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Mitigation of light-induced damage on modern digital prints: Photographs and documents

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This study is part of a larger research project dedicated to digital print preservation issues – the Digital Print Preservation Portal (DP3). This work quantifies the potential of glazing materials to mitigate different types of light-induced damage – colorant fade, paper yellowing, changes in paper gloss, and loss of optical brightening agent (OBA) function – that occur to digitally printed photographs and documents when on display. Prints were subjected to xenon lighting to simulate daylight through window glass in a series of arrangements: without glazing, with plain framing glass (soda-lime) in a sealed or unsealed package, and with UV blocking glass in a sealed or unsealed package. Sealed packages served the purpose of isolating the samples from atmospheric pollutants, known to contribute to the deterioration of certain print types. In this study, the use of UV-filtering glass protected prints from colorant fade, paper yellowing, and paper gloss change to an extent. Protection conveyed by plain glass was less comprehensive and less effective than UV glass. Neither type of glazing was able to keep the OBAs functional by the end of the light exposure. It was also seen that light-induced damage to digital prints is due not only to UV radiation, but also to visible light, and that different digital prints may be more vulnerable to one or the other. Protecting sensitive prints from UV radiation and budgeting the amount of light they may be exposed to should be essential to any print display policy in order to ensure longevity.

Keywords: Digital print, Inkjet, Light, Mitigation, UV, Glass, Filter, Fade

Introduction

This investigation is an extension of previous work published in *Studies in Conservation*. It is also part of a larger research project, the Digital Print Preservation Portal (DP3), which examines digital print preservation issues and provides information, skills, and tools for the care of digitally printed collections (http://www.DP3project.org). Our previous work examined the light fastness of prints (photographs and documents) created with the most commonly used digital technologies – inkjet, electrophotography, dye sublimation, and digital press. The study showed that these prints undergo colorant fade, paper yellowing, and changes in paper gloss when exposed to light (Venosa *et al.*, 2011). It is well known that both UV radiation and visible light play important roles in the fading of colorants and paper discoloration (Jürgens, 2009, p. 222). Although visible light is necessary for viewing purposes, UV radiation is essential only for the function of optical brightening agents (OBAs). In the absence of OBAs, eliminating virtually all UV radiation without affecting the visual light spectrum is thought to be ideal, as it removes some of the harm while keeping the color quality of the image. Although there have been several studies on the use of glazing to protect other types of materials such as paintings (Hackney, 2007) and textiles (Bowman & Reagan, 1983; Crews, 1988, 1989), there is no known work by an academic or heritage organization on the effectiveness of glazing in mitigating light-induced damage on digital prints (some work has been done by manufacturers and for-profit testing laboratories). It cannot be assumed that digital prints behave in the same way as other materials. Furthermore, it cannot be assumed that all digital prints share the same behavior. In addition, previous studies focus mainly on colorant fade, which is not the only type of light-induced damage digitally printed materials undergo.

In this study we examine the success of plain framing glass (soda-lime) and UV filtering glass, in sealed and unsealed packages, to mitigate

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light-induced colorant fade, paper yellowing, changes in paper gloss, and loss of OBA function in prints produced with modern digital technologies (inkjet, electrophotography, dye sublimation, and digital press), as well as offset lithography and traditional color photography (chromogenic) as points of comparison. The results of this investigation will help establish the best practices for framing and displaying digitally printed objects to limit light-induced damage.

Experimental methods

Test samples

This study included modern digital prints – inkjet, black-and-white (B&W) electrophotography, color electrophotography, dye sublimation, and digital press, traditional color photographs (chromogenic), and offset lithographs. The digital prints were created using a wide variety of the primary digital printing technologies and manufacturer brands used today and should therefore reflect in general the types of objects in, or entering, collections. For inkjet and digital press, variations in paper type and/or colorant type were included in the sample set. Traditional color photography (chromogenic) and offset lithography were included as reference points for readers familiar with the behaviors of prints produced by these technologies. B&W electrophotography is also likely to serve as a reference point.

Only one sample of each category was used. The particular samples were chosen from a larger pool of samples used in a previous DP3 study (Venosa *et al.*, 2011) based on their performance (with the exception of the inkjet dye print on fine-art paper sample which is an added category). For the purpose of this study, samples known to exhibit one or more aspects of light-induced damage (colorant fade, change in paper gloss, and/or paper yellowing) were deemed ideal.

All digital samples were printed using original equipment manufacturer materials that dated from 2010 through 2013. The printing technology and paper types tested are presented in Table 1.

Table 1 Test samples: photographs and documents

Printing technology	Paper type*
Photographs	
Digital	
Inkjet – dye	Inkjet photo-porous 1
Inkjet – dye	Inkjet photo-polymer**
Inkjet – dye	Inkjet fine art 1
Inkjet – pigment	Inkjet photo-porous 2
Inkjet – pigment	Inkjet fine art 2
Dye sublimation	Dye sublimation
Traditional reference	
Color photo	Chromogenic silver-halide
Documents	
Digital	
Inkjet – dye	Plain office
Inkjet – pigment	Plain office
Color electrophotography	Plain office
Digital press – dry toner	Coated glossy 1
Digital press – liquid toner	Coated glossy 2
Traditional reference	
B&W electrophotography	Plain office
Offset lithography	Coated glossy 3

*1, 2, and 3 indicate different brands or treatments within a paper type.
**Also known as *swellable*.

Test target

The test target consisted of a color step wedge containing 10 levels of cyan, magenta, yellow, red, green, blue, and black to assess color change, and a non-printed patch to assess paper yellowing, gloss change, and loss of OBA function. Prints of a pictorial image were also included in the exposures for illustrative purposes. For each technology tested, 20 replicates of the target were printed to be tested in the light or to be kept in the dark (as controls), in different framing arrangements.

The targets and pictorial images were printed in sRGB color space. Best-quality printer settings (e.g. 'Best Photo' and 'Photo Enhanced') were selected, when available, for photo printing systems. Default settings were used for document printing systems. After printing, all samples were left to dry at 23°C and 50% RH for two weeks before testing.

Light exposures

Samples were exposed to high-intensity xenon arc illumination for six weeks in the following framing arrangements: without glazing, with plain glass (soda-lime) in a sealed or unsealed package, and with UV filtering glass in a sealed or unsealed package.

The spectral power distributions of the light source (xenon arc through Window-Q filter) and of the light source through each of the glazings used in this study (Fig. 1) show how the UV glass eliminates all of the UVB radiation (280–315 nm), most of the UVA radiation (315–400 nm), and as much visible light (400–750 nm) as the plain glass. The thickness of the glazing was 2 mm. Exposure time and intensity were selected to replicate 25 years of display in institutions; this allowed for time to complete the experiments during the project's three-year duration.

Sealed packages served the purpose of isolating the samples from atmospheric pollutants, which are known to contribute to the deterioration of certain print types. (In sealed packages, the air was not evacuated, nor replaced with inert gas; any atmospheric pollutants trapped inside are predictably consumed without further ingress of pollutants.) In addition to photolysis (direct damage by light), some prints

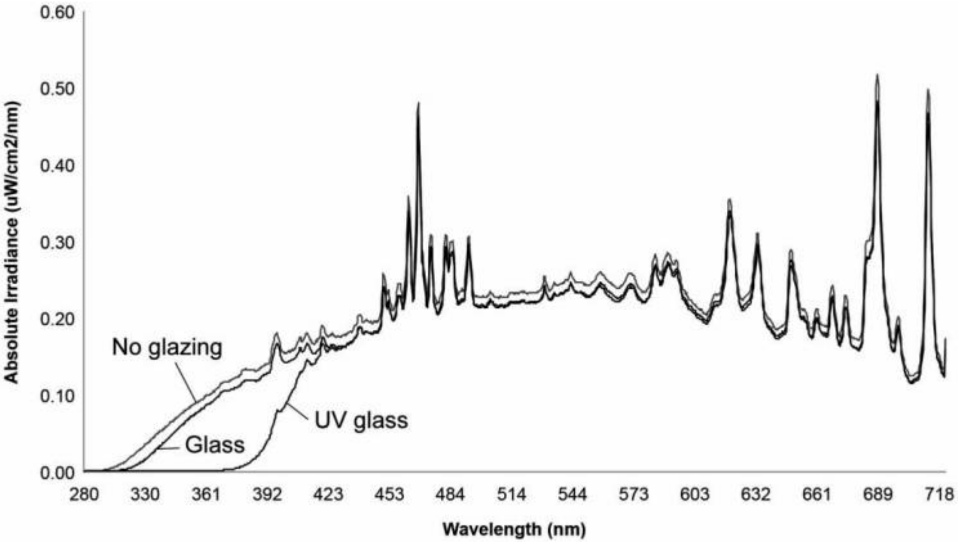

Figure 1 Spectral power distribution of the light source (xenon arc through Window-Q filter), the light source through plain glass, and the light source through UV glass.

undergo photo-oxidation (Brill, 1980, p. 181) (i.e. the oxidation of colorants accelerated by light and/or UV radiation), which occurs in the presence of airborne oxidizing agents. Certain prints are sensitive to ozone and/or nitrogen dioxide, two pollutants commonly found in the atmosphere. The long-term harmful effects of these pollutants on digital and traditional prints have been well documented and include colorant fade, paper yellowing, embrittlement, and colorant bleed (Zinn *et al.*, 1994a, 1994b; Burge *et al.*, 2010, 2011). However, pollutants were not accelerated in this test, so their effects on the results of this study are thought to be minor.

Control samples were kept in the dark without glazing, with plain glass in a sealed package or with UV glass in a sealed package. All configurations were tested in duplicate.

A Q-Sun Xenon Test Chamber (Westlake, USA) with Window-Q filters with an illumination intensity of 50 klx was used to simulate diffuse daylight through window glass. The samples were positioned on the specimen tray mounted in metal holders with metal backings. In unsealed framing arrangements, the glazing was separated from the print by two strips of white mat board (100% cotton cellulose, four-ply) placed between the short sides of the sample holder and the glass. This mat board was non-reactive according to ISO 18916 (Imaging materials – Processed imaging materials – Photographic activity test for enclosure materials). Sealed packages were prepared in the same way as unsealed packages, and then sealed with non-reactive polyester tape with acrylic adhesive. The samples' location on the tray was rotated weekly to account for the asymmetry of the position of the light source with respect to each sample. The temperature and humidity across the specimen plane were set to 25°C and 50% RH.

Assuming a typical display intensity of 450 lx for 12 hours per day (Wilhelm, 1993, pp. 107–11), six weeks of constant, high-intensity exposure is approximately equivalent to 25 years of typical display. This calculated prediction also assumes that all degradation is caused only by light, and excludes the simultaneous effects of pollutants, humidity, and heat, which also occur during typical display, and that the reciprocity law holds true. The reciprocity law states that the total chemical change is constant for a given exposure, independent of the intensity, where exposure equals intensity multiplied by time (Bunsen & Roscoe, 1862). A number of external factors and intrinsic properties of the material in question can cause deviations from this law (Feller, 1994, pp. 50–4).

Each material/framing arrangement was evaluated for colorant fade, paper yellowing, loss of OBA function, and changes in paper gloss occurring during the six-week light exposure. In addition, the spectral transmission of the glazing was assessed to monitor changes in the ability to filter UV radiation and light during the testing period.

Glazing stability

An Ocean Optics Jaz spectrometer (Winter Park, USA) and Ocean Optics SpectraSuite Software were used to obtain the spectral power distribution of the light source (xenon arc through Window-Q filter), the light source through plain glass, and the light source through UV filtering glass. Measurements were taken at the beginning and end of the six-week light exposure. The spectroscope's light sensor (connected to the unit through a fiber optic) was placed at the sample plane through a hole in the sample tray. The software was set to average 20 scans, with an integration time of 20 milliseconds. Results are based on the average of three measurements taken through each glazing.

Density measurements

To evaluate the fade of colorants and the yellowing of papers, all target patches, including a non-printed patch ($D_{\min}$), were measured in ANSI/ISO Status A visual, red, green, and blue density using a Gretag Spectrolino/Spectroscan (Grand Rapids, USA) (no UV filter, 2° observer, D50 illuminant) before testing and at 1-week intervals during exposure. In density mode, this device conforms to ISO Standard 5-4:1995, ISO Standard 5-3:1995, and ISO Standard 5-2:1991. Results for each material/framing arrangement are based on the averages of the two replicates.

Colorant fade

The amount of colorant fade undergone by the samples during testing (calculated as percentage of change from original density) was determined for the cyan, magenta, and yellow colorants in the primary color patches (cyan, magenta, and yellow), in secondary color patches (red, green, and blue), and in the composite neutral patch. All calculations were performed for an initial density of 0.5.

For each material, the weakest colorant is considered the life-limiting colorant and is used for reporting purposes. The weakest colorant of a set was selected based on its relative performance throughout the exposure period in all framing configurations. The data are presented as the average percentage of life-limiting colorant remaining after the six-week exposure.

Paper

Papers were assessed for three types of light-induced damage: yellowing, changes in gloss, and loss of OBA function.

Yellowing

Paper yellowing was determined as the average change in blue density of the $D_{\min}$ patch (calculated as percentage of change from original density) after six weeks of exposure to high-intensity light.

Gloss change

Papers were classified as *glossy*, *semi-glossy*, and *matte* according to the gloss meter's operating manual's directives. A non-printed portion of the targets was measured with a BYK Gardner micro-TRI-gloss meter (Columbia, USA). This device measures gloss using three different angles of incident light. Glossy surfaces were measured at 20°, semi-glossy surfaces at 60°, and matte surfaces at 85°, as recommended by the manufacturer. Measurements were taken before testing and at one-week intervals for a total of six weeks. For each material/framing arrangement, the average gloss change (calculated as percentage of change from original gloss value) endured over the six-week exposure is reported. Averages reported are based on two replicates.

OBA loss

OBAs are compounds that absorb light in the ultraviolet and violet region (340–370 nm) of the electromagnetic spectrum, and re-emit light in the blue region (420–470 nm). They are added to some papers during manufacture to make them appear brighter and whiter. There are numerous compounds used as OBAs; however, the type/s of OBAs present in the papers used in this study are unknown.

The reflective spectrum of each paper type was obtained with a Gretag Spectrolino (Grand Rapids, USA) (no UV filter, 2° observer, D50 illuminant) to determine the presence of brighteners and document changes in reflectance. Observations and measurements were made on unexposed samples and samples exposed to high-intensity illumination for six weeks. Spectra obtained are based on the average of two replicates.

Results and discussion

All results are based on numerical data confirmed by visual assessment. This data is based non-optimal light levels and light source to create a worst-case scenario. Objects exposed to very low light levels or low-UV light sources may undergo less change.

Glazing stability

The hue of the UV glass used in the test was initially orange and shifted to green-yellow during the six-week exposure to light. This color shift was due to the fade of dyes that the manufacturer adds to the glazing with the intention of changing the characteristic green hue of plain glass for one more appealing. In spite of the noticeable change in the appearance of the UV glass (Fig. 2), its spectral transmission in the UV region was not altered in great measure (Figs. 3 and 4). As expected, the spectral transmission of the plain glass did not change during the testing period.

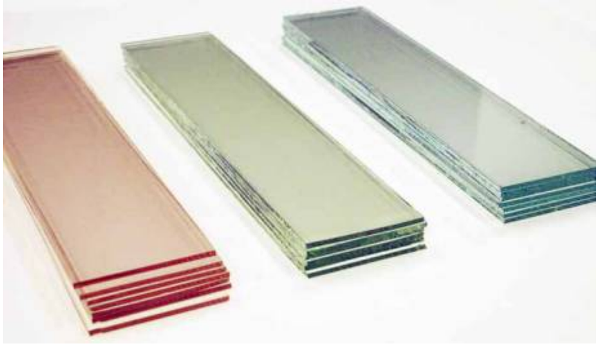

Figure 2 Color shift of UV glass from orange to yellow-green after six weeks of exposure to 50 klx xenon arc light (equivalent to 25 simulated years of exposure to daylight through window glass). Unexposed UV glass – left; exposed UV glass – center; and plain glass – right.

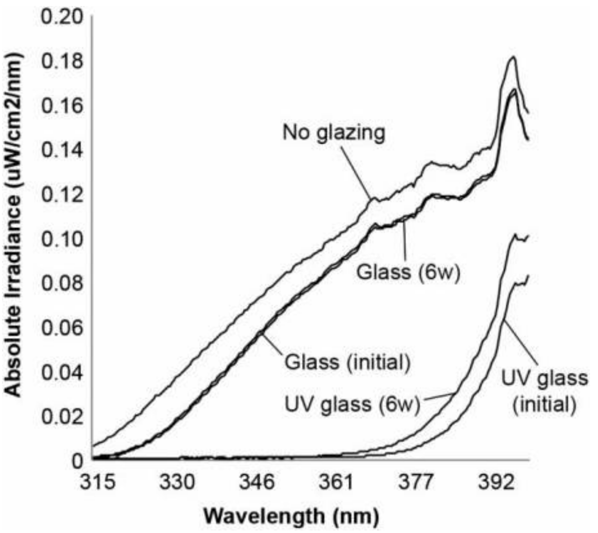

Figure 3 Spectral power distribution in the UV region of the light source (xenon arc through Window-Q filter), the light source through plain glass, and the light source through UV glass at the beginning and end of the six-week exposure to 50 klx of xenon arc light.

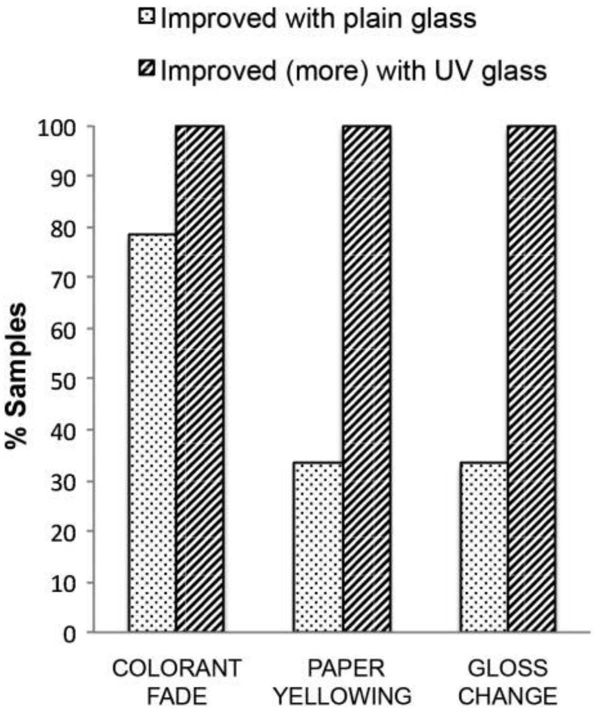

Figure 5 Percentage of samples subjected to 50 klx of xenon arc light for six weeks that saw a decrease in light-induced damage (colorant fade, paper yellowing, and gloss change) when exposed in a sealed frame with plain glass or UV glass, relative to samples exposed unframed.

General effects of glazing

The use of UV filtering glass offered a certain level of protection from colorant fade, paper yellowing, and paper gloss change to every sample tested. Protection conveyed by plain framing glass was less comprehensive, providing partial protection from fading to most of the samples tested (79%), and from yellowing and gloss change to a third of them (Fig. 5). The protection conveyed by the different glazing configurations varied from subtle to substantial depending on the sample and is analyzed in detail below. These results cannot be extrapolated beyond the test exposure period because the deterioration rate may not be linear nor conform to any other known polynomial or logarithm.

Neither type of glazing, whether sealed or unsealed, was able to keep the OBAs functional after the six-week exposure.

Effects on colorant fade

For each sample, the same colorant remained the weakest (life limiting) of the set throughout the exposure in all the framing configurations. It is worth pointing out that some samples presented more than one weak colorant, but only the weakest was considered for the goal of this study. In some cases, two colorants of a set showed similar behavior when exposed without glazing, but when exposed with glazing only one was protected; the other colorant was therefore considered the weakest (life limiting).

The average percentage of life-limiting colorant remaining after 25 simulated years of display is presented in Table 2. In the great majority of samples the life-limiting colorant was yellow.

There was no significant difference between samples exposed in sealed and unsealed framing configurations to a 95% confidence using a paired-difference test. The visual assessment of the samples correlated well with the data. It is important to stress that the methodology employed in this study accelerates only the effects of light, and not the effects of pollutants. The

Figure 4 OBA-containing print behind different glazings, viewed under UV lamp to show the ability of new and aged UV glass to filter UV radiation. Without glazing – left; with plain glass – center-left; with unexposed UV glass – center-right; with UV glass previously exposed to 50 klx of xenon arc light for six weeks.

Table 2 Average percentage of life-limiting colorant remaining in the 0.5 density patch after six weeks of exposure to 50 klx of xenon light in different framing configurations

Print type*	Life-limiting colorant	Framing configuration No glazing (%)	Framing configuration Glass unsealed (%)	Framing configuration Glass sealed (%)	UV glass unsealed (%)	UV glass sealed (%)
IJ dye/photo-porous 1	Yellow	16**	18**	18**	35	39
IJ dye/photo-polymer	Yellow	44	39	43	54	56
IJ dye/fine art 1	Magenta	9	14	16	49	51
IJ pigment/photo-porous 2	Yellow	10	18	24	77	79
IJ pigment/fine art 2	Yellow	13	23	31	82	86
Dye sublimation	Cyan	4	24	24	38	38
Chromogenic	Yellow	18	18	18	23	21
IJ dye/plain	Yellow	27	27	26	48	49
IJ pigment/plain	Yellow	22	28	30	85	93
B&W EP/plain	n/a	90	95	95	99	98
Color EP/plain	Yellow	29	31	30	76	74
DP dry toner/coated glossy 1	Yellow	66***	70***	71***	80	81
DP liquid toner/coated glossy 2	Yellow	57***	67***	66***	78	78
Offset/coated glossy 3	Yellow	22**	23**	24**	21**	20**

*IJ, inkjet; EP, electrophotography; DP, digital press.
**Percentage due to paper yellowing only (total colorant fade).
***Percentage partially due to paper yellowing.

concentration of atmospheric pollutants during the test did not (nor was intended to) replicate the amount of pollutants a print may be exposed to in 25 physical years, which would expectedly be much higher. The use of sealed frames may prevent the detrimental effect long-term exposure to pollutants has on certain digital print types. In this test, the benefit of using the sealed framing configuration was most noticeable for Inkjet Pigment/Fine Art 2 and Inkjet Pigment/Plain.

For all digital prints, the use of UV filtering glass extended the life of the print. In most cases, the use of plain glass was beneficial, but always to a lesser extent than the UV glass. It is important to note that yellowing of the substrate may increase the measurement of the yellow colorant. Consequently, in prints that yellow, the loss of yellow colorant may be underestimated. This was the case for DP Dry Toner and DP Liquid Toner (no glazing and plain glass), in which yellow colorant and paper yellowing were both present after exposure (Table 2, footnote ***). It was also true for Offset (all framing configurations) and IJ Dye/Photo-Porous 1 (no glazing and plain glass) in which the yellow colorant faded completely and the measurement of the yellow colorant was actually due solely to paper yellowing (Table 2, footnote **). Visual assessment of the prints was key in confirming such occurrences. Even in these cases, the advantage of using UV glass remains clear.

The use of UV glass had a great impact on the retention of colorants in pigment prints. On average, the retention of the life-limiting colorants increased from 15 to 86% (Fig. 6). In dye prints, the retention of the weakest colorant increased several folds with the use of UV glass; however, the maximum retention attained was 56% of the original density (Fig. 7).

Since the use of UV glass did not prevent all light-induced fade, it is clear that UV radiation is not the only cause of fade. The rest of the fade can be attributed to other factors, essentially visible light. In all but one of the prints tested, the cause of fade was clearly a combination of both UV radiation and visible light. Fig. 8 shows the proportion of fade due to each of these factors after 10 simulated years of display. After this time period, fade of the life-limiting colorant in the pigment prints was mainly due to UV radiation. In dye prints instead, the life-limiting colorant was on average roughly equally sensitive to visible light and UV radiation. The relative contributions of visible light and UV radiation may vary throughout the light exposure. This variation will occur for a given sample, unless the colorant-fade rates are linear for both the unframed and the UV-glass-framed replicates. Non-linear colorant-fade rates are commonly the case. Once the colorants have reached total fade, the calculation of relative contributions of visible light and UV radiation can no longer be made. After 25 simulated years of display, some of the samples tested had reached this point of complete (or nearly complete) colorant loss.

Effects on paper

Of the papers evaluated in this study, all but one underwent at least one type of light-induced damage.

Figure 6 Inkjet pigment print on photo-porous paper after exposure to 50 klx of xenon arc light for six weeks in different sealed framing configurations. Unexposed – left; exposed with UV glass – center-left; exposed with plain glass – center-right; and exposed without glazing – right. The use of UV glass noticeably preserves the print's weakest colorant (yellow).

Figure 7 Inkjet dye print on photo-porous paper after exposure to 50 klx of xenon arc light for 6 weeks in different sealed framing configurations. Unexposed – left; exposed with UV glass – center-left; exposed with plain glass – center-right); and exposed without glazing – right. The use of glazing noticeably protects the colorants, but retention of the weakest colorant (yellow) was only 39% of the original density with UV glass.

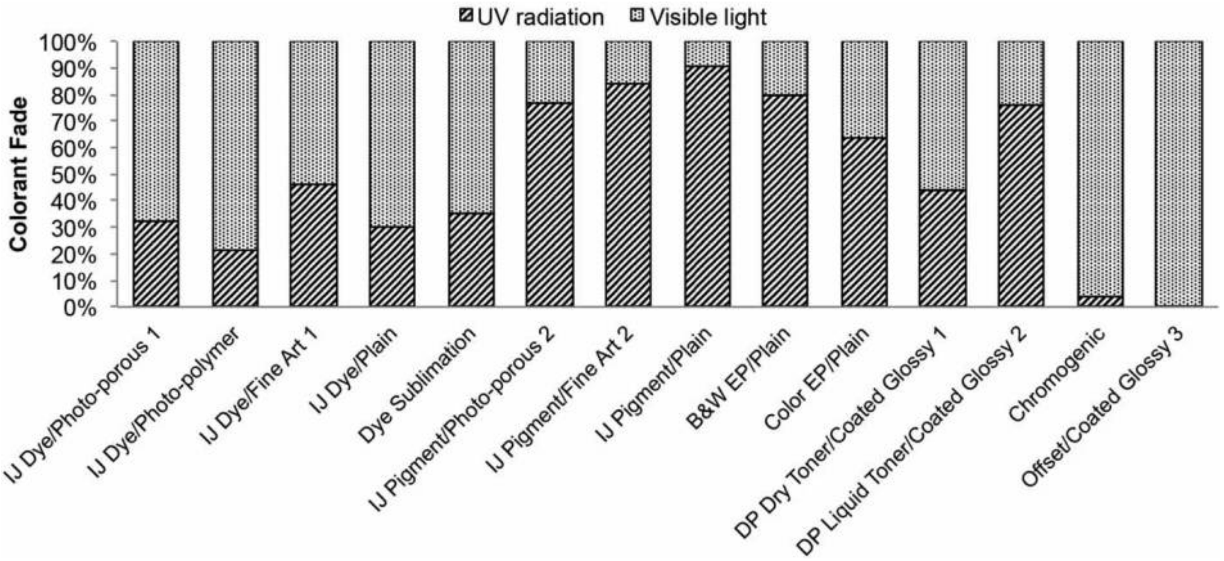

Figure 8 Proportion of colorant fade prevented by use of sealed frames with UV glass after 10 simulated years of display under daylight through window glass. The rest of the fade is due to factors other than UV radiation, essentially visible light. (IJ: inkjet; EP: electrophotography; DP: digital press.)

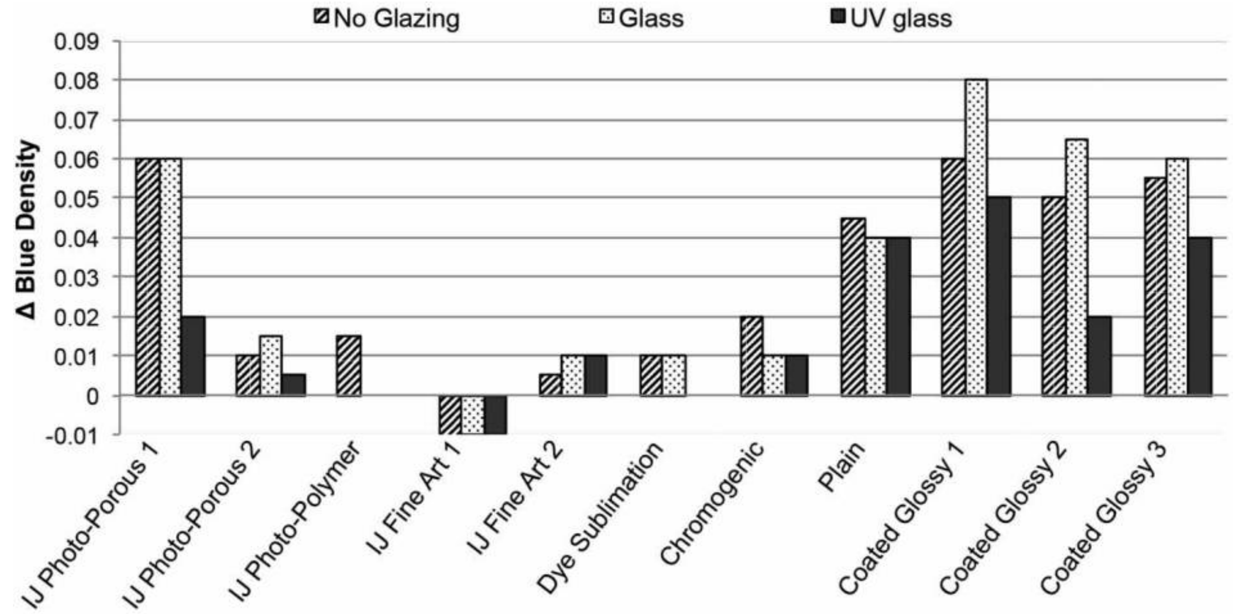

Figure 9 Paper yellowing calculated as average change in blue density values for the non-printed patch (D_{min}) after exposure to 50 klx of xenon arc light for six weeks in different framing configurations: without glazing, in a sealed frame with plain glass, and in a sealed frame with UV glass. (IJ: inkjet; DP: digital press.)

The paper that did not suffer any of the changes evaluated was the Inkjet Photo Fine Art 1 paper. This was a matte paper without OBAs.

Yellowing

Eleven different papers were used to produce the 14 samples tested. Of these, six yellowed (Fig. 9) and the yellowing was visually detectable. The yellowing was very subtle in plain paper, consequently the benefit of glazing was hard to discern. In the other five samples, UV glass visibly mitigated the effect of light to varied extents. The benefit of using UV glass was more pronounced in Inkjet Photo-porous, Coated glossy 2 (for liquid-toner digital press), and Coated glossy 3 (for offset) papers. All three coated glossy papers framed with glass were yellower (numerically and visually) than their unframed counterparts. This may be the result of light bleaching of the yellowed unframed sample, while the sample framed with glass was still yellowing. Yellowing and light bleaching are known to occur sequentially and repeatedly in some papers (Wilhelm, 2003, pp. 444–49; Jürgens, 2009, p. 259). The Inkjet Fine Art 1 paper also underwent bleaching.

Samples in sealed and unsealed packages showed similar results. As mentioned in the section on Color fade, the amount of pollutants that interact with a print in actual time is expected to be higher than during this study, thus any benefit that pollutant-sensitive prints may receive from the use of sealed frames is not fully represented here.

Gloss change

Fig. 10 shows the average percent change in gloss for samples subjected to six weeks of exposure to xenon arc illumination. Most of the glossy papers suffered changes in gloss after exposure to light. Matte papers did not show any change in this respect. All papers that underwent light-induced changes in gloss benefited from the use of glazing (Fig. 10). Chromogenic paper followed by Inkjet Photo-polymer and Inkjet Photo-porous 1 papers showed the greatest changes in gloss. The use of either type of glazing prevented the gloss changes in the first two papers, while only UV glass was able to prevent the gloss change in the third paper. In the Digital Press and Offset samples,

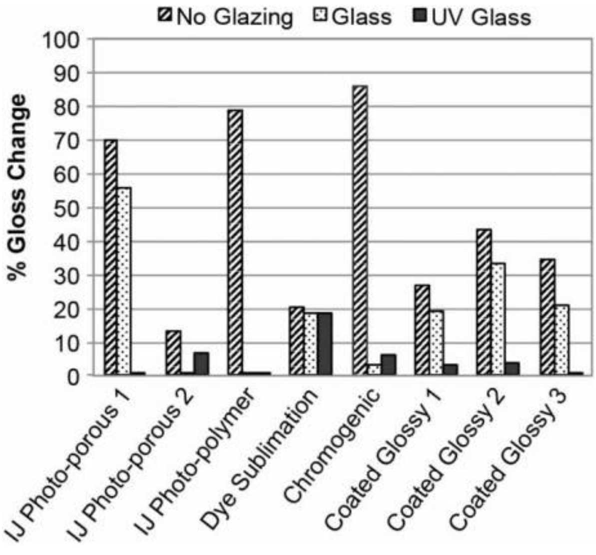

Figure 10 Percent of paper gloss change after exposure to 50 klx of xenon arc light for six weeks in different framing configurations: without glazing, in a sealed frame with plain glass, and in a sealed frame with UV glass. (IJ: inkjet; DP: digital press.)

Figure 11 Inkjet dye print on photo-porous paper after exposure to 50 klx of xenon arc light for 6 weeks in different framing configurations, viewed under UV lamp to show degrees of OBA protection conveyed by UV glass and plain glass. Unexposed – left; exposed with UV glass – center-left; exposed with plain glass – center-right; and exposed without glazing – right.

the changes were more subtle and the benefit of using glass, while measurable, was not visually noticeable; conversely, UV glass did provide visually detectable gloss protection to these papers.

The results for samples in sealed and unsealed packages were similar.

OBA loss

All papers tested, except Fine Art 1, contained OBAs. After six weeks of exposure to high-intensity xenon light, in every case the OBAs were almost completely degraded regardless of the framing package in which they were exposed. This was evidenced by a decrease in reflection in the blue region of the spectrum corroborated by visual inspection under UV lamp. Spectra were obtained only in unexposed and six-week exposed samples, thus we do not know how soon after starting the exposure the OBAs lost the ability to fluoresce. However, in most cases, in samples framed with UV glass the decrease in the reflectance was less than in unframed samples or samples framed with plain glass. While this difference was not enough to sustain the ability of the brighteners to fluoresce at their original levels (or close), it shows a delay in their degradation. A time-based study would help understand how much light these samples can tolerate before the brighteners lose their capacity. The prevention of the degradation of OBAs by UV glass was greatest in the Inkjet Photo-porous 1 and Coated glossy 2 (for liquid-toner digital press) papers. Fig. 11 illustrates the visual appearance of one of the samples with the best-preserved OBAs.

Samples in sealed and unsealed packages showed similar results.

Conclusions

This study should be understood as an assessment of the value of using glazings to mitigate light-induced damage to digital prints. It cannot be assumed that all prints within a category (e.g. inkjet pigment on fine art paper) will behave as the particular print from that category actually used in this study. It was previously seen that differences in the light sensitivities of samples *within* a category can be larger than differences in performance *between* categories (Venosa *et al.*, 2011).

In this study, the use of frames with UV glass benefited all prints tested to different degrees. In some cases the use of UV glass had a critical impact on the permanence of the print, while in others the improvement was less dramatic. The ability of plain framing glass to reduce light-induced damage was much more limited than that of UV glass. Even if harmless and potentially beneficial, other considerations may be necessary when considering the use of glazings. Glazings may change the appearance of prints in a number of ways. The glazing's tint can alter the color rendition of the print; its reflectivity can alter the perceived sheen and topography of the print and, prints made on papers containing OBAs, appear duller when viewed behind UV glass due to the removal of incident UV radiation. In addition, glazing may be costly depending on its type and size. Ultimately, the preservation benefits, effects on aesthetics of the print, and cost of the glazing are to be weighed by the conservators and curators caring for the object.

It is important to appreciate that light-induced damage to digital prints is due not only to UV radiation, but also to visible light, and that some prints are more vulnerable to visible light than to UV radiation, and vice versa. It is critical to understand that light-induced damage is irreversible and that rest periods between exhibitions do not provide recovery. Budgeting the amount of light an object may be exposed to should be an essential component to any print display policy in order to ensure longevity.

Light has been shown to induce or increase the cracking of the ink-receiving layer of inkjet prints (Salesin & Burge, 2012). In the same way, light may increase the tendency of some digital prints to abrade or scratch. Exploring the potential of light to affect the physical vulnerability of digital prints and the effectiveness of framing glazings to mitigate light-induced physical damage would be an important addition to our current understanding of the practicality of glazings in the preservation of digitally printed materials. This work is currently underway at IPI.

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