Effect of Light on Modern Digital Prints: Photographs and Documents

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This project examines the light fastness of prints created with the most commonly used digital technologies (inkjet, color electrophotography, dye sublimation and digital press) along with prints created using traditional technologies (color photography, black-and-white (B&W) electrophotography and offset lithography). The inclusion of traditional prints provides benchmarks for collection care professionals to better gauge the significance of the results. In this study, prints were subjected to two types of lighting used independently to simulate daylight through window glass and artificial indoor illumination. Five aspects of light damage were assessed: fade in the mid-tone neutral, fade in the darkest neutral tone, paper yellowing, changes in paper gloss and text readability. In general digital prints were less sensitive to light than traditional prints; but each digital printing technology produced at least one sample that performed worse than its traditional benchmark in at least one of the aspects of light damage studied. Therefore, it is recommended that cultural heritage institutions strive to provide the most benign environment possible, taking display practices currently in use for traditional prints as a minimum starting point for the care of digital prints. Close monitoring for signs of change is also recommended.

INTRODUCTION

With a growing number of digitally printed materials –photographs and documents– entering cultural heritage institutions, information about the vulnerabilities of these materials is of vital importance. Cultural heritage institutions have already reported deterioration of digital prints in their collections [1]. One of the factors that can cause deterioration is light. The sensitivity of digital printing materials to light has long been recognized by the industry, giving rise to many small-scale, brand-specific studies. There has not been a comprehensive examination of digital prints, including a large number of samples representing the diversity of digital printing technologies, colorants and papers used today. The purpose of this project was to carryout such an examination. In this study, the main digital printing processes and materials were studied along with traditional printing processes and materials. The inclusion of traditional prints provides reference points for collection care professionals to better gauge the significance of the results. Unlike previous work that was focused only on pictorial images, this study includes text-based documents as well. The results of this study will provide collection care professionals with an understanding of the sensitivities of digital printing materials compared to those of traditionally printed material.

EXPERIMENTAL METHODS

Test Samples

The test samples represented the main digital printing technologies used today to produce digital photographs and documents – inkjet, color electrophotography, dye sublimation and digital press (production scale color electrophotography). Traditional prints were represented by traditional color photography, B&W electrophotography and offset lithography. For each technology, variations in colorant type and paper type were also represented when possible. Multiple systems (printer/paper combinations) for each print type were tested when possible to improve the validity of the results. All samples were printed using original equipment manufacturer (OEM) materials that dated from 2007. The printing technology and paper types tested as well as the number of systems of each type, tested under xenon and fluorescent light, are presented in Table 1.

Table 1. *Test samples: photographs and documents*

Print Type		No. of Systems Tested	
Printing Technology	Paper	Xenon	Fluorescent
PHOTOGRAPHS			
Digital			
Inkjet – Dye	Inkjet Photo – Porous	3	3
Inkjet – Dye	Inkjet Photo – Polymer [a]	3	3
Inkjet – Pigment	Inkjet Photo – Porous	2	2
Inkjet – Pigment	Inkjet Photo – Fine-Art	3	3
Dye Sublimation	Dye Sublimation	2	2
Traditional Reference			
Color Photo	Chromogenic Silver-Halide	2	2
DOCUMENTS			
Digital			
Inkjet – Dye	Plain Office	3	3
Inkjet – Pigment	Plain Office	3	3
Color Electrophotography	Plain Office	3	3
Digital Press – Dry Toner	Coated Glossy	2	2
Digital Press – Liquid Toner	Coated Glossy	1	1
Traditional Reference			
B&W Electrophotography	Plain Office	3	3
Offset Lithography	Coated Glossy	1	1

[a] Also known as *swellable.*

Test Targets

Three different targets were designed to assess the effect of light on different aspects of a digital photograph or document. Prints of a pictorial image were also included in the exposures for comparative and illustrative purposes. All targets were printed in sRGB color space.

COLOR TARGET. The color target was used to examine color changes (in paper and colorants) caused by exposure to xenon arc and fluorescent light. This target included cyan, magenta, yellow, red, green and blue patches each at ten levels of darkness, and neutral patches at twenty levels of darkness in roughly equal increments as well as a non-printed patch (Fig. 1).

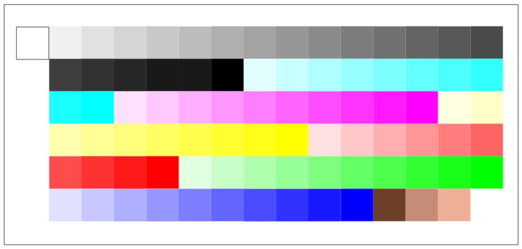


Figure 1. *Color target, used to assess changes in color occurring in the colorants and the paper of a print type.*

GLOSS TARGET. Gloss targets were used to evaluate changes in gloss caused by xenon arc illumination. (Xenon arc was the light source of choice because preliminary results had shown that xenon has a greater effect on paper gloss than fluorescent light.) The gloss target consisted of non-printed paper except for the cases of dye-sublimation and traditional color photo papers. Dye-sublimation papers were printed to Dmin to include the protective layer that is applied during printing. Traditional color photo papers were unexposed and processed to Dmin.

TEXT TARGET. The text target was used to assess the effects of fluorescent light on the readability of documents. (Due to the limited space in the xenon arc unit, text targets were only tested under fluorescent light.) This target consisted of a white area with lines of black text and a black area with lines of white text. The text font was Times New Roman with sizes ranging between 8 points and 14 points (Fig. 2).

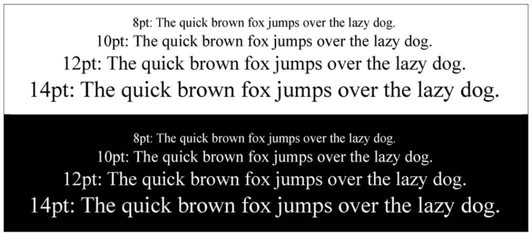


Figure 2. *Text target, used to assess the readability of documents after exposure to light.*

PICTORIAL IMAGE. Pictorial images were exposed to xenon arc and fluorescent illumination for illustrative purposes (Fig. 3).

Figure 3. *Pictorial image, used for illustrative purposes.*

Five replicates of each target were printed. Two samples were tested in each light source and one was kept as a control in the same room the testing occurred, but in the dark. 'Best Photo' and 'Photo Enhanced' printer settings 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 ºC and 50% RH in the dark for two weeks before testing.

Light Exposures

Samples were subjected to two types of lighting –xenon arc and fluorescent– used independently, for a total of 12 weeks. Assuming a typical display intensity of 450 lux for 12 hours per day, 12 weeks of constant, high-intensity exposure is approximately equivalent to 50 years of typical display. This prediction also assumes that all degradation is caused only by light, and excludes the simultaneous effects of pollutants, high humidity and heat, which also occur during typical display.

XENON ARC LIGHT. A *Q-Sun Xenon Test Chamber* with an illumination intensity of 50 kilolux was used to simulate daylight through window glass. *Window-Q* filters were placed between the xenon lamps and the samples. The samples were positioned on the specimen tray mounted in metal holders with metal backings. 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 ºC and 50% RH.

FLUORESCENT LIGHT. A custom built fluorescent light unit with an illumination intensity of 50 kilolux was used to simulate artificial indoor illumination. The unit uses forty-two GE F72T12- CW-1500-0 cool white fluorescent tubes positioned on a cylinder that constantly rotates, changing the relative position of each lamp with respect to each sample. This rotation accounts for possible variations in intensity between lamps. A non-reactive and non-yellowing white material (100% cotton cellulose, 4-ply white mount board) was used as a backing for the sample. The temperature and humidity across the specimen plane were set to 23 ºC and 50% RH.

For both tests, the ambient air was filtered through a carbon filter to reduce the presence of air pollutants.

Measurements and Evaluations

Each sample was evaluated for colorant loss, paper yellowing, changes in paper gloss and text readability. Evaluations were made after 2, 6 and 12 weeks of exposure to high-intensity light which are approximately equivalent to 8, 25 and 50 simulated years under the assumptions described above.

COLORIMETRY. All color targets were measured using a Gretag Spectrolino/Spectroscan (no UV filter, 2º observer, D50 illuminant) for CIELAB L*a*b* before exposure and at weekly intervals. Delta E (CIE 1976) values, for exposure times of 2, 6 and 12 weeks, were then calculated.

The following equation was used to calculate delta E:

$$\Delta E = \sqrt{\left(L^*_t - L^*_i\right)^2 + \left(a^*_t - a^*_i\right)^2 + \left(b^*_t - b^*_i\right)^2}$$

where L^*, a^* and b^* represent the coordinates of a three-dimensional color space; L^* being the lightness, a^* the redness-greenness and b^* the yellowness-blueness that describe a specific color. Subscripts i and t correspondingly indicate measurements taken before and after exposure.

Because delta E captures the changes occurring in any of the three color dimensions (L^*, a^* or b^*), it was considered the best overall measure to report here. Delta E indicates the occurrence of change and its extent; however it does not indicate in which direction that change occurs. The average delta E value for each print type is reported.

PAPER YELLOWING. The density of a non-printed patch (Dmin) in all color targets was measured with both the Gretag Spectrolino/Spectroscan (no UV filter, 2º observer, D50 illuminant) for CIELAB L*a*b* and an X-Rite 310 densitometer. Measurements were taken in unexposed samples and in samples exposed to 12 weeks of high intensity illumination.

Note: Visual observations correlated better with the measurements taken with the densitometer than with those taken with the spectrophotometer; the reason for this is that the illuminant in the spectrophotometer includes UV radiation which confounds the results when optical brighteners are present in some papers.

CHANGES IN GLOSS. Gloss targets were measured with a BYK Gardner micro-TRI-gloss meter. This device measures gloss using three different angles of incident light. Glossy surfaces were measured at 20°, semi-gloss surfaces at 60° and matte surfaces at 85°, as recommended by the manufacturer. Measurements were taken before exposure and after 2, 6 and 12 weeks of exposure to xenon light. Three measurements were taken on each gloss target and averaged. The average change in gloss for each paper type is reported.

TEXT READABILITY. Text targets exposed to constant high-intensity fluorescent light for 12 weeks were assessed visually to determine the smallest readable font size between 8 and 14 points.

RESULTS AND DISCUSSION

As stated previously, the goal of this project was to evaluate the light sensitivities of the primary digital print technologies (inkjet, electrophotography, and dye sublimation) and their most common sub-categories (e.g. dye inkjet on porous-coated photo paper, liquid toner electrophotography, etc.) and to compare these results to the light sensitivities of the various traditional print materials (silver-halide color photo, B&W electrophotography, and offset lithography) with which collection care personnel are already familiar. It was not within the objectives or scope of the project to evaluate the myriad of ways in which *individual* digital printing products (for example an Epson 3800 printer using Epson K3 inks on Hahnemühle Photo Rag paper) would change on display. The results described in the figures below, therefore, are *averages* of multiple prints within each category (Table 1).

While measurements were taken on all of the patches in the color targets, it was critical to select from this data quantitative measures that most closely matched the visual appearances of the prints. It was determined that delta E of the maximum black (usually mostly or just black colorant, and a good measure for text fade) and a grey mid-tone (a mixture of cyan, magenta, yellow and sometimes black colorants, and a good measure for image fade) was the best measure allowing analysis of hue shift and fade all in one relevant parameter. Blue density was used for paper yellowing because visual observations of the prints correlated better with blue density than delta E or delta b*; the reason for this may be that the illuminant in the spectrophotometer includes UV radiation which may confound the results when optical brighteners in papers are present.

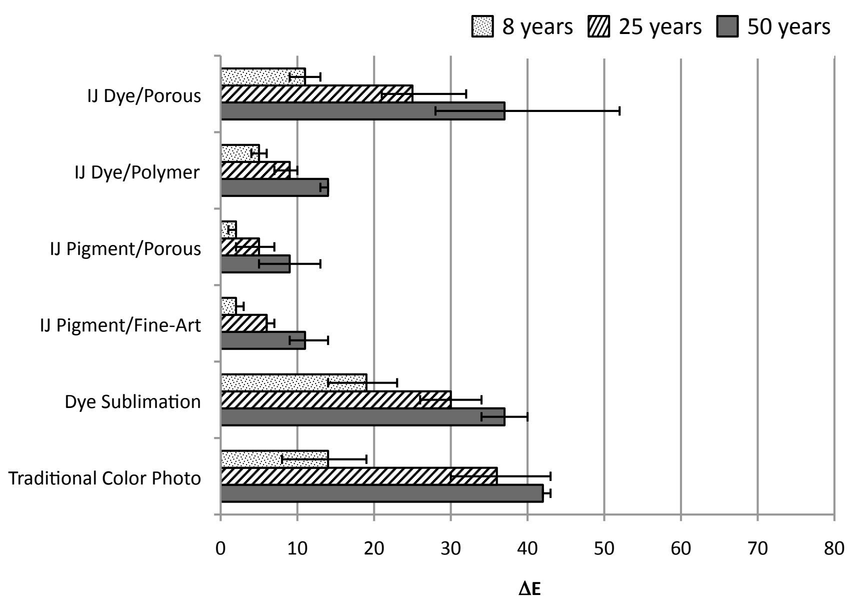
Note that in all graphs below, error bars indicate the range of values for each print type. Therefore, print types for which only one system was tested do not have error bars. Wide error bars (large variability within a print type) do not allow for generalizations and make comparisons to other print types difficult or impractical.

Colorimetry

Fig. 4 shows average delta E values for Dmid after 2, 6 and 12 weeks of exposure to xenon arc illumination.

The following is a summary of the effects of light on **Dmid**: Over time the relative sensitivities of the print types changed. After 50 simulated years, all types of digitally printed photographs performed on average as well or better than the traditional color photographic prints. However one individual system of inkjet dye on porous paper performed worse than the traditional color photographs tested. The vulnerability of all digital documents fell in between the sensitivities of our reference documents –B&W electrophotography (the least sensitive) and offset lithography (the most sensitive). Of all the prints tested, those in which the image is formed by dyes (inkjet dye, dye sublimation and traditional color photography) were the most vulnerable. Color electrophotographic prints were more sensitive than B&W electrophotographic prints. Digital press prints were less sensitive than offset prints.

a)



b)

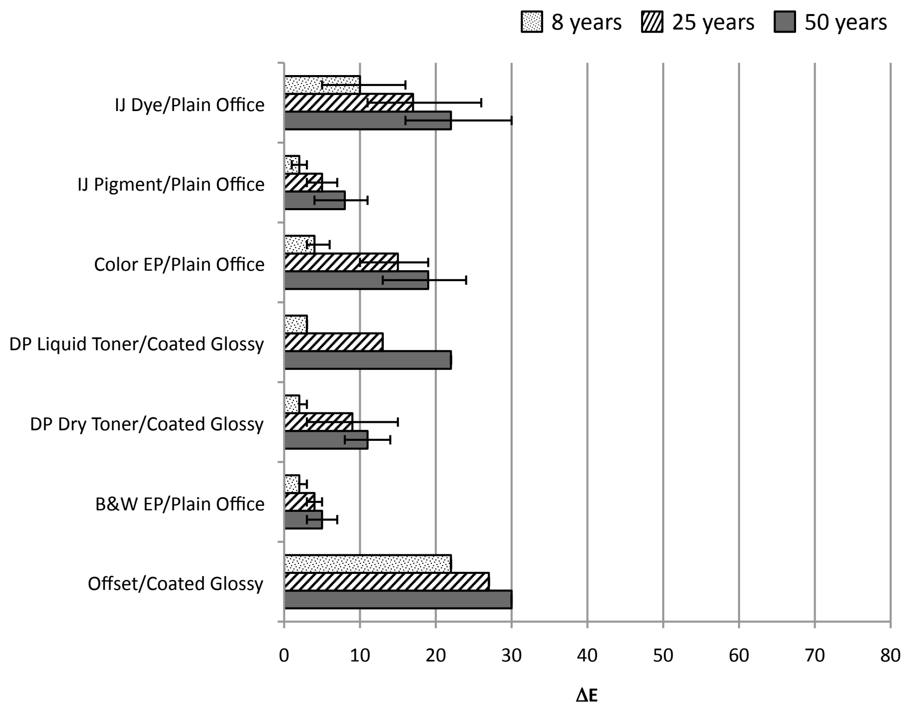
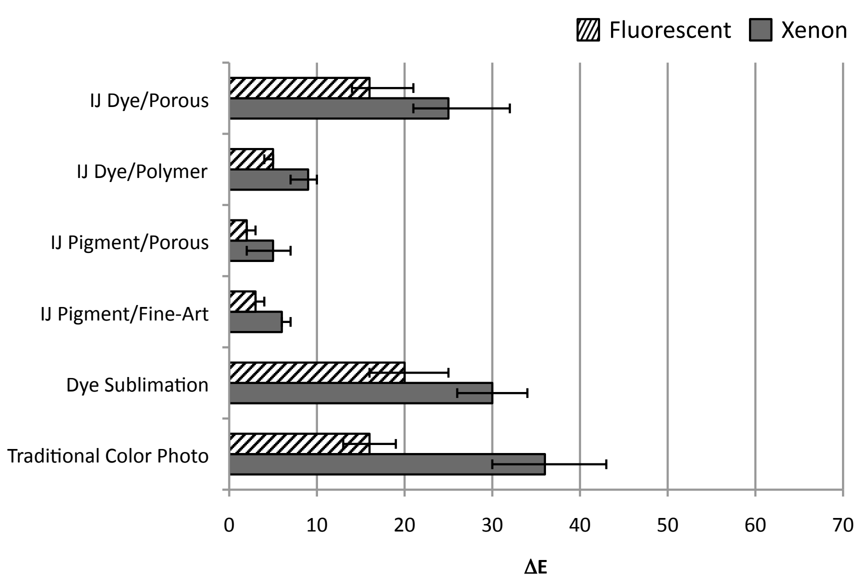


Figure 4. *Average delta E values for the mid-tone neutral patch (Dmid) (RGB 125, 125, 125) after 2, 6 and 12 weeks of exposure to 50 Klux xenon arc light (equivalent to 8, 25 and 50 simulated years of display under daylight though window glass);* ***a)*** *photographs* ***b)*** *documents. The error bars indicate the range of values for each print type. IJ, inkjet; EP, electrophotography; DP, digital press.*

Fig. 5 is a comparison between delta E values for Dmid in prints exposed to xenon arc light versus prints exposed to fluorescent light for 6 weeks.

a)



b)

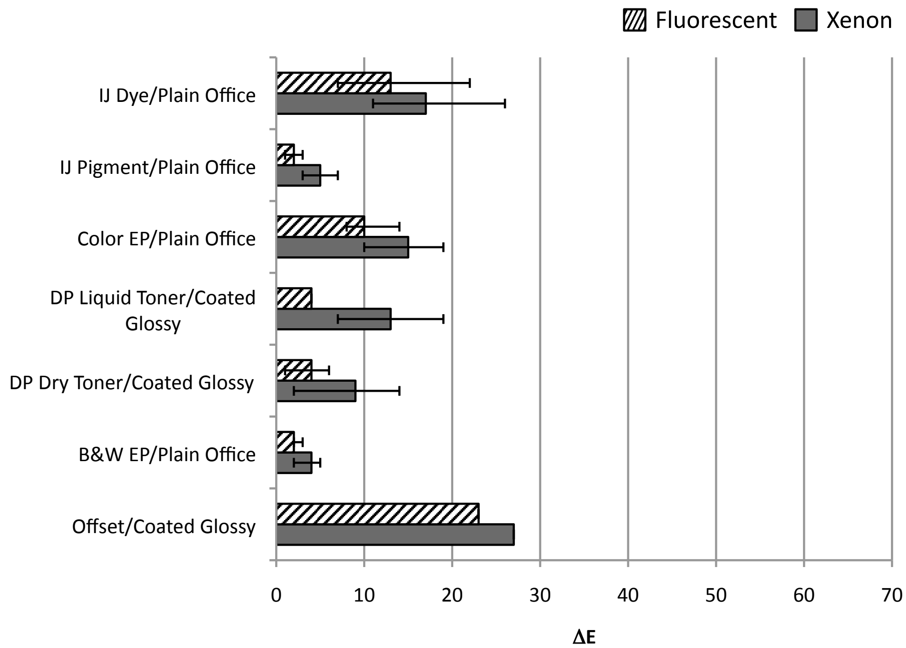


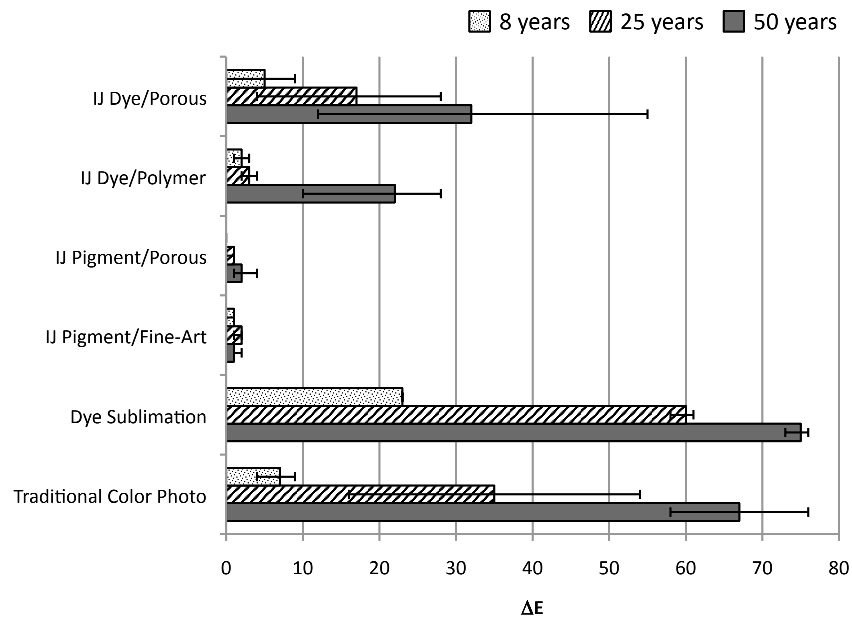
Figure 5. *Average delta E values for the mid-tone neutral patch (Dmid) (RGB 125, 125, 125) after 6 weeks of exposure to 50 Klux fluorescent or xenon arc light (equivalent to 25 simulated years of display under artificial indoor illumination and daylight through window glass respectively);* ***a)*** *photographs* ***b)*** *documents. The error bars indicate the range of values for each print type. IJ, inkjet; EP, electrophotography; DP, digital press.*

For all prints tested, xenon arc light produced greater changes than fluorescent light in Dmid after 25 simulated years of exposure. Fig. 6 is an example of the different degrees of fade produce by the two light sources. The ratios between the changes produced by xenon arc light to those produced by fluorescent light varied between print types.

Figure 6. *Dye sublimation print in which xenon arc produced more fade than fluorescent light after 12 weeks of exposure to 50 Klux intensity. Unexposed (left), exposed to fluorescent light (center) and exposed to xenon arc light (right).*

Fig. 7 shows average delta E values for Dmax after 2, 6 and 12 weeks of exposure to xenon arc illumination.

a)



b)

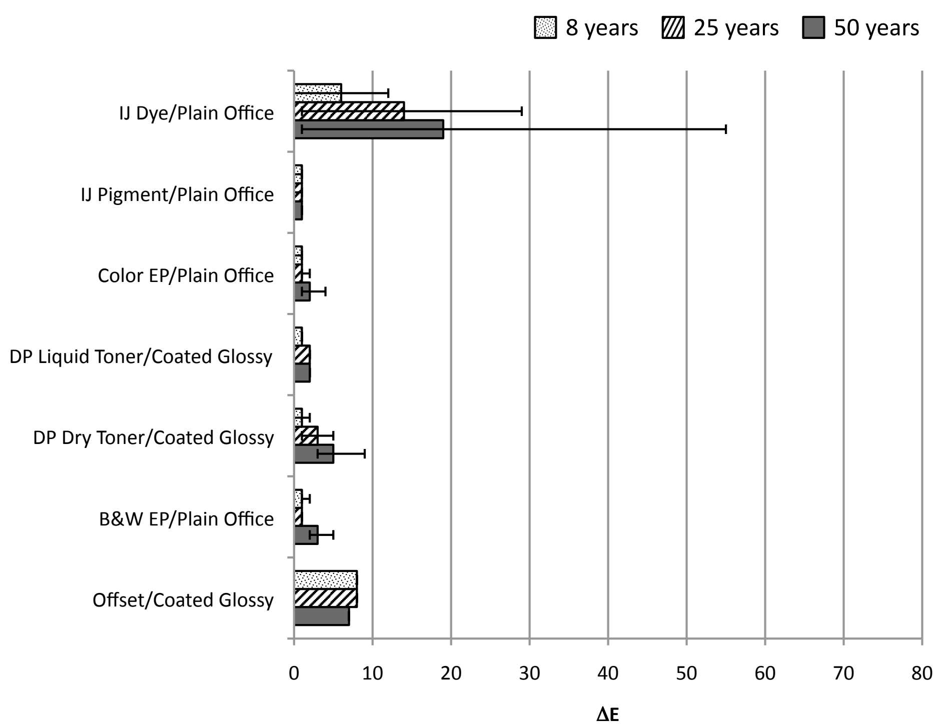


Figure 7. *Average delta E values for the darkest neutral patch (Dmax) after 2, 6 and 12 weeks of exposure to 50 Klux xenon arc light (equivalent to 8, 25 and 50 simulated years of display under daylight though window glass);* ***a)*** *photographs* ***b)*** *documents. The error bars indicate the range of values for each print type. IJ, inkjet; EP, electrophotography; DP, digital press.*

The following is a summary of the effects of light on **Dmax**: On average, dye sublimation and traditional color photographic prints were much more vulnerable than the rest of the samples. However, after 8 and 25 simulated years of display, one individual system of inkjet dye on porous paper was as sensitive as traditional color photographs. After 50 simulated years of display, though, the sensitivity of all traditional color photographs tested was greater than that of inkjet dye on porous paper. Dye inkjet prints were more sensitive than pigment inkjet prints regardless of the paper they were printed on. Color electrophotographic prints were as resistant as B&W electrophotographic prints –the same black toner is probably used in both types of printers. Digital press prints were either as sensitive as or less sensitive than offset prints. In general documents were less sensitive to light than photographic prints.

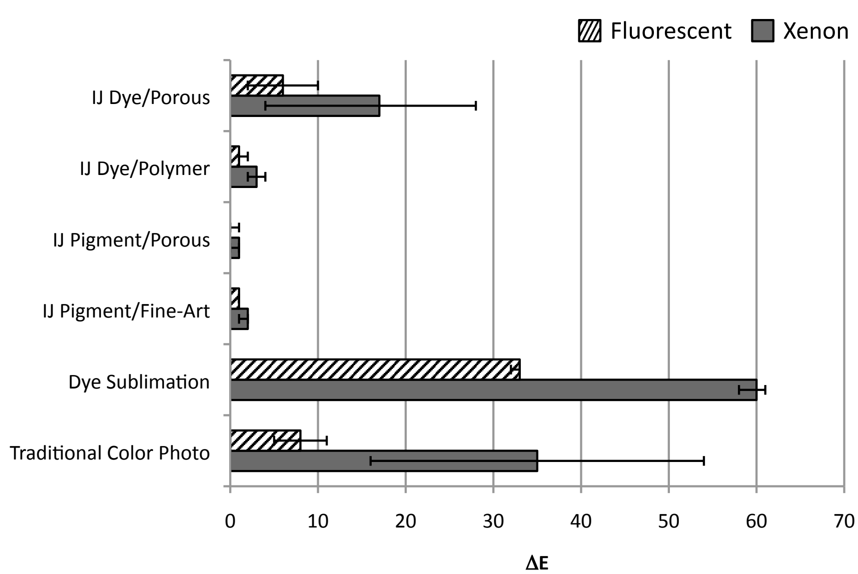
The Dmax patch was more resistant to light than the Dmid patch; this was true for all samples with exception of the dye sublimation and the traditional color photographic prints, which are three-color systems and contain no black colorant. The greater resistance of the Dmax patch could be due to the colorant itself or the amount of colorant layered to print black areas.

Fig. 8 is a comparison between delta E values for Dmax in prints exposed to xenon arc light and prints exposed to fluorescent light for 6 weeks.

For photographic prints, xenon arc light produced greater changes in Dmax after 25 simulated years of exposure than fluorescent light. All digital documents were as or more sensitive to xenon arc compared to fluorescent light. The only print type that showed more sensitivity to fluorescent light over xenon arc light was the offset lithographic reference print. The ratios between the changes in Dmax produced by xenon arc light to those produced by fluorescent light varied between print types.

The changes in Dmid and Dmax observed in inkjet-dye prints on porous papers may possibly be magnified by the effect of atmospheric pollutants. Ozone sensitivity studies have shown fading of dyes in these types of prints, while dyes on inkjet polymer and plain office papers remain practically invulnerable to ozone [2].

a)



b)

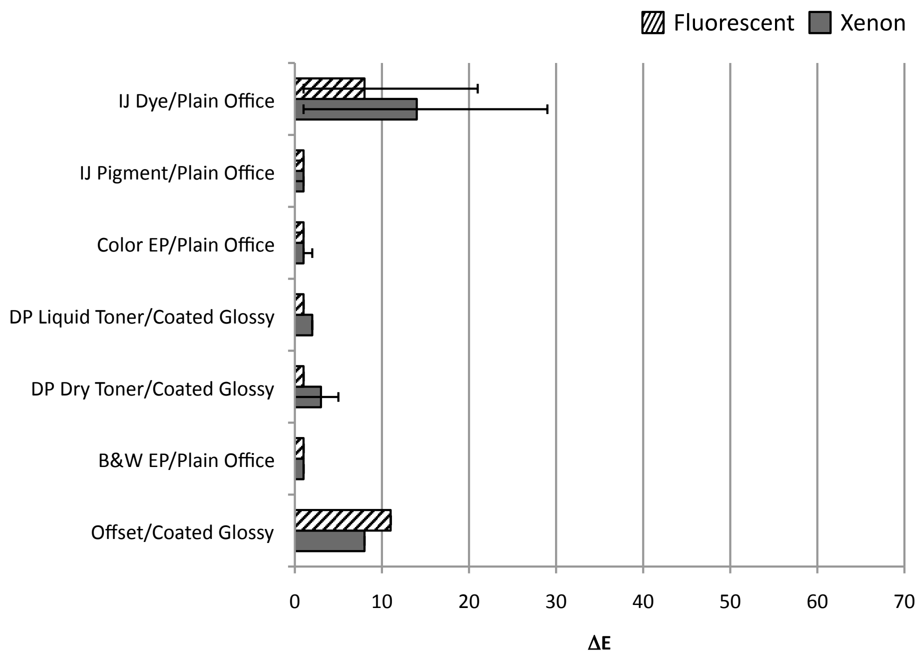
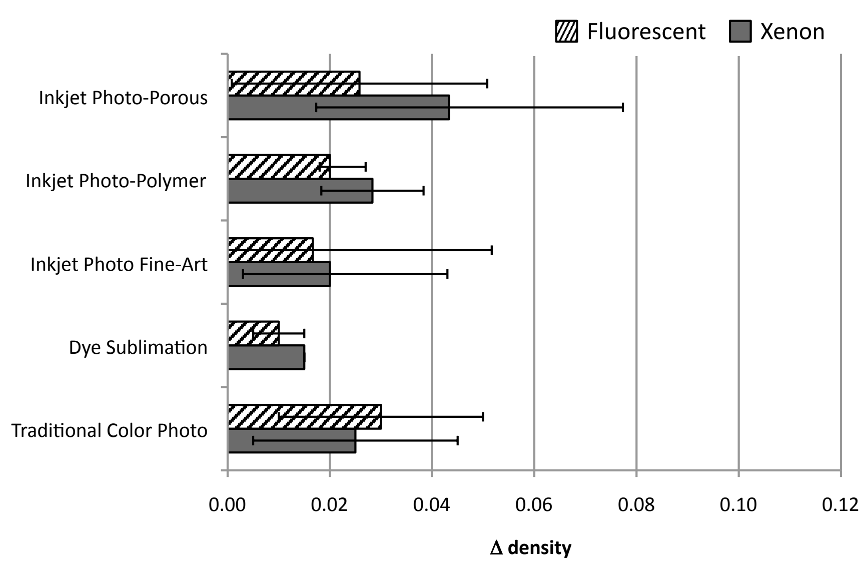


Figure 8. *Average delta E values for the darkest neutral patch (Dmax) (RGB 125, 125, 125) after 6 weeks of exposure to 50 Klux fluorescent or xenon arc light (equivalent to 25 simulated years of display under artificial indoor illumination and daylight through window glass respectively);* ***a)*** *photographs* ***b)*** *documents. The error bars indicate the range of values for each print type. IJ, inkjet; EP, electrophotography; DP, digital press.*

Paper Yellowing

Fig. 9 shows the average change in density values for Dmin in prints exposed to xenon arc light and prints exposed to fluorescent light for 12 weeks.

a)



b)

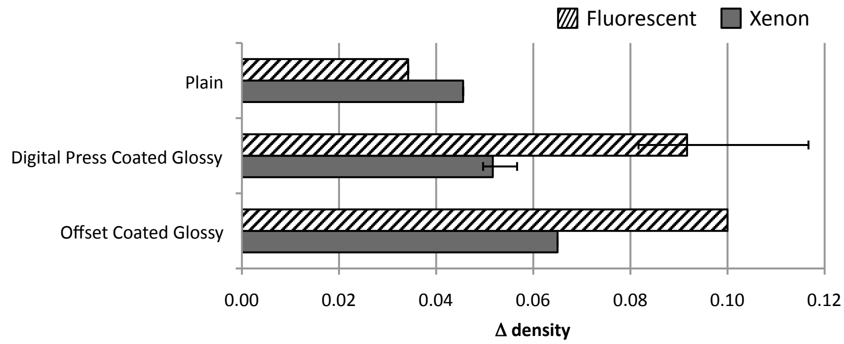


***Figure 9.** Average change in density values for the non-printed patch (Dmin) after 12 weeks of exposure to 50 Klux fluorescent or xenon arc light (equivalent to 50 simulated years of display under artificial indoor illumination and daylight through window glass respectively); **a)** photographs **b)** documents. The error bars indicate the range of values for each print type.*

The following is a summary of the effects of light on **Dmin yellowing**: The papers most susceptible to yellowing were two document papers –offset lithography and digital press coated glossy papers. Fluorescent light had a greater effect than xenon on these papers. Of the papers used for photographic purposes, inkjet photo-porous was on average the most susceptible; dye sublimation paper was on average the least vulnerable and presented less yellowing than traditional photographic paper. For digital photographic prints, xenon arc light produced greater changes in Dmin after 25 simulated years of exposure than fluorescent light. In what refers to digital documents, while plain paper was more sensitive to xenon arc than to fluorescent light, the reverse was true for digital press coated glossy paper. The ratios between the changes in Dmin produced by xenon arc light to those produced by fluorescent light varied between print types.

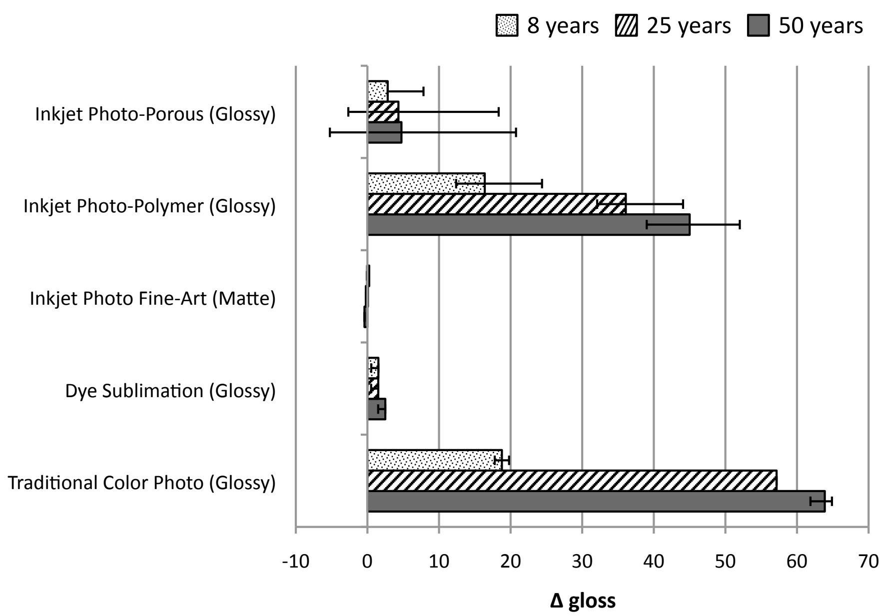
The paper yellowing observed in inkjet photo-porous and fine-art papers may be enhanced by the effect of atmospheric nitrogen dioxide as seen in recent unpublished studies performed at IPI.

Changes in Gloss

Fig. 10 shows the average change in gloss values for gloss targets subjected to 2, 6 and 12 weeks of exposure to xenon arc illumination. Papers were classified as *glossy*, *semi-glossy* and *matte* according to the gloss meter's operating manual's directives.

The following is a summary of the effects of light on **Dmin gloss**: Glossier papers underwent greater changes in gloss due to exposure to xenon light with the exception of dye sublimation papers, which showed a small change in gloss that was not visibly detectable after 50 simulated years of exposure. Traditional color photographic paper followed by inkjet photo-polymer papers showed the highest average changes in gloss value. Of the digital document papers, digital press coated paper underwent the most change in gloss; this change was less than that suffered by the offset paper. None of the matte papers showed changes in gloss.

a)



b)

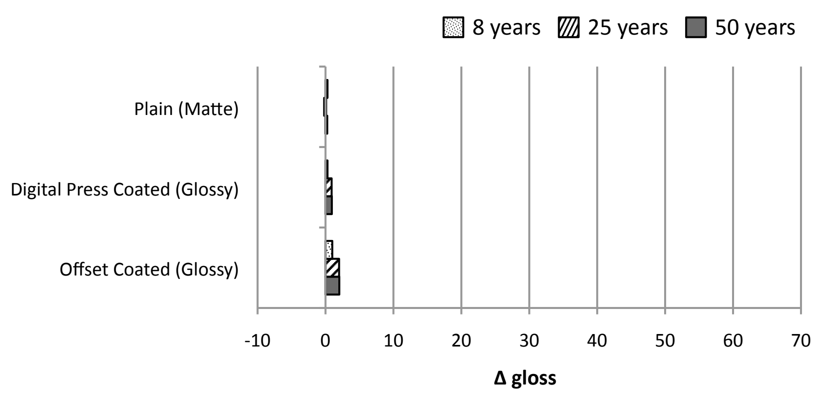


Figure 10. *Average change in gloss values for non-printed area (Dmin) after 2, 6 and 12 weeks of exposure to 50 Klux xenon arc light (equivalent to 8, 25 and 50 simulated years of display under daylight though window glass);* ***a)*** *photographs* ***b)*** *documents. The error bars indicate the range of values for each print type. Positive values indicate loss in gloss.*

Text Readability

Visual inspection of the text targets revealed that after 50 simulated years of exposure to fluorescent light, the smallest font (8 points) was readable even in the most damaged sample, which was a print made with an inkjet dye printer on plain office paper (Fig. 11). While still readable, the worst performing samples were seriously damaged as artifacts.

Since text targets were not exposed to xenon light, the color targets exposed to xenon light were examined visually to infer if the amount of fade suffered by the black patch would impede readability. The black patch was clearly visible and dark in all documents exposed to xenon light, therefore it can be assumed that text targets subjected to xenon light would also be readable after 50 simulated years of exposure.

a)

Figure 11. *Worst performing text target print; a) before and b) after 12 weeks of exposure to 50 Klux fluorescent light.*

CONCLUSIONS

Digitally printed photographs and documents can undergo colorant loss, paper yellowing and changes in paper gloss when exposed to light for extensive time. In this study, digital prints were, on average, less sensitive than their traditional benchmark; but each major category of digital prints (inkjet/photo paper, dye sublimation, color electrophotography, inkjet/plain paper and digital press) had at least one sample that performed worse than such benchmark in at least one of the aspects of light damage studied. Therefore, current care policies for traditional prints may be considered a minimum starting point for the care of digital prints. Providing the most benign environment possible (low light intensity and low frequency of display) and close monitoring of the prints for signs of change is essential. It is also important to bear in mind that third party printing materials may be more sensitive than OEM materials and that earlier dye digital prints are more sensitive than those tested here which dated from 2007.

Changes tend to be more objectionable in a photograph than in a document, since photographs are usually considered artifacts as opposed an information vessel. In a document, the main concern may be the irretrievability of the information within, while paper yellowing, changes in gloss and even colorant fade, may be inconsequential. Provided that the text is readable, the document is usually acceptable –unless we are considering a historic document in which case it would be treated as an artifact. Therefore, documents may tolerate less stringent care strategies than photographs.

The major groups of digital prints may be identified under magnification. However, both *inkjet* groups contain subgroups, for which currently there is no simple, non-destructive method of identification known. The group *inkjet on photo-coated paper*, for instance, includes two colorant types –dyes and pigments, and two paper types –porous and polymer. The sensitivity of inkjet prints on photo-coated papers varies greatly, depending on the combination of materials used in the making. This is true, in reference to their sensitivity to light, but also to other factors such as atmospheric pollutants, high humidity and abrasion [2, 3, 4]. A method to identify the different types of inkjet prints contained in a collection in an easy, accessible, non-destructive way, would allow institutions to concentrate their efforts on the more vulnerable prints, saving time and valuable resources. However, a method of this sort has yet to be developed.

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