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Influence of Temperature and Humidity on Typographic and Colorimetric Properties of Ink Jet Prints

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Abstract. *The aim of this study was to examine the influence of temperature and relative humidity on the changes in typographic and colorimetric properties of ink jet prints in order to establish what typeface style is appropriate for business correspondence, where information permanence needs to be ensured. The prints were made with three ink jet printers from different manufacturers on four different office papers. Four different, widely used typefaces (one oldstyle, one transitional, and two sans-serif) in two different sizes (10 and 12 pt) were tested. The fastness of printed business correspondence under four different conditions of temperature and relative humidity were defined using Xenotest Alpha. The color differences were determined spectrophotometrically. The differences in typographic tonal density and wicking of typefaces were measured by image analysis. On average, the biggest difference in typographic tonal density was observed after a transitional typeface was exposed to the highest humidity and temperature values. © 2011 Society for Imaging Science and Technology.*
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INTRODUCTION

The influence of technology on people's work is increasing on a daily basis; in consequence, the requirements for various materials are changing. One of the latter is also paper, which is used for different purposes, the basic being to carry visual information. Visual information has been in the past decades mainly recorded by means of digital machines or printers, respectively, leading to the question regarding the long-term permanence of the print.

Ink jet technology has recently become important and widely used in many different areas, not only for home applications but also for professional use. For the latter, fastness of prints can present a problem. Under the influence of external factors, i.e., light, heat, and humidity, the appearance of an ink jet print can change significantly.[1–3] Ink jet inks can be dye-based or pigment-based. The application of pigments ensures better fastness, however, it is connected with a more complex ink formulation.[4,5] As is known, paper quality has an important influence on the quality of ink jet prints.[6–11]

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There are recommendations for preserving different substrates used in graphic arts production (e.g., paper).[12–14] For example, the studies on the influence of humidity on paper showed that humidity had little effect on the photochemical loss of tear strength at the room temperature. As the temperature increased in the range 50–56 °C, humidity became increasingly important.[12] There is extensive scientific evidence suggesting that paper retains its chemical stability and physical appearance for a longer period of time at a constant, low storage temperature, i.e., below 10 °C, and relative humidity (RH), i.e., 30–40%. Heat together with high relative humidity encourages mildew growth and creates an environment conducive to pests and insects. Above 70% RH, a biological attack is a serious probability even if temperatures are low. In the areas of poor air circulation, relative humidity should not exceed 60%; and even when air circulation is good, relative humidity should not exceed 65% in order to avoid mildew growth. If temperatures do rise above 20 °C, it is vital that relative humidity levels do not rise or fall beyond acceptable levels.[13] The recommended climatic conditions for a long-term storage of archives and library materials, e.g., paper, are between 14–18 ± 1 °C and 35–50% RH ± 3%.[14]

On the other hand, there are no available recommendations or standards about the preservation of different typeface styles and type sizes, which would give a print better quality and better fastness, thus ensuring legibility.[15,16] A number of typographic characteristics are observed to make a text more legible, i.e., distinctive character features (counter shape), x-height, ascender, descender, serifs, contrast (stroke weight), set width, type size, leading (i.e., space between lines) etc., (cf. Figure 1).[15,18] A precise type size depends on the x-height of a typeface—typefaces with larger but moderate x-heights are generally more legible at small sizes.[15,17–19] For a normal reading distance, the optimum type size for a continuous text (i.e., body text) is usually between 9 and 11 pt,[16] or even between 8 and 12 pt.[15] It is also recommended for a body text that the leading be larger than the type size by 1 or 2 pt,[15] or its value should be 120% of the type size.[20]

In the visualization of information, typographic tonal density (or typographic tonality) has a significant

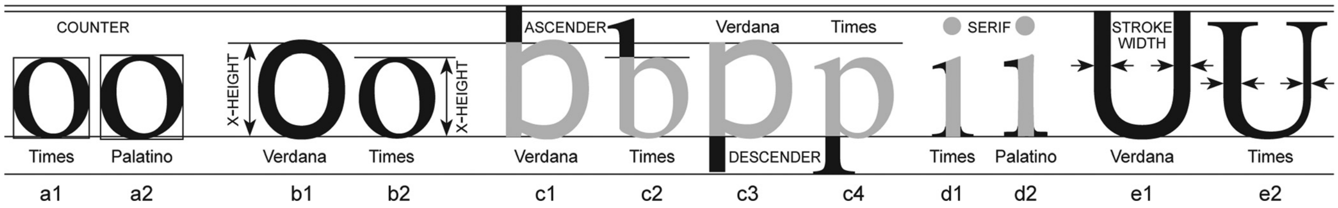

Figure 1. Some typographic characteristics which are important for text legibility, i.e., counter size (a1, a2), x-height (b1, b2), ascender (c1, c2), descender (c3, c4), shape and size of serifs (d1, d2), contrast or stroke width (e1, e2).

influence. The typographic tonal density refers to the relative blackness or shades of grey of type on a page. It can be expressed as the relative amount of ink per square centimeter, pica or in.[21] The changes in various type features can create variations in typographic tonal density.[15,16,22] A larger leading decreases the value of typographic tonal density, while a smaller leading increases the value of typographic tonal density. Typefaces with larger counters trap a larger amount of white space in the enclosed spaces of letters. The cumulative effect decreases the typographic tonal density. A thicker stroke width uses more ink per unit area.[22–24]

Usually, the evaluation of colorimetric properties of prints with 100% intensity does not give a complete view of typeface legibility; therefore, the influence of aging with alternative methods of numerical evaluation was studied, as it was expected that some conclusions and recommendations could be given. In the previous study,[2] it was established that light has a higher influence on some typeface styles and type sizes than on others. As documents are usually stored in the dark, the purpose of this study was to examine the influence of temperature and humidity conditions on the changes in typographic and colorimetric properties of ink jet prints in order to establish what typeface style is appropriate for business correspondence, where information permanence needs to be ensured.

EXPERIMENTAL

In the previous study,[2] the influence of light on the changes in typographic and colorimetric properties of ink jet prints was examined in order to establish what typeface style is appropriate for business correspondence, to ensure information permanence. In this study, the influence of temperature and humidity on the permanence of business correspondence was evaluated. Therefore, we used the papers for which it was already established[2] that there are only minor differences among them, and we used merely those printers among which the differences in quality were not substantial, again with the purpose of establishing what typeface style ensures information permanence.

Paper Properties

The prints included in the study were made on four different office papers, all of them uncoated.

Prior to printing, the basic surface and optical properties of papers were measured. Paper grammage was measured according to the ISO 536[25] standard, while paper thickness was measured according to the ISO 534[26] standard. Density was calculated according to the ISO 534[26] standard. Specific volume is related to porosity, rigidity, hardness and strength, and influences several physical and optical properties of paper. The measurements were performed according to the ISO 534[26] standard. The paper roughness measurement was conducted with the Bendtsen method in accordance with the ISO 8791/2[27] standard. The measurement of airflow was used to describe the porosity of paper, which was tested according to the Bendtsen method with regard to the ISO 5636/3[28] standard. The water absorption of paper was measured by the Cobb method in accordance with the ISO 535[29] standard, where the time of the test was 60 s ($Cobb_{60}$). Specular gloss refers to the relative amount of light reflected from the paper surface at a selected angle, and depends on surface smoothness. The measurement was conducted according the ISO 8254-1[30] standard. Brightness refers to the degree of blue light reflected from the paper surface at the wavelength of 457 nm, where paper yellowing is most easily gauged. The measurement of brightness was made according the ISO 2470[31] standard. Opacity describes the amount of light transmitted through paper and was measured with regard to the ISO 2471[32] standard. Before determining paper characteristics, samples were conditioned according to the ISO 187[33] standard. The measured properties of the felt side of the four papers (S1–S4) are presented in Table I. Paper 3 (S3) has a recycled paper declaration.

Test Form and Printer Properties

Black prints were made with three ink jet printers with original cartridges: HP DeskJet™ 5740 (P1) with C8767EE HP No. 339 Black Ink jet Print Cartridge; Epson Stylus™ DX 8450 (P2) with Epson T071140 Ink Cartridge—Black; and Canon Pixma™ IP 4200 (P3) with Canon CLI8BK Black Ink jet Cartridge.

The printer Epson Stylus DX 8450 (P2) uses inks comprising pigments.[34] According to the information provided by the manufacturers,[35,36] Printers P1 and P3 use inks comprising dyes. Four different, widely used typefaces were tested, i.e., two sans-serif (Arial and Verdana),[23,24,37] one old-style (Palatino),[23,24,37] and one transitional typeface (Times),[23,24,37] each in two different sizes (10 and 12 pt for body text). On each of the four papers, the 100% (K100)

Table I. Properties of tested papers (S1–S4).

Properties	S1	S2	S3	S4
Grammage (g/m^2)	79.13	78.71	79.75	78.88
Thickness (mm)	0.098	0.100	0.100	0.103
Density (kg/m^3)	812.50	792.10	798.50	770.60
Specific volume (cm^3/g)	1.23	1.26	1.26	1.30
Roughness (ml/min)	160	71	175	205
Porosity (ml/min)	959	992	646	875
Water absorption (g/m^2)	32.30	35.00	30.90	37.60
Gloss (%)	3.80	5.60	4.30	3.50
ISO brightness (%)	98.30	97.93	78.15	102.02
Opacity (%)	94.85	96.07	94.70	93.40

field intensity was printed. The test form was designed with the program Adobe INDESIGN™ CS5 and was used as a PDF file. This ensured the unified appearance of the form on various computers and operating systems, and in consequence, on the print. With regard to different user interfaces and settings, all printers had the same settings, i.e., Paper type: plain paper; Print quality: normal; Page setup: A4; Border: none; Page scaling: none; Print resolution: 600 dpi.

Fastness of Prints

The fastness of printed business correspondence under different conditions of temperature and relative humidity (RH) in the dark was defined using Xenotest Alpha (Atlas), which is usually used to determine the light fastness of a substrate or/and prints.[2] In the study, we simulated four different conditions which are considered unsuitable with respect to the recommended document storage values, and are combinations of the following parameters: temperature slightly above the recommended value (over 18 °C[14] or even above 20 °C)[13]; temperature (50–56 °C)[12] highly increased above the recommended value; recommended relative humidity (30–40%[13] or 35–50%[14]); and relative humidity (70%)[13,14] highly increased above the recommended value. The simulated conditions were:

$T_1 = 35\,°C$, $RH_1 = 35\%$ (X1),
$T_2 = 50\,°C$, $RH_2 = 35\%$ (X2),
$T_3 = 35\,°C$, $RH_3 = 70\%$ (X3),
$T_4 = 50\,°C$, $RH_4 = 70\%$ (X4).

The samples were not exposed to light; they were covered to simulate a dark storage place where substrates are normally stored. The samples were exposed to constant conditions described above for 144 h.

The CIE L*a*b* parameters of the prints were measured with a spectrophotometer EFI/ES—1000 (Gretag Macbeth) in accordance with the ISO 13655[38] standard using the D50 standard illumination, 2° standard observer, black backing and instrument geometry 45/0. The color difference (ΔE) between the nonexposed and exposed samples was calculated, according to the CIE L*a*b* equation for color differences:

$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (1)$$

The differences in typographic tonal density and wicking[39,40] or circularity[41] of the typefaces were measured by image analysis (IMAGE J).[39–41] This software gives the opportunity to measure, analyze and provide output values, e.g., area, number of particles, percentage of coverage, and circularity.[41] The value of wicking is between 0 and 1, where the calculation is made according to the following equation:

$$\text{wicking(or circularity)} = 4\pi \frac{\text{area}}{\text{perimeter}^2} \quad (2)$$

The value 1.0 indicates a perfect circle; in consequence, the edges or obliqueness of letter strokes are perfectly smooth. As the value approaches 0.0, it indicates an increasingly elongated polygon, and consequently, the edges of letter strokes are no longer smooth (Figure 2).[39,41] All the measured samples were of the same size, i.e., 1100 × 175 pixels.

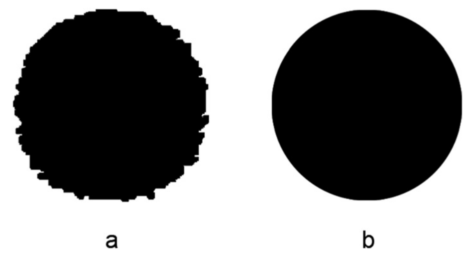

Figure 2. Example of different wicking or circularity of graphic element; poor smoothness with value 0.092 (a), almost perfect smoothness with value 0.899 (b).

RESULTS AND DISCUSSION

Colorimetric Properties of Prints

Table II shows the CIE L*a*b* parameters of black prints with 100% intensity printed with different ink jet printers. The obtained results show that there are only minor differences among the samples and printers. Sample 2 with the highest gloss (Table I) gave the best prints, while sample 1 gave on average the least satisfactory results, regardless of the printer used. The results show a minor difference in the quality among the tested printers. According to the value of lightness at prints, it was noticed that the least satisfactory prints were obtained with Printer 3, which gave prints with slightly higher values of lightness. The best results were obtained with Printer 2, as they were the least chromatic and exhibited the lowest values of lightness L*.

The color differences (ΔE) on the printed samples after the exposure to different conditions of temperature and relative humidity were calculated (see Figure 3). The smallest changes were noticed on black prints obtained with Printer 2, while the highest color differences were measured on the prints printed with Printer 3. It could be observed that on average the smallest color differences after all different

Table II. CIE L*a*b* parameters of black prints with 100% intensity printed with different printers (P1–P3) on different papers (S1–S4).

		P1	P2	P3
	L*	31.96	28.24	32.18
S1	a*	0.81	0.62	1.39
	b*	2.42	1.97	4.27
	L*	28.00	28.35	29.33
S2	a*	0.99	0.60	1.50
	b*	2.57	1.94	4.02
	L*	29.05	28.16	31.42
S3	a*	0.94	0.72	1.36
	b*	3.04	2.38	4.24
	L*	30.47	27.94	30.11
S4	a*	1.25	0.76	1.49
	b*	3.59	2.30	4.36

exposures appeared on sample 4. Slightly higher color differences were measured on samples S2 and S3 printed with Printers P1 and P3 at conditions X3 and X4. A comparison of fastness of prints, according to the influence of different temperature and relative humidity was conducted. Figure 4 shows the average values of lightness and color differences after each exposure for all tested printed samples (Papers S1–S4, Printers P1–P3). It is evident that the biggest differences on prints occur at a substantially higher temperature and relative humidity (condition X4) than that suggested[13,14] for paper preservation. It can also be noticed that higher differences on prints occur at higher relative humidity (conditions X3 and X4), regardless of the temperature. The rise in temperature alone (condition X2) did not contribute to lower fastness of prints, as long as relative humidity remained low enough (i.e., 35%). Although the temperature alone did not lead to a significant difference on prints, it did intensify the effect of relative humidity. A higher temperature usually causes a degradation of paper, whereas it does not lead to a photochemical reaction.[42] At the temperature which is higher than that recommended for paper preservation (i.e., 20 °C),[13,14] humidity becomes very important.[12,13]

Typographic Properties of Prints

The typographic tonal density (TTD) of each typeface, each in different size, was measured before and after the exposure to heat and humidity. The samples of the studied typeface, 10 pt in size, after the exposure to condition X4 are presented in Figure 5. TTD of the tested typefaces according to the used type sizes, printed on different papers with different printers is presented in Tables III–V. The differences in TTD of black prints after the exposure to various conditions are presented in Figures 6–9.

The results show an expectedly higher TTD at sans-serif typefaces (Tables III–V) due to smaller differences in the letter stroke width. It was also expected that Verdana gives smaller TTD than Arial due to wider letters and bigger counter size. The lowest TTD was observed for the old-style typeface Palatino. Palatino letters have large counter size, the difference between thick and thin strokes is not very significant, and the thick strokes are not very wide. It is also evident that the differences in TTD among the printers and papers used are smaller than among the used typefaces. Among the used papers, the differences in TTD are minor. Nevertheless, the highest TTD was printed on sample 2, which has the highest gloss among the used papers. A noticeable difference is seen between Printer 2, which printed all the typefaces at the highest TTD, and Printer 3, where all the typefaces had the lowest TTD.

After exposure to different conditions of temperature and relative humidity, the most noticeable average difference in TTD occurred for the Times (transitional) typeface and a slightly smaller difference at the Palatino (old-style) typeface (Fig. 6). Between the typefaces without or with a

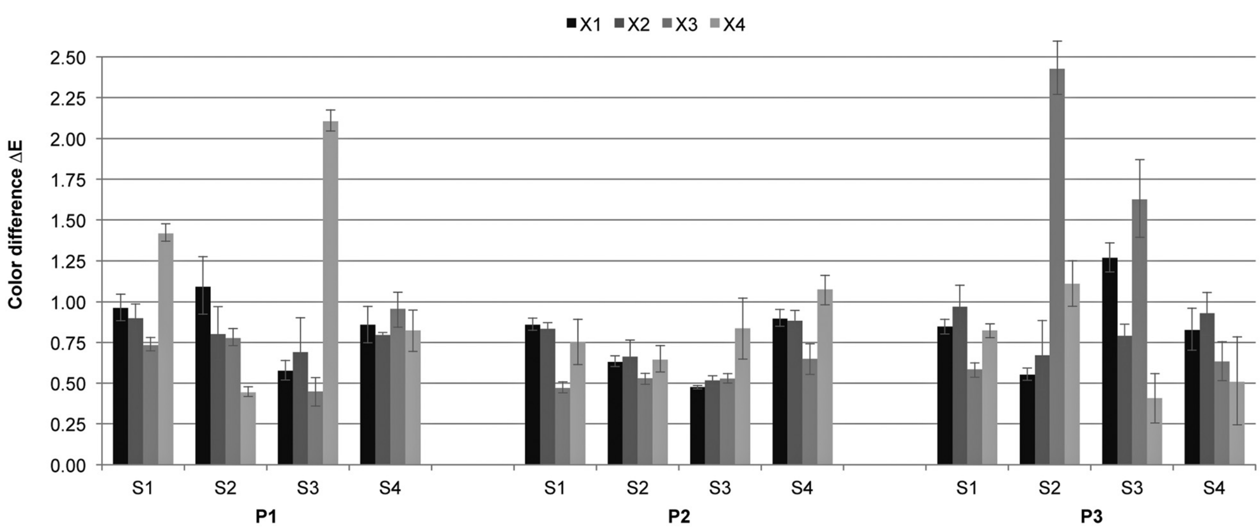

Figure 3. Color difference (ΔE) for prints with 100% intensity printed with printers (P1–P3) on papers (S1–S4) after exposure to different conditions of temperature and relative humidity (X1–X2).

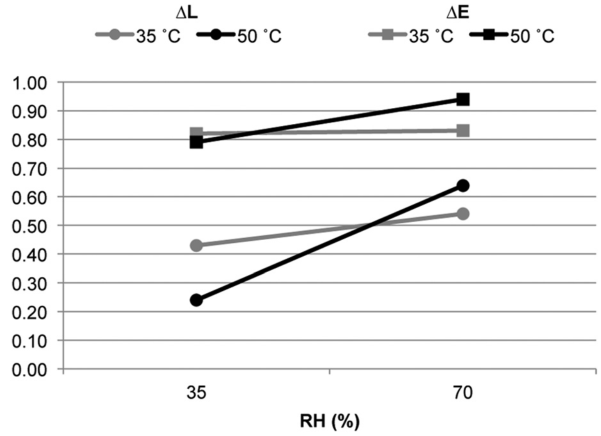

Figure 4. Average difference in lightness (ΔL) and total color difference (ΔE) on prints after exposure to different conditions of temperature and relative humidity (X1 [35°C, 35%], X2 [50°C, 35%], X3 [35°C, 70%], X4 [50°C, 70%]).

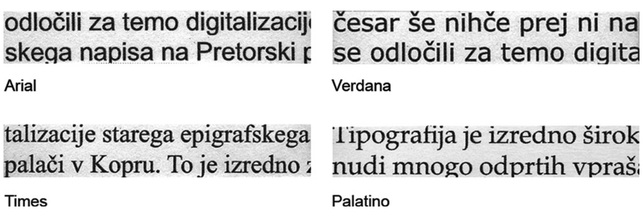

Figure 5. Sample of exposed typefaces, 10 pt in size, after X4 exposure (P3, S2).

Table III. Average value of typographic tonal density (TTD) of tested typefaces according to type size.

	TTD (%)		
Typeface	10 pt	12 pt	Average
Arial	26.72	25.14	*25.93*
Verdana	24.66	24.71	*24.68*
Times	22.44	21.37	*21.90*
Palatino	21.98	20.55	*21.26*

Table IV. Average value of typographic tonal density (TTD) of tested typefaces printed on different papers (S1–S4).

	TTD (%)			
Typeface	S1	S2	S3	S4
Arial	25.46	26.42	26.22	25.61
Verdana	24.41	25.09	24.73	24.52
Times	21.35	22.51	22.04	21.72
Palatino	20.70	21.87	21.41	21.06
Average	*22.98*	*23.97*	*23.60*	*23.23*

Table V. Average value of typographic tonal density (TTD) of tested typefaces printed with different printers (P1–P3).

	TTD (%)		
Typeface	P1	P2	P3
Arial	26.36	26.70	24.73
Verdana	24.88	25.85	23.31
Times	22.01	23.05	20.65
Palatino	21.42	22.25	20.11
Average	*23.67*	*24.46*	*22.20*

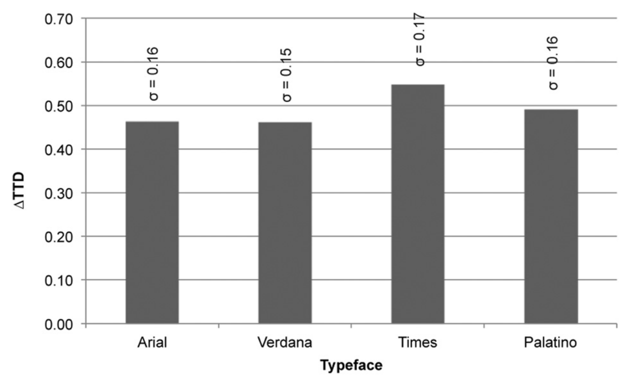

Figure 6. Average differences in TTD of tested typefaces.

minor difference in stroke width (i.e., Arial and Verdana), on average, slightly bigger differences were observed with the Arial typeface (0.463 versus 0.462 at Verdana). Obviously, the old-style typeface (i.e., Palatino), where the thick strokes are not very wide and which has large counter size, is not resistant enough, as its starting TTD value was the lowest (Table III and Fig. 6).

While comparing the influence of different conditions (Fig. 7), it can be seen that relative humidity and temperature (condition X4) higher than suggested for paper preservation,[13,14] had the greatest influence on the fastness of printed typefaces. It can also be noticed that bigger differences on prints occur under the conditions of higher relative humidity (i.e., 70%). The rise in temperature alone did not contribute to lower print fastness, while it did intensify the effect of relative humidity.

Comparing the printed samples, the most noticeable differences appeared above all on samples 2 and 3, and the least noticeable on sample 4 (Fig. 8). The smallest changes in TTD were obtained on samples printed with Printer 2 (Fig. 9). Moreover, the prints printed with this printer had the highest TTD (Table V). The most evident differences in TTD were observed on prints printed with Printer 3, which gave prints with the lowest TTD.

The influences of samples, printers and different conditions of temperature and relative humidity on the biggest

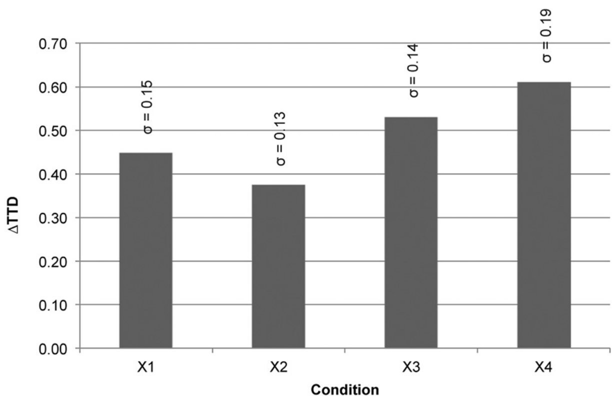

Figure 7. Average differences in TTD at exposure conditions (X1–X4).

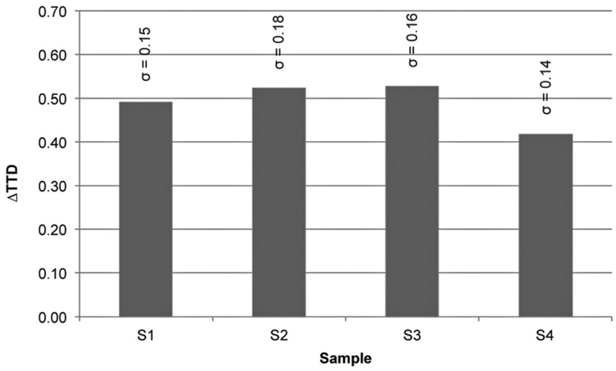

Figure 8. Average differences in TTD of papers (S1–S4).

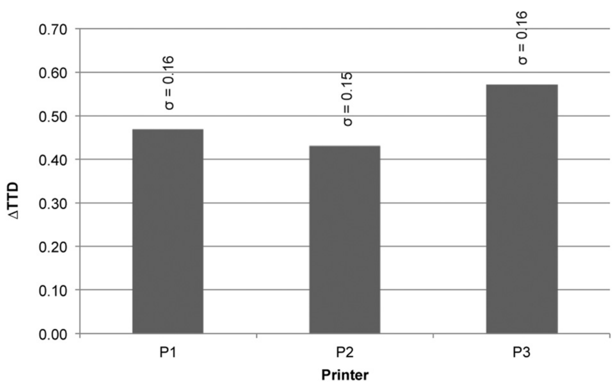

Figure 9. Average differences in TTD of printers (P1–P3).

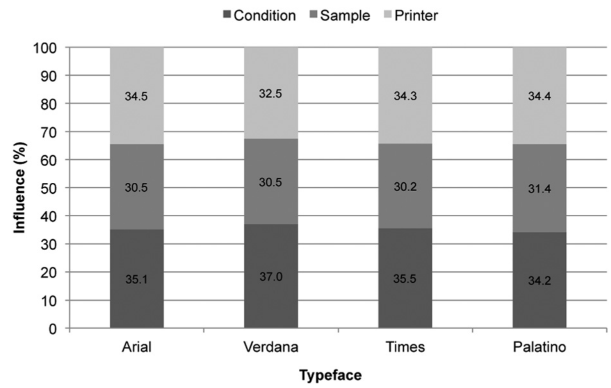

Figure 10. Influence of exposure conditions (X1–X4), papers (S1–S4) and printers (P1–P3) on fastness of tested typefaces.

Table VI. Average value of wicking of tested typefaces according to type size.

	Wicking		
Typeface	10 pt	12 pt	Average
Arial	0.241	0.237	*0.239*
Verdana	0.263	0.257	*0.260*
Times	0.220	0.210	*0.215*
Palatino	0.215	0.203	*0.209*

difference in TTD are presented in Figure 10. A comparison of various influences on the biggest differences in TTD at typefaces led to the conclusion that the influence of higher temperature and relative humidity was for almost all typefaces greater than the influence of printers and samples. The only exception is the Palatino typeface, where it is seen that the printer is slightly more important for the fastness of the printed text.

The results show that the differences in TTD among the tested typefaces, e.g., typefaces without or with minor differences in stroke width versus typefaces with differences in stroke width, were bigger than those among the printers and tested papers, most likely due to the difference in the typographic properties of the typefaces used (Tables III–V). It is also evident that the changes after different storage conditions are larger for typefaces with differences in stroke width than for typefaces without or with minor differences in stroke width (Fig. 6). The properties, e.g., stroke width, x-height, counter size and set width, strongly affect TTD and the legibility of the text (Fig. 5). We have to be aware of the starting TTD value as well as its change after the exposure.

By employing image analysis, wicking of the small letter *o* before and after exposure to different conditions was measured. The results of the wicking values before exposure are presented according to the type sizes used in Table VI. The differences in the value of wicking after the exposure to different conditions are presented in Figures 11–14. Enlarged photos of the measured letter *o* of the Palatino typeface is seen in Figure 15. After exposure to higher temperature and relative humidity in the dark, the difference in the wicking value was small (Fig. 11). Thus higher temperature and relative humidity had a smaller influence on the fastness of printed typefaces than had illumination.[2] The best smoothness of letter strokes was seen for the typeface Verdana (Table VI). The biggest difference in the wicking value was measured for the typeface Palatino, and the smallest for the Arial typeface (Fig. 11). A comparison of

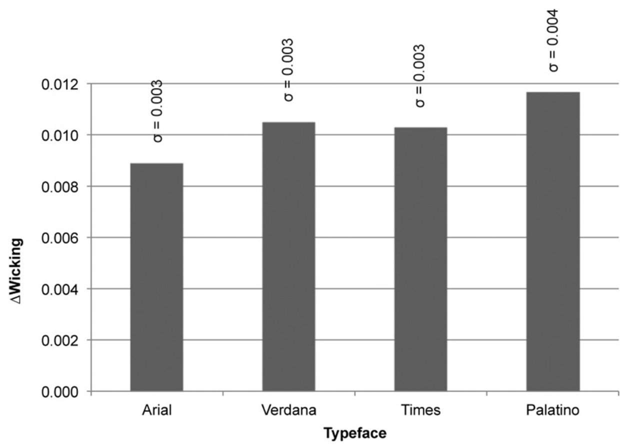

Figure 11. Average differences in wicking of tested typefaces.

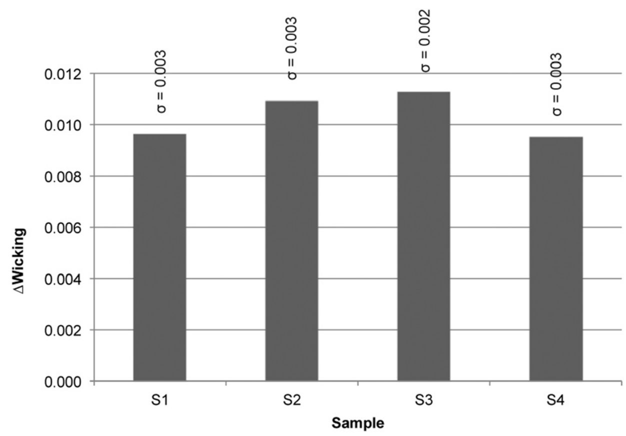

Figure 13. Average differences in wicking of papers (S1–S4).

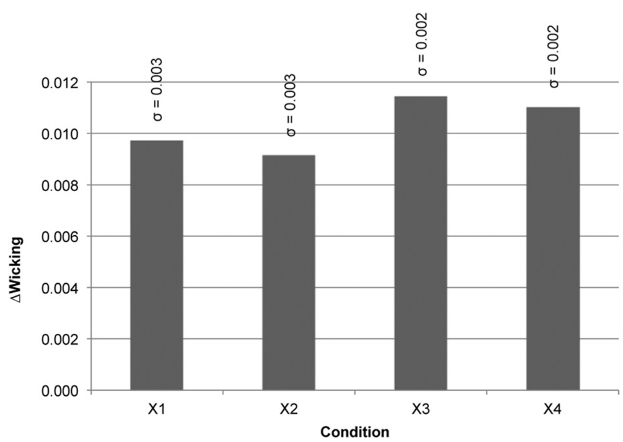

Figure 12. Average differences in wicking at exposure conditions (X1–X4).

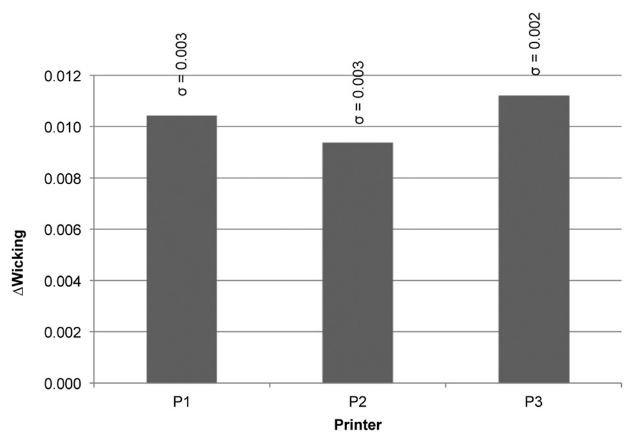

Figure 14. Average differences in wicking of printers (P1–P3).

the influence of different conditions of exposure (Fig. 12) showed that higher relative humidity (i.e., 70%) and temperature (i.e., 35 and 50 °C) than those suggested for paper preservation[13,14] had the highest influence (conditions X3 and X4) on the fastness of printed typefaces. After exposure, the biggest differences in wicking were demonstrated on samples 2 and 3 (Fig. 13). The smallest changes in wicking were noticed on the samples printed with Printer 2 (Fig. 14). The biggest difference in the wicking value was measured on the samples printed with Printer 3; nevertheless, the differences were very small.

The results show that the biggest color differences and differences in TTD were observed under conditions of both higher temperature and relative humidity (condition X4). As for the difference in the wicking value, it could be seen that the influence of higher relative humidity is more destructive, regardless of the temperature (conditions X3 and X4). Since the wicking values may not be accurate for very small elements,[41] it is suspected that this might not even be helpful when measuring the body text.[2] On the contrary, TTD offers important data about the typeface and its leading.

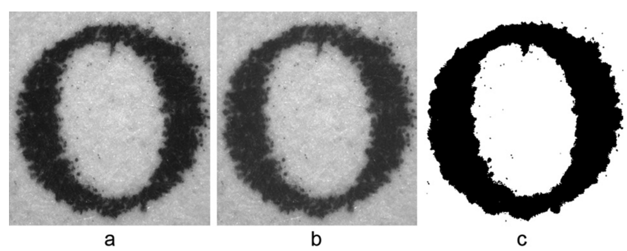

Figure 15. Letter o before exposure (a), after exposure (b) and its binary picture (c), which is base for imaging analysis (condition X4) at typeface Palatino at 10 pt (P3, S2); microscopic photo is enlarged 25-times.

CONCLUSIONS

The results of the study show that the influence of temperature and relative humidity is generally smaller in the absence of light than in the presence of light.[2] Nevertheless, to avoid the negative influence of light, temperature and humidity in a long-term storage, it is necessary to consider the typeface style to ensure information permanence. Typefaces with thin strokes and big counter size (e.g., Palatino), consequently having a lower TTD value, are therefore not recommended. The results obtained reveal that a higher temperature (i.e., 35, and 50 °C) does not have a significant influence on the fastness of prints, while it does intensify the destructive influence of relative humidity on the fastness of prints, especially at 70% RH. The results also show that small differences in paper quality are not of great significance for print fastness even at higher temperature and relative humidity. Measured CIE L*a*b* parameters, the values of typographic tonal density, and wicking revealed that the type style and temperature higher than recommended, together with higher relative humidity have a greater impact than the properties of the tested papers or printers.

In order to ensure information permanence under different storage conditions, the value of typographic tonal density being at least 22% for the body text (i.e., 8–12 pt) at ordinary leading (i.e., 120% of the type size) would be recommended, although the typeface design needs to be taken into consideration to enable better legibility, i.e., small differences between thick and thin strokes, higher x-height, counter shape. For smaller typefaces (i.e., 6 pt),[2] the value of typographic tonal density should be higher (e.g., 24%) to ensure light fastness as well. Furthermore, the smoothness of letter stroke edges should not be ignored. It can be concluded that for the body text and smaller type sizes, an appropriate typeface style and typographic tonal density which is high enough are essential to ensure information permanence.

Future systematic research which would include different ink jet technologies, and papers, and would take into consideration the negative influence of light, temperature and humidity might, together with a corresponding study of their influence on reduced text legibility, result in a method for a quantitative evaluation of changes in typography.

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