Brightened Substrate Correction on a Spectral Scale

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Keywords: Spot color, psychophysical tests, visual-instrumental correlation, 2° & 10° observers, LLAB, RLab, ZLab

Abstract

Optical brighteners in substrates have a major impact on the perception of color and in particular on the perception of halftone prints. The main objective in this context is to describe the illumination-dependent interaction of brightened substrates with inks or colorants in general. In contrast to tristimulus value approaches, the here presented brightened substrate correction on a spectral scale allows the physically founded prediction of the brightener-effects concerning arbitrary illuminations. Included are CIE standard illuminants as well as arbitrary for measurement and for color validation used light sources.

1 Introduction

Optical brighteners - fluorescent brightening agents (OBAs) - in substrates have a major impact on the perception of color. This article describes solutions to consider the illumination-dependent interaction of brightened substrates with inks tailored to the print- and media industry.

Measurements of identical samples printed on brightened substrate show significant differences in the visible spectrum, if different illuminations are used for measuring (cf. figure 1). Factually, these effects cannot be compensated by solely considering the target-illumination -- if different to the measurement-illumination -- with the classical calculation of XYZ-values (tristimulus values) and the corresponding $L^*a^*b^*$-values (coordinates in the CIELAB-color-space). Figure 4 (on top) shows occurring CLIELAB-color differences up to 7.02 ΔE^*ab

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units for samples measured with illuminations A' respectively D65' (Dattner, 2011a). For the ΔE^*_{ab} calculation, the corresponding spectra are converted to $L^*a^*b^*$-values according to the established approach (CIE, 1971) using the 2° CIE standard observer and the CIE standard illuminant D65 without any adjustments.

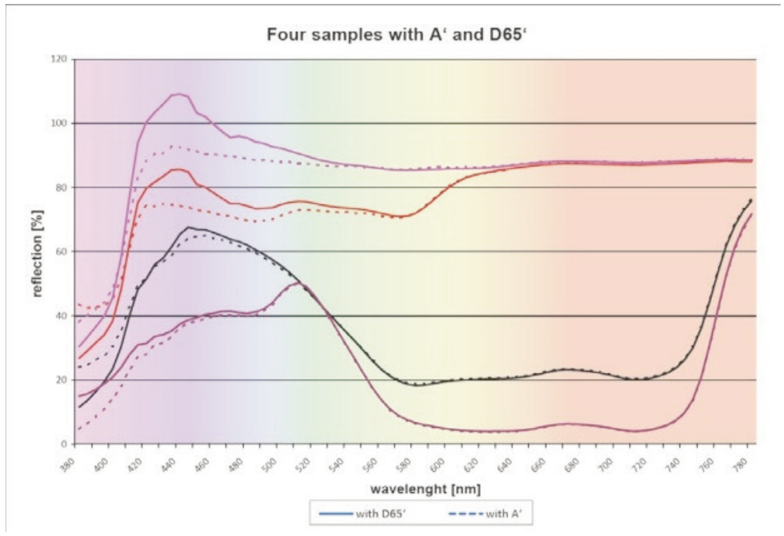

Figure 1: *The influence of two illuminants on brightened samples shown concerning CIE-A and CIE D65 (Dattner, 2011a)*

The related dilemma in printing standardization (e.g. ISO 12647-2) is the more and more usage of production papers containing OBAs that cause an exceeding of ISO tolerance limits (ISO, 2010) if a sufficient substrate correction is not conducted in the workflow. For a physically founded substrate correction, the characteristic spectral behavior of OBAs and inks and related combinations in the UV wavelength range must be considered additionally to the well- known effects in the visible range. This provides a possibility to apply substrate correction to the aim and not to the measurement, which is an alternative solution to CHUNG & TIAN's for calculating substrate-corrected aims without (Chung, 2011) applying the ISO 13655 backing correction (ISO, 2009). The main advantage of the author's solution is the possibility to estimate the impact of OBAs in terms of color validation for arbitrary measurement-illuminants or color light box conditions.

2 State of the related knowledge

2.1 Existing approaches for considering the influence of optical brightener

It is documented and explored that the effects of different OBAs in various printing substrates lead to individual, illumination-dependent effects with unprinted and fully printed surfaces (Erhard, 2003), (Green, 2008), (Zwinkels, 2008). The optical behavior of halftone samples on brightened substrates is also empirically determined

(Kraushaar, 2006), (Fiebrand, 2007), (Pertler, 2007). As mentioned, also the ISO 13655 backing correction is adapted to substrate correction in the context of OBAs (Chung, 2011), but the corresponding effects are only once physically founded described for one measurement-illumination with given relative spectral power distribution (Dattner, 2011a).

To focus on two approaches: One concerning tristimulus values by CHUNG & TIAN based on the ISO 13655 backing correction (Chung, 2011) and another related to spectral data by DATTNER & BOHN (Dattner, 2011a), spectacular similarities in the principles can be identified: Both solutions start with color data concerning samples printed on unbrightened substrate (APCO). Furthermore, this information is substrate-corrected in both cases by using the weighted difference of substrate relevant color data concerning APCO and the relevant brightened substrate. Table 1 shows both approaches in the initial form Eq.(1.1) & Eq.(2.1) (with all Summarized, a substrate correction or a compensation of related metameric effects (Dattner, 2011a) becomes possible, even though OBAs are involved. The consideration of arbitrary measurement-illuminants is not available, yet.

<table>
<tr><th>Tristimulus values based substrate correction</th><th>Spectral based substrate correction</th></tr>
<tr><td>Initial formula of CHUNG & TIAN:

Eq.(1.1)
$X_2 = X_1 \cdot (1 + C) - X_{min} \cdot C$</td><td>Initial formula of DATTNER & BOHN:

Eq.(2.1) $\beta_{calc}(\lambda) = \beta_{APCO}(\lambda) \cdot (1 + B(\lambda) \cdot \eta)$
with $\lambda \in [400\ nm, \ldots, 730\ nm]$</td></tr>
<tr><td colspan="2">Compare view:
Itemizing both initial formulas provides in brackets the comparable weighting of the associated base-value (X_{APCO} respectively β_{APCO}) with “1 + a fraction”, where differences in the numerator and also in the denominator consider OBA-affected and OBA-unaffected color information. The similarities become even more clear, since also β^{UVcut} in B(λ) can be approximated by β_{APCO} in this context of visualization.

Eq.(1.2) $X_{calc} = X_{APCO} \cdot \left(1 + \frac{X_{PW\_APCO} - X_{PW}}{X_{PW\_APCO} - X_{min}}\right) - X_{min} \cdot C$

Eq.(2.2)
$\beta_{calc} = \beta_{APCO} \cdot \left(1 + \frac{\beta_{PW\_APCO} - \beta_{PW}}{\sum_{300nm}^{410nm} |\beta_{PW\_APCO}(\lambda) - \beta_{PW}(\lambda)| \cdot \Delta\lambda} \cdot (-1) \cdot \Delta A_R \cdot (1 + D_K) \cdot \Delta S\right)$</td></tr>
</table>

Table 1: *Comparison of a tristimulus and a spectral based solution for substrate correction*

2.2 Colorimetric issues

The well known tristimulus value (XYZ) calculation considers sample-reflection, relative spectral power distribution of illuminants and CIE standard observer in the wavelength range between 380 nm and 780 nm (CIE, 1971). The illumination-dependent effects caused by brightened substrates are considered concerning arbitrary target-illuminations and one single measurement-illumination-combination (Dattner, 2011a). The consideration of arbitrary measurement-illuminations is not available, yet.

3 Method of Evaluation

Information concerning the relevant technical equipment will be introduced before results concerning an accuracy- analysis comparing the mentioned tristimulus- and the spectral-based solution are presented. Finally in this chapter, the spectral based solution is the initial point for extending the OBA-effect-modulation to the usability of arbitrary measurement-illuminations.

3.1 Test environment

An UV-Vis spectrophotometer (measurement geometry 45°x / 0°) is used to determine spectral information in the visible and in particular in the UV-range (250 nm - 780 nm) of unprinted substrate and halftone prints. Several light sources and optical filters are used to generate spectral data concerning various illuminations, including the simulations A', D50' and D65' of the CIE standard illuminants A, D50 and D65 (cf. figure 2).

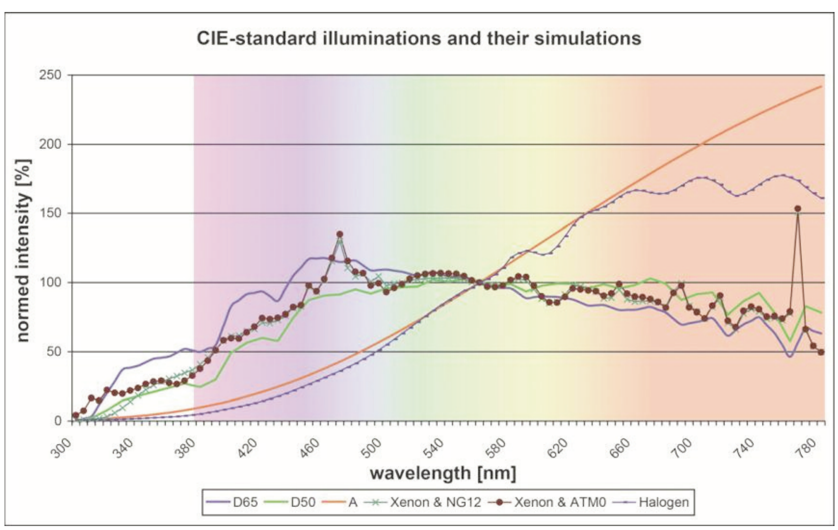

Figure 2: *CIE standard illuminants A, D50 and D65 and simulations A', D50' and D65'*

Sample-materials for the research are different substrate samples (APCO, brightened Offset-papers & brightened Proof-papers) with different OBA-types and -concentrations cf. figure 3 (left). Furthermore, relevant halftone samples printed on each mentioned substrate with warranted identical conditions and significant absorptions in the UV-Vis-wavelength range are included cf. figure 3 (right).

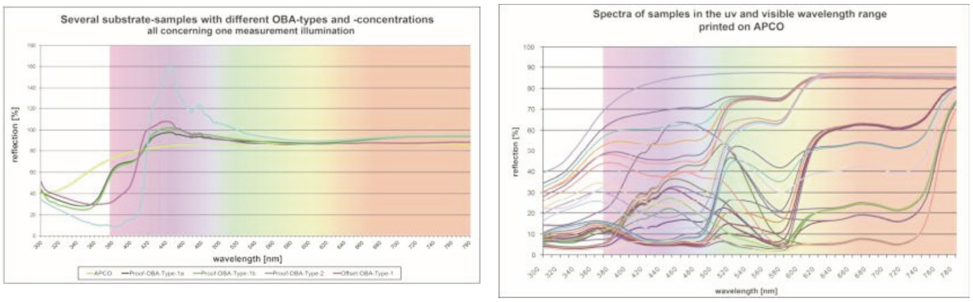

Figure 3: *Substrate samples (left) and halftone samples printed on APCO (right)*

3.2 Comparison of the mentioned tristimulus- and spectral-based solutions

An accuracy-analysis concerning the sample materials shows considerable differences between the two approaches. To classify the achieved results, figure 4 (on top) illustrates the uncorrected color differences (up to 7,02 ΔE^*_{ab} units) concerning various halftone samples measured twice, with A' respectively D65'. All spectra are transferred to CIELAB-values concerning 2° CIE standard observer and CIE

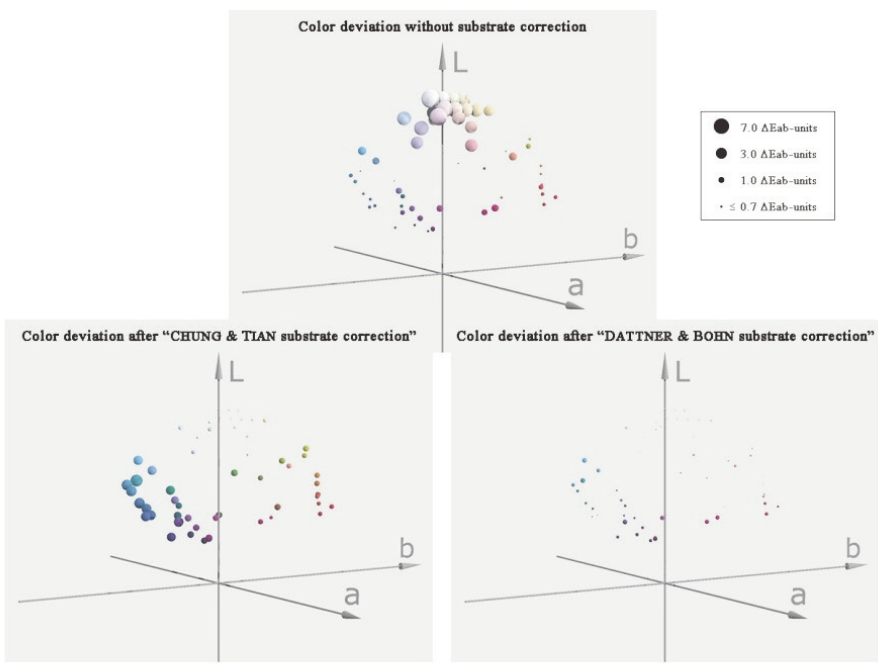

Figure 4: *Color differences in ΔE*ab-units at 2°, D65 concerning Offset-OBA-Type-1*

standard illuminant D65. Applying the CHUNG & TIAN solution reduces these color differences to a max of 3.24 (mean 1.45) ΔE^*_{ab}-units. The author's approach reduces even this reduction further more to a max of 1.13 (mean 0.58) ΔE^*_{ab}-units between measured and predicted spectra for 2°, D65 conditions cf. figure 4 (bottom-left & -right). The high prediction accuracy for pale printing- samples in both approaches is extended to all regions in the CIELAB-color-space by the author's solution due to considering the extra spectral information concerning the UV-range.

3.3 Basis for the extension of the OBA-effect-modulation to arbitrary measurement-illuminations

Since the accuracy of the author's solution is higher and the physically background is especially fitted to the brightened-substrate-correction, the mentioned extension to arbitrary illuminations is presented solely concerning the spectral approach.

Illuminations with different intensity but the same relative power distribution have no influence to the spectral data of brightened samples (X-Rite, 2008). In contrast, different relative spectral power distributions lead to individual OBA-excitations (and therefore to individual OBA-emissions) with one and the same substrate-sample.

Considering this, strong correlations concerning OBA-effects between spectra of unprinted substrates and those of halftone prints can be identified. UV-Vis spectral measurements of unprinted brightened substrate and substrate without OBAs (APCO II/II) (cf: figure 3) provide all necessary information about the effects of the involved OBA (cf.: $B(\lambda)$ defined in Eq. (2.6) Table 4). Furthermore, color information of samples printed on both substrates (with warranted identical conditions)

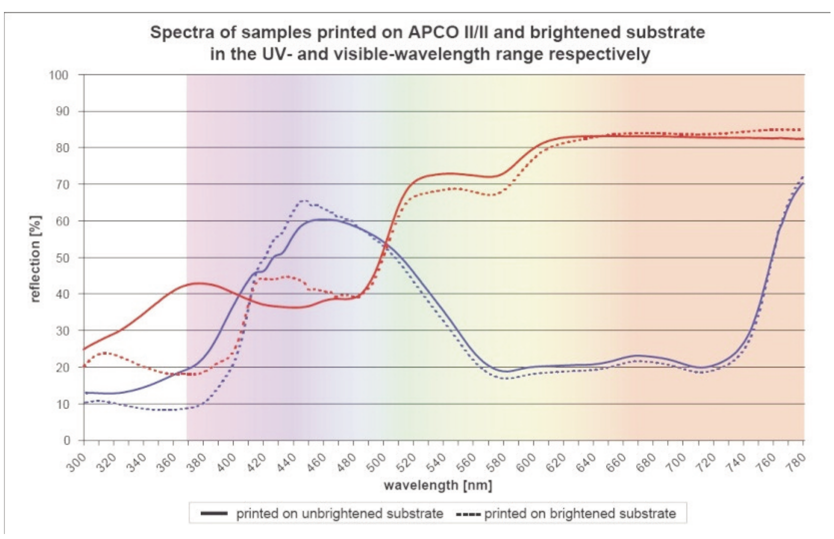

Figure 5: *Spectra of two samples printed on APCO II/II and brightened substrate (Dattner, 2011a)*

(cf: figure 5) must be included in the substrate correction (cf.: ΔA & DK defined in Eq. (2.8) & Eq. (2.9) Table 4) (Dattner, 2011a).

The expected consideration of arbitrary measurement-illuminations in the spectral solution is based on ΔS, the illumination-dependent weighting factor of the initial spectral DATTNER & BOHN approach, introduced in Eq. 2.2. Until now, ΔS is defined through the constant-weighted Riemann-sum-difference between the relative spectral power distributions $S^{UVcut}(\lambda)$of the measurement-illumination with UVcut-filter and $S(\lambda)$the light source wherefore the OBA-effects should be calculated (target-illumination). These sums are limited to the wavelength range of the OBA-excitation (300 nm - 410 nm) cf. Eq.(2.3).

$$\Delta S = \sum_{300nm}^{410nm} |S^{UVcut}(\lambda) - S(\lambda)| \cdot 3 \cdot \Delta\lambda \tag{2.3}$$

Starting point for the intended extension is that each combination of two measurement-illuminations (one with and one without UVcut-filter for calculating the brightener factor $B(\lambda)$) needs its own and individual constant-weighting factor for the OBA-effect prediction. Thus, this constant "3" in ΔS (cf. Eq.(2.3)) is only valid for one actually used combination of a single light source with and without an UVcut-filter to calculate the substrate correction for e.g. the CIE standard illuminant D65.

4 Results

To get rid of this inexpedient link between the spectral data of brightened substrate and the actually used measurement-illumination, this individual constant-weighting factor must be replaced by a universal parameter. Therefore, this parameter is localized in the context of considering the relative spectral power distributions of illuminations cf. Eq.(2.4).

$$\Delta S = \sum_{300nm}^{410nm} |S^{UVcut}(\lambda) - S(\lambda)| \cdot \varsigma \cdot \Delta\lambda \tag{2.4}$$

This ς is derived through evaluating measurements of several brightened substrates using Halogen and Xenon permanent light sources in combination with various optical filters (cf. figure 6) to simulate numerous illuminations. Using this whole set of available lamb-filter-combinations, with individual UV-intensities, offers beneficial analyzing-possibilities to the itemized solution (cf. Eq.(2.5)) concerning ς.

The values determined for ς and visualized in figure 7 are correlated to the Riemann-sum of the relative spectral power distributions of the measurement-illumination (without UVcut-filter) and concerning the wavelength range of the OBA-excitation, in the following termed as $\nabla S_{measure}$.

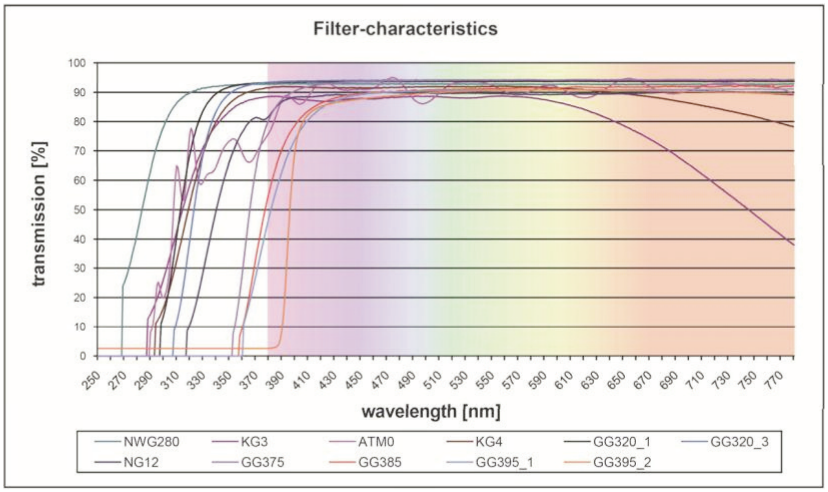

Figure 6: *Transmission of relevant filters in combination with a Xenon permanent lamp*

$$\beta\lambda = \beta_{APCO}(\lambda) \cdot \left(1 + B(\lambda) \cdot \frac{\Delta A_R \cdot (1 + D_K)}{\Delta A_{PW}} \cdot \sum_{300nm}^{410nm} |S^{UVcut}(\lambda) - S\lambda| \cdot \varsigma \cdot \Delta\lambda\right) \quad (2.4)$$

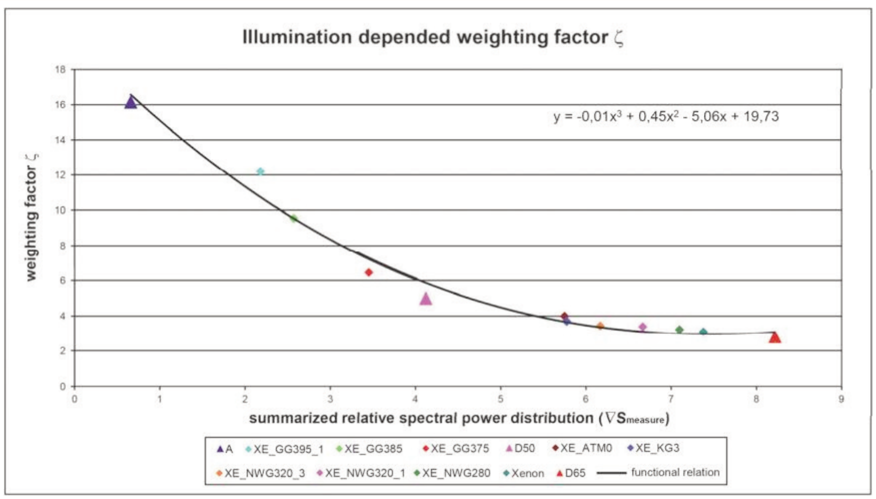

Figure 7: *Weighting factor ς of the brightener-factor in dependency of the relative spectral power distribution concerning the wavelength-range of the OBA-excitation extended by the standard illuminants D50 and D65*

Is the relative spectral power distribution of the users actual measurement-illumination known, it becomes possible to apply the OBA-effect prediction by using the functional relation for ζ (cf. figure 7), based on the individual $\nabla S_{measure}$, concerning arbitrary measurement-illuminations and target-illuminations.

This brightened substrate correction performs with measurement-illumination with a low UV-intensity even though the target-illuminations have high UV-intensities

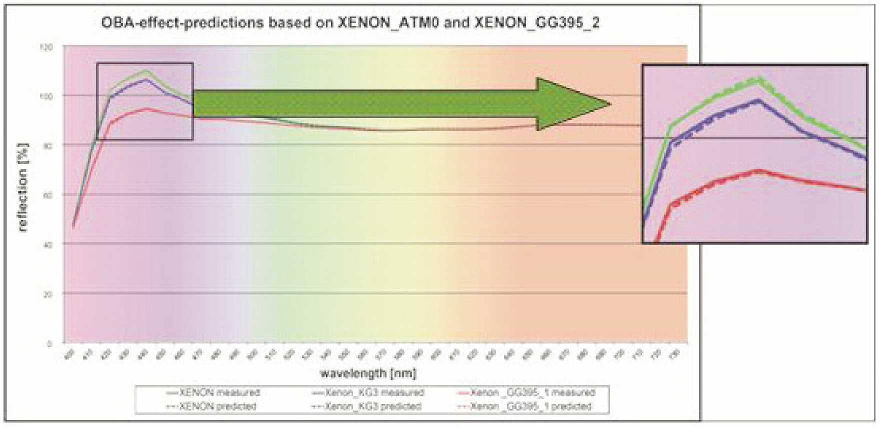

Figure 8: *Xenon with ATM0 respectively GG395_2 as measurement-illumination-combination to predict OBA-effects concerning three different target-illuminations with different UV-intensities*

OBA-effect prediction results concerning various illuminations

ΔEab optimized - functional relation	Target-illuminations (summarized relative spectral power distribution): XENON 7.38	XE_NWG280 7.1	XE_NWG 320_1 6.67	XE_NWG 320_3 6.17	XE_KG3 5.77	XE_ATM0 5.75	XE_GG375 3.45	XE_GG385 2.57	XE_GG395_1 2.81	Halogen (A) 0.66
Combination of measurement illumination with respectivly without UVcut-filter (weighting factor ζ)										
XENON [XE] 3.14	**0.19** - 0.25	**0.17** - 0.17	**0.15** - 0.07	**0.21** - 0.28	**0.18** - 0.49	**0.27** - 0.12	**0.23** - 0.41	**0.23** - 0.31	**0.34** - 0.27	**0.67** - 0.57
XE_NWG280 3.27	**0.26** - 0.49	**0.24** - 0.40	**0.22** - 0.29	**0.27** - 0.48	**0.25** - 0.69	**0.33** - 0.10	**0.30** - 0.52	**0.32** - 0.38	**0.40** - 0.32	**0.67** - 0.51
XE_NWG 320_1 3.43	**0.36** - 0.57	**0.33** - 0.47	**0.32** - 0.36	**0.36** - 0.55	**0.34** - 0.75	**0.43** - 0.16	**0.39** - 0.55	**0.35** - 0.40	**0.49** - 0.35	**0.67** - 0.50
XE_NWG 320_3 3.6	**0.16** - 0.35	**0.14** - 0.27	**0.14** - 0.18	**0.11** - 0.33	**0.14** - 0.57	**0.21** - 0.09	**0.19** - 0.45	**0.19** - 0.34	**0.25** - 0.29	**0.66** - 0.54
XE_KG3 3.76	**0.14** - 0.04	**0.15** - 0.05	**0.17** - 0.15	**0.17** - 0.11	**0.15** - 0.31	**0.10** - 0.29	**0.12** - 0.31	**0.13** - 0.24	**0.16** - 0.21	**0.66** - 0.62
XE_ATM0 4.26	**0.47** - 0.82	**0.45** - 0.73	**0.44** - 0.60	**0.46** - 0.70	**0.46** - 0.96	**0.52** - 0.35	**0.49** - 0.67	**0.49** - 0.49	**0.55** - 0.41	**0.69** - 0.45
XE_GG375 6.55	**0.20** - 1.04	**0.21** - 1.09	**0.22** - 1.16	**0.22** - 0.88	**0.21** - 0.56	**0.17** - 1.14	**0.19** - 0.20	**0.18** - 0.10	**0.16** - 0.06	**0.68** - 0.88
XE_GG385 9.7	**0.17** - 0.12	**0.18** - 0.18	**0.18** - 0.28	**0.18** - 0.11	**0.17** - 0.22	**0.15** - 0.38	**0.16** - 0.25	**0.16** - 0.20	**0.14** - 0.18	**0.68** - 0.65
XE_GG395_1 12.52	**0.16** - 0.83	**0.17** - 0.74	**0.17** - 0.62	**0.17** - 0.77	**0.16** - 0.97	**0.14** - 0.35	**0.15** - 0.68	**0.15** - 0.49	**0.13** - 0.41	**0.69** - 0.44
Halogen (A) 16.15	**1.69** - 1.64	**1.6** - 1.55	**1.51** - 1.48	**1.41** - 1.36	**1.52** - 1.45	**1.20** - 1.20	**0.97** - 0.92	**0.67** - 0.64	**0.54** - 0.51	**0.35** - 0.39

Table 2: *Accuracy overview for the OBA-effect prediction concerning various illuminations: all CIELAB-values are calculated concerning 2° CIE standard observer and the target-illumination to characterize the achieved results.*

and vice versa. For example, the summarized UV-intensity of the measurement-illumination XE_Atm0 is in between of the $\nabla S_{measure}$ values of the target-illuminations XENON, XE_KG3 and XE_GG395_1, never the less the prediction accuracy is very high in each case (cf. figure 8).

Only slight adjustments concerning the weighting factor $\zeta$for B(λ) are necessary (cf. figure 7), if different measurement-illuminations are close to the CIE standard illuminant D50, like it is recommended in ISO 13655 to minimize the variations in measurement results between instruments due to fluorescence. The related fundamental adjustments are done implicit in the background at the brightener-factor-calculation, where the illumination specific spectra of the unprinted substrate are included.

If there are large deviations to the measurement condition M1 (e.g. illuminations of low UV-intensity comparable to measurement condition M0 or the CIE standard illuminant A), adjustments of ζ(in parallel to the implicit adjustments of B(λ)) provides a substrate correction for arbitrary target-illuminations with an accuracy shown in table 2, last row. These results are suitable, especially if compared to the color-deviation which occurs, if OBA- effects are not considered but eliminated by measurements with UVcut-filter (cf. table 3).

OBA-impact without correction										
Illumination	XENON	XE_NWG280	XE_NWG 320_1	XE_NWG 320_3	XE_KG3	XE_ATM0	XE_GG375	XE_GG385	XE_GG395_1	Halogen (A)
ΔEab between spectra measured with and without UVcut-filter	8.30	8.04	7.78	7.23	6.68	6.57	3.79	2.54	1.97	2.03

Table 3: *Color deviation caused by OBA-effects between spectra measured with respectively without UVcut-filter, calculated for CIELAB-values concerning 2° CIE standard observer and the particular illumination*

Focused solely to illuminations close to measurement condition M1, the adapted functional relation for ζleads to negligible deviations between "optimized" and calculated via the mentioned "functional relation" (cf. table 2). Thus the ΔE-values in table 2 become nearly identical for both cases and this holds true even for different OBA-type- samples (cf. figure 3 left) visualized in and figure 9.

For users, with no more information concerning their measurement-illumination than "close to measurement condition M1", $\zeta$is fixed to one single value e.g. ζ:= 3.36 and the solution provides even though a prediction accuracy of 0.55 ΔE-units (mean value) concerning the six measurement-illuminations with the highest $\nabla S_{measure}$ values of this survey (XENON, XE_NWG280, XE_NWG320_1, XE_NWG320_3, XE_KG3, XE_ATM0). Concerning the target-illumination A' the prediction accuracy is even though acceptable at 1.03 ΔE-units.

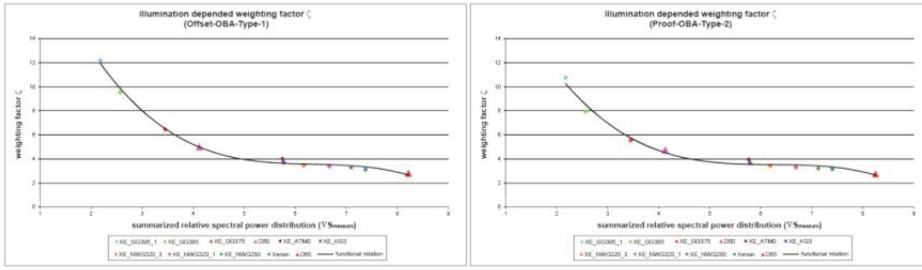

Figure 9: *Functional relation for ⌘ with focus on illuminations close to measurement condition M1 concerning two different OBA-types*

Considering this completed OBA-effect prediction concerning unprinted substrates, arbitrary halftone-spectra can be substrate corrected by using the solution of Dattner & Bohn without any restrictions. In figure 4 (bottom right) the very high accuracy of the mathematical implementation of the spectral approach is already shown on a CIELAB- scale. Holding in mind the results mentioned concerning the consideration of arbitrary measurement-illuminations (cf. figure 5 and table 3), figure 10 shows the accuracy also concerning corrected spectra of halftone-samples. Without the zoom-in-window the nearly perfect match can hardly be visualized, as mentioned with the unprinted substrate correction before (cf. figure 8).

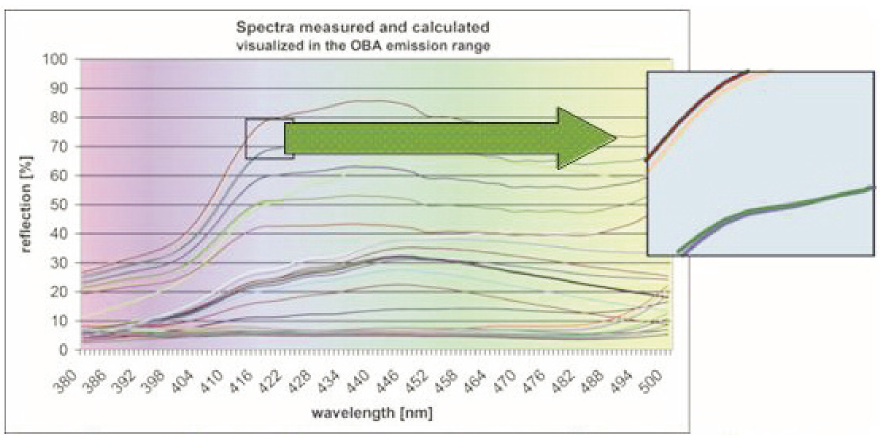

Figure 10: *Measured and predicted spectra concerning the relevant wavelength range Note: the zoom-in window shows the nearly perfect match (Dattner, 2011a)*

Remark 1:
Several types of OBAs were identified and analyzed in this survey. Samples with an OBA-excitation solely in the visible spectrum above 400 nm are individual tasks: The OBA-emission is completely unchanged even though measurements are done with or without UVcut-filter; only a Halogen illumination provides a lower OBA-emission as achieved with illuminations mentioned before. The author's solution can be adapted also to this type of OBA, by shifting the relevant wavelength range accordingly to the actual OBA-excitation and -emission-range along with using suitable illumination-combinations.

Remark 2:
If there are large differences in the relative-power-distribution-characteristic between measurement- and target- illumination, the consideration of different distributions in the visible range (e.g. 480 nm - 500 nm) enhances the prediction accuracy. Typical effects due to the OBA-wavelength-shift at narrow-high peaks in the distribution takes place, while there are no effects with illuminations with a smooth distribution, like e.g. the CIE-A illuminant. These must be compensated, if a higher spectral-resolution (e.g. 3 nm) in the substrate correction is intended.

5 Conclusions

The comparison of a tristimulus substrate correction with the spectral based solution confirms that spectral color data includes more detailed information, which is necessary to achieve a high accuracy in the prediction of OBA-effects. The additional spectral information concerning the UV-range enables the physically founded modulation and the consideration of the related relative power distributions of the measurement-illumination show the robust and reliable performance of the author's solution.

Color samples printed on both unbrightened and brightened substrate measured without UVcut filter provide all necessary information to predict OBA-effects also for illuminations that differ to the measurement conditions. Remarkable improvements are achieved concerning all tested illuminations and best results are generated by using illuminants with relative spectral power distributions close to CIE-D50 or CIE-D65. These provide an OBA-effect prediction with a high accuracy even for target-illuminations which are close to the CIE standard illuminant A. Using A' for measurements tends to not such a perfect match.

Never the less, OBAs will no longer be unconsidered and hidden by measurements with UVcut-filter at the colorimetric cross-validation of printing products. The introduced spectral approach can be used to estimate the color perception of arbitrary samples independent of the measurement-light-source and the illumination at which the samples should be validated. Therefore, reliable color-difference-estimations via CIELAB-ΔE are provided even though OBAs are involved and the sufficient substrate correction becomes more flexible.

In figure 11 the general overview of the brightened substrate correction on a spectral scale is visualized to line up all fundamental steps and their relations. It is easy to see where and how further research will be conducted, by looking at figure 12. The main improvement will be getting rid of the necessity of spectral information within the UV-range and of required color data concerning samples printed on unbrightened substrate. Our ongoing research bases on very promising laboratory results, by now.

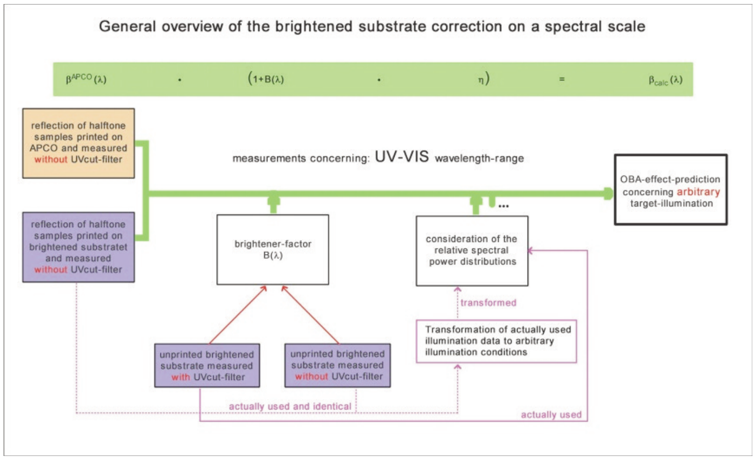

__Figure 11:__ Measured and predicted spectra concerning the relevant wavelength range
Note: the zoom-in window shows the nearly perfect match (Dattner, 2011a)

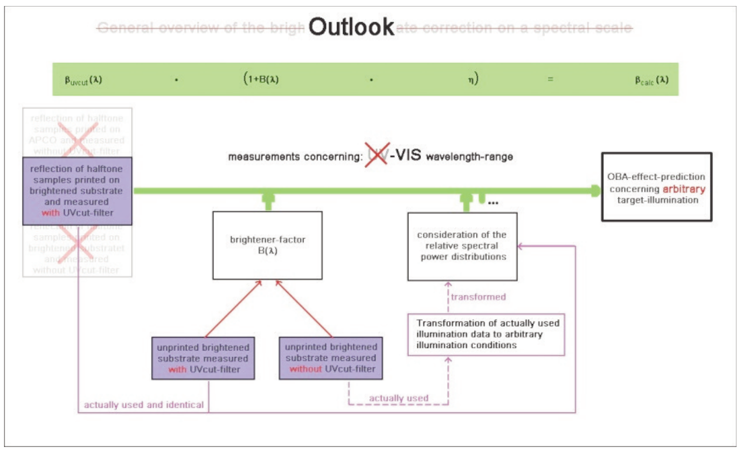

__Figure 12:__ Outlook

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Initial CHUNG & TIAN formula:	*Initial DATTNER & BOHN formula:*
Eq.(1.1) $X_2 = X_1 \cdot (1 + C) - X_{min} \cdot C$	Eq.(2.1) $\beta_{calc}(\lambda) = \beta_{APCO}(\lambda) \cdot (1 + B(\lambda) \cdot \eta)$ with $\lambda \in$[380 nm, …, 730 nm]
Eq.(1.2) $C = \frac{X_{w2} - X_{w1}}{X_{w1} - X_{min}}$ X_1 is one of the tristimulus values of Substrate_ 1 or target aim. X_2 is one oft he substrate-corrected tristimulus values based on Substrate_2. C is a constant. X_{w1} is one of the measured tristimulus values of Substrate_ 1. X_{w2} is one of the measured tristimulus values of Substrate_2. X_{min} is one of the minimum tristimulus values of TAC_{Max} printed on Substrate_1.	Eq.(2.6) $B(\lambda) = \beta_{PW}(\lambda) - \beta_{PW}^{UVcut}(\lambda)$ with $\lambda \in$[380 nm, …, 730 nm] Eq.(2.7) $\eta = \frac{\Delta A_R \cdot (1 + D_K)}{\Delta A_{PW}}$ Eq.(2.8) $\Delta A = \sum_{300nm}^{410nm} \lvert\beta_{APCO}(\lambda) - \beta(\lambda)\rvert \cdot \Delta\lambda$ Eq.(2.9) $D_K = \lvert\beta_{APCO}(450nm) - \beta(450nm)\rvert$ Eq.(2.3) $\Delta S = \sum_{300nm}^{410nm} \lvert S^{UVcut}(\lambda) - S(\lambda)\rvert \cdot 3 \cdot \Delta\lambda$ $\beta_{calc}(\lambda)$ is the substrate-corrected spectrum of halftone samples. $\beta^{UVcut}(\lambda)$ is the corresponding measurement with UVcut- filter. $B(\lambda)$ is the wavelength dependent brightener factor (Dattner, 2011b) based on (Eitel, 1968). η is a weighting factor, which contains: • ΔA_{PW} and ΔA_R, which are defined as a Riemann integration concerning the wavelength range of the OBA-excitation between $\beta_{APCO}(\lambda)$ and $b(\lambda)$ for unprinted and printed samples respectively with step size $\Delta\lambda$. • D_K is the difference between printed samples at the wavelength range of the main emission of the OBA. • ΔS is the previous illumination-dependent weighting factor without possibility to estimate the impact of arbitrary illuminants.

Table 4: *Related definitions for both mentioned substrate correction solutions*