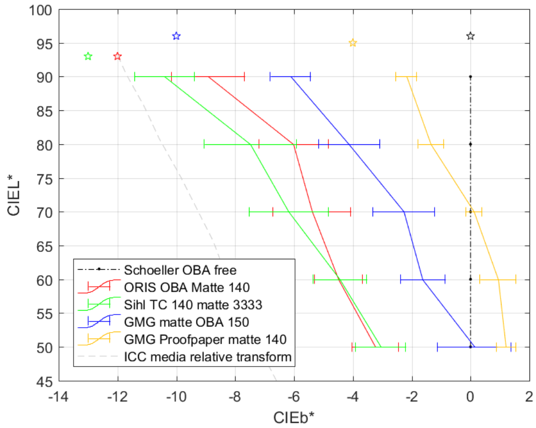

Figure 3. *Resulting $CIEb^*$-$CIEL^*$ functions of the achromatic matching experiment for the different substrates listed in Table 1. The stars indicate the white points of the respective substrates and the grey dashed line indicates the ICC media relative transform.*

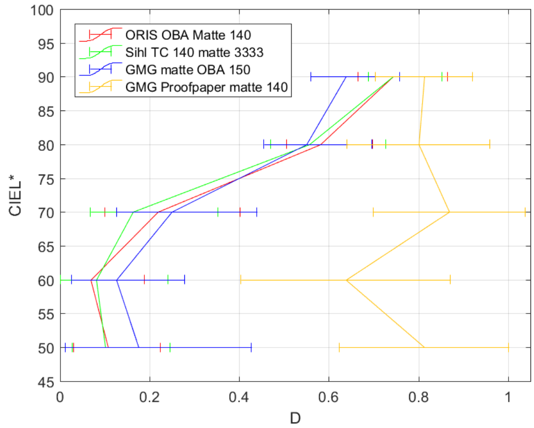

Figure 4. *Degree of adaptation plotted versus the corresponding CIEL*-values for the substrates shown in Table 1. These graphs are based on the same data as shown in Figure 3.*

Note, that the $CIEa^*$-values of the patches are changing as well; however, their change is comparatively small (see Table 2) and OBA-rich samples affect the blue-yellow axis ($CIEb^*$) much stronger. Hence, $CIEa^*$ will be disregarded in the following. The black dash-dotted line at $CIEb^* = 0$ indicates the reference grey-axis for the OBA-free substrate and the grey dashed line shows a media relative transformation of the ”ORIS OBA Matte 140” data set. For all OBA-rich substrates used here, the results show a trend toward larger $CIEb^*$-values for increasing $CIEL^*$-values, while for lower $CIEL^*$-values, the lines approach the reference grey-axis. Regarding the trend between the different substrates, it is clearly visible, that the shift toward lower $CIEb^*$-values follows the white point, i.e. for lower $CIEb^*$-values, the curve is more tilted towards lower $CIEb^*$-values for larger $CIEL^*$-values. As the near neutral candidates patches have been created using a partial chromatic adaptation transform (Bradford), it is instructive to visualize the trend of the most fitting degree of adaptation D for the various lightness steps and OBA contents. This is done in Figure 4 for the “normal” orientation.

Note, that $D = 0$ means full adaptation to the reference white point and therefore reflect an established absolute colour match. Full adaptation toward the OBA-rich reproduction substrate is reflected by $D = 1$. That can be considered as a ICC media relative match. The most striking feature in Figure 4 is the two-cluster formation, between the OBA-rich samples (red, green, blue) and the medium to low OBA samples (orange). The latter stays more or less constant around $D = 0.8$, while the former starts around $D = 0.65$ ($CIEL^* = 90$) for all three and falls to $D = 0.1$ ($CIEL^* = 60$), where it remains. There is even a trend visible where D could increase again for even lower $CIEL^*$-values. Regarding the inverted samples, their $CIEb^*$-$CIEL^*$-curves are plotted alongside their “normal” counterparts in Figure 5. Note, that for any test sample, the reference is always on the left side. In both cases, the inverted configuration lead the observers to the perception, that slightly lower $CIEb^*$-values are more fitting compared to the “normal” configuration. Overall, the trend for both configurations are similar.

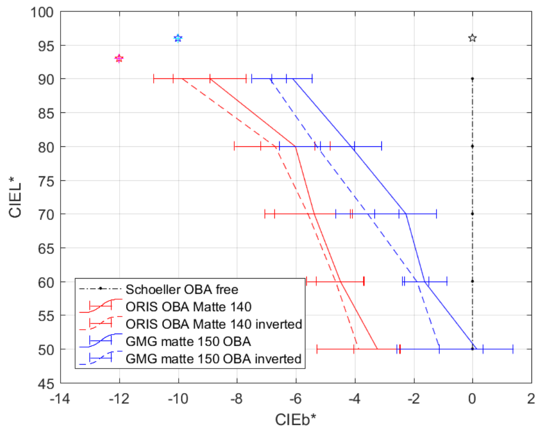

Figure 5. *$CIEb^*$-$CIEL^*$-curves for the inverted case (dashed lines) plotted alongside their counterparts (already shown with the same colour in Figure 3). The stars indicate the white points of the respective substrates and the dash-dotted black line indicates the values of the reference substrate.*

Discussion

This experiment was based on the hypothesis of the existence of a perceptolute transform, which provides a pleasing visual match between two substrates with strongly different white points. It was shown that there is a consistent observer response toward a mapping that lies between an absolute and an ICC media relative match. The strongest change was found, as expected, for the light colours since here the mixed adaptation results in the largest difference. The darker the colours, the lower the impact of the white point differences.

If it is assumed, that the absolute colour transformation is the best fit in this experiment, all of the graphs in Figure 3 would be congruent with the black dash-dotted line. Instead of this, the graphs seem to approach the reference grey-axis for smaller $CIEL^*$-values and approach their respective white points for higher $CIEL^*$-values. This is a strong indicator, that the hypothesis is correct, as the former is indicative of an absolute transform and the latter is indicative of a perceptual transform. Additionally, this confirms many practical findings, which consider the media relative reproduction as too cool or too cold, as can be seen in the grey dashed line in Figure 3. With this, all parts of the curve are clearly shifted towards more bluish values. It has to be acknowledged, that the range of measurements has to be extended toward even smaller and larger $CIEL^*$-values to further clarify this point. As a gradual convergence is observed, instead of a clear change in progression, it can be assumed, that there is no clear cut between both transformation types, but rather a gradual progression with the transition region starting at $CIEL^* < 60$.

In general, it is expected that the perceptolute transform depends on two main parameters: Firstly, the white point of the OBA-rich substrate, wp_{OBA}, which governs the adaptation process by defining the bluish tint in the unprinted areas. Theoretically, a reproduction paper with no OBA, but with a bluish white point, would result in the same need for a perceptolute transform. For many reasons, this is practically not relevant. Secondly, the presence of two different "whitish" substrates will result in a mixed adaptation situation. Therefore, it is expected that the unprinted portions of both substrates in the field of view impact the degree of adaptation of colour.

The impact of the OBA induced colour changes can be seen in the shift between the various curves in Figure 3 with increasing shift for more bluish white points (more negative $CIEb^*$-values). This tendency is expected, as chromatic adaptation toward the more bluish tinted paper will lead to more bluish colours being perceived as neutral. Both substrates seen by themselves will be perceived as white substrates, so a fundamental requirement for a print production is met, namely, unprinted areas remain unprinted. However, the results nicely illustrate the difference between a media relative approach (grey dashed line), being a simply linear scaling of $CIEXYZ$ values (see Figure 3) and the preferred reproductions being less "cool", i.e. more yellowish. The ICC media relative approach overstates the visual effect over the lightness range by predicting too bluish colours. The results show that preferred renderings should be closer to $CIEa^* = CIEb^* = 0$, which is conceptually a perfect grey. Additionally, any change in the order of the patches, as in the move from "normal" to "inverted" configuration (see Figure 2) does not yield a significant change. It has to be noted, though, that the offset between both configurations goes in the same direction (toward more bluish colours). This is a bit unexpected, but outside the scope of this paper and subject of future experiments.

Interestingly, the degree of adaptation D in Figure 4 seems to be approximately similar for the three high OBA samples and vastly different for the low/medium OBA sample. Note, that D is used relative to the respective white point of the sample. Nonetheless, this clear separation leads to the idea of a threshold in ΔB or Δb^* (between reference and sample) upon which the partial chromatic adaptation exhibits more complex behaviour. Please note that this experiment is designed to reflect practical print assessment and hands-on solutions. This includes standard colour measurements using CIELAB [3]. Therefore, colour measurements are based on the perfect diffusor (not present in the visual field) and also based on CIELAB, which already includes a wrong von Kries type of adaptation. It is also based on standard illuminant and standard observer and not individual light source or an individual observer, which are known to yield superior performance.

Interaction of UV-amount and OBA-amount – the "UV Checker"

As part of the switch from discharge lamps ('tubes') to LEDs, technical aspects become relevant. Natural daylight and mercury fluorescent lamps generate UV radiation, some of which is converted into visible light. LED-based indoor lighting is predominantly free of UV-A radiation (i.e. energy below 400 nm). The visual effect of fluorescence, i.e. the process of determining colour values for a CIE daylight illuminant and standard colourimetric observer, is difficult to evaluate. This is specified by the spectral reflectance factor, the relative spectral distribution of radiance due to fluorescence, and the spectral external radiant efficiency of the fluorescent specimen [10]. This can be measured using a two-monochromator device to measure the matrix of bispectral excitation and emission, also known as the Donaldson matrix [11]. Alternatively, the perceived colour can be assessed by measuring the spectral radiance using a tele-spectroradiometer aimed at the specimen of interest. Both methods are time-consuming and tedious, and therefore impractical for quick assessments. Therefore, a prototype print sample pair, the UV Checker, was developed to enable practitioners to determine the UV content of the current lighting.

Development of the UV-Checker

To determine the UV content of a given lighting situation, two lightfast proof papers were selected that matched each other in all properties except for the amount of optical brighteners (OBA). Ideally, both should have the same matte surface to avoid differences in gloss which would make a judgement in the application process more difficult. In addition, the OBA-rich paper should not be too light or too purple so that its white point under D50 (M1) and under D50noUV (M2) can be reproduced by the OBA-free paper using paper simulation. In this specific case, a paper simulation was applied to the entire surface of the OBA-rich paper in order to lower the lightness that it can be proofed by the OBA-free paper, i.e. its white point must be inside the gamut. By reducing the lightness it is important to avoid reducing the "fluorescence effect", e.g. expressed as the difference between M1 and M2. The colour measurement values of the identified papers are listed in Table 3. It can be seen that the "fluorescence effect" between D50 (M1) and D50noUV (M2) was shifted from $-12.5 < CIEb^* < -4$ to $-4 < CIEb^* < 5$ into the yellowish range - but remains approximately the same at $\Delta CIEb^* \approx 8$.

Table 3. CIELab colour values of the proof papers used. ID 1 is Sihl 3333 - TrueColor 140 g/m^2 matte unprinted, ID 2 represents the same paper as ID1 but with paper simulation and ID3 is Hahnemühle Agave 290 g/m^2.

ID	OBA (ΔB)	$CIELab$ (D50, 2°,wb)			Mode
1	20.5 (high)	93.4	3.1	-12.5	M1
		92.8	1	-4	M2
2	17.1 (high)	91.7	1.9	-3.9	M1
		92.0	0.5	4.8	M2
3	0.2 (free)	96.2	0.0	1.3	M1 = M2

Subsequently, CMYK device values were identified for the OBA-free paper that would allow the M1 and M2 CIELab colour values to be reproduced as accurately as possible, i.e. achieving a $\Delta E00 < 1$, preferably $\Delta E00 < 0.5$. Instead of printing a classic IT.8-7/4 test chart [12] colours and creating an ICC output profile, a tone value grid of 384 CMYK values was used. This was designed to sample colours that are considered potential candidates for an absolute colour match. The M1 and M2 measured values of resulting colour patches were used to find the smallest colour distance for the reproduction of the M1 value (D50) and the M2 value (D50noUV). These two CMYK device values were printed and designated as patch ”A” for the reproduction of the M1 value and patch ”F” for M2. Please note, that these symbols shall not be confused with the categories in the previous section. In addition to patches “A” and “F”, four intermediate values were printed by linearly interpolation between the two CMYK values, resulting in patches ”B”, ”C”, ”D”, and ”E”. This results in a total of six colour patches (“A” to “F”) - the matching strip.

The aim of this interpolation is to enable not only two reproductions (M1 and M2), but also intermediate steps to be identified. Assuming an approximately linear behaviour of the brightening effect, these colour patches thus correspond to the respective UV component: 100% UV component (patch ”A”), 80% (patch ”B”), 60% (patch ”C”), 40% (patch ”D”), 20% (patch ”E”), and 0% UV component (patch ”F”). The measurement of the six colour patches is shown in Table 4. The comparison of the values for ”A” and ”F” with the values from Table 3 shows that the reference with $\Delta E00 < 1$ could be adjusted very well.

Table 4. M1 CIELab-values of the matching strip patches.

Patch	A	B	C	D	E	F
L^*	92.0	92.3	92.3	92.0	92.1	92.0
a^*	1.1	1.1	1.1	0.7	0.2	0.5
b^*	-2.9	-1.6	-0.3	1.5	3.4	5.0

The print sample pair called ”UV Checker” consists of two components: a reference strip (OBA-rich paper) and a matching strip (OBA-free paper). To enable precise evaluation of the UV content, both papers were carefully attached next to each other on a stable surface to prevent any movement during observation. This arrangement enables a direct visual evaluation by comparing the colour changes under different lighting conditions and their varying UV components. The prototype is shown in Figure 6.

It demonstrates that brightener-containing paper under D50 illumination with 100% UV content corresponds to patch ”A”. In contrast, paper under D50 illumination without UV (D50noUV) corresponds to the more yellowish patch ”F”. In principle, such a UV checker could also be designed for other reference illuminants, such as D65, but this was beyond the scope of this study. By October 2025, around 1,000 UV-checker samples had been produced and delivered to interested parties. Many examples of the evaluation can be seen on the Fogra project webpage.

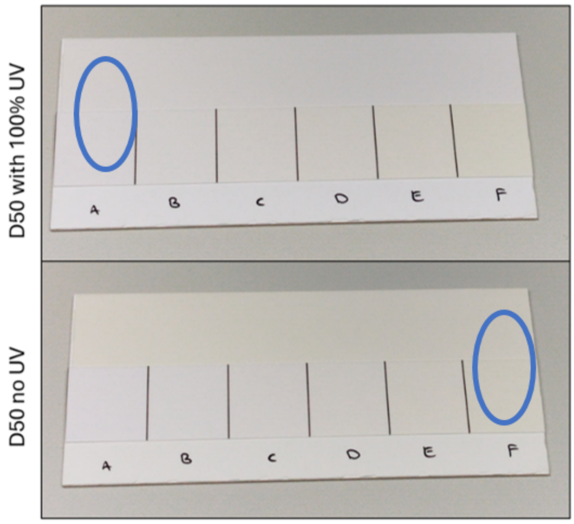

Figure 6. Top: UV Checker photographed under D50 illumination. A good colour match between the reference strip and the patch “A” shows that the illumination has UV component of approximately 100%. Bottom: The same UV Checker photographed under D50 illumination without UV component (UV LEDs switched off), with can be seen by the colour match between the reference strip and the patch “F”.

Summary and Outlook

In this paper, the challenge of graphic reproduction on OBA-rich substrates was addressed. For this, the idea of a perceptolute colour transform was introduced and experimentally investigated. The basic concept of this transform is, that it consists of a absolute transform for colours of low lightness and of a perceptual transform for colours of high lightness. It was experimentally confirmed that for achromatic colours this concept provides a good basis. To further substantiate the idea of this perceptolute transform, the experiment needs to be extended toward more chromatic and darker colour patches. This includes additional complexities, as the final colour of a print does not only depend on the OBA-level of the substrate but also on the UV absorption characteristic of the printing inks and the specific type of screening. Moreover, the research could be extended to semi matte papers, which cover a wider range of OBA-contents. Currently, an online version of this experiment is underway to get an even better understanding of the data (Link to the experiment: https://quickeval.no/observer/1694) [13]. Pictorial comparison with ICC profiles reflecting different ”perceptolute” transforms are also planned. Based on the findings, an evaluation regime will be proposed that allows for an objective evaluation of a perceptolute transform based on the established Fogra Media Wedge. That is subject for inclusion for printing standards such as Fogra Process Standard Digital [7]. In addition to the transform, a practical tool, namely the UV-Checker, has been introduced with which the amount of UV in most common light sources can be easily estimated. The UV Checker tool makes the assessment of the UV component not only possible, but significantly more practical and accessible for real-world applications

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Author Biography

Moritz J. Feil joined Fogra after obtaining his PhD in chemical Physics at the Technical University of Munich in 2025. He published and co-authored multiple papers in peer reviewed journals such as Electrochimica Acta and the American Chemical Society. This paper is his first contribution to the field of Colour Science.

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