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Minding the gap: evaluating the image quality gap between digital print technologies and traditional offset lithography - how big is it and who cares?

Susan Farnand

Marcos Esterman

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By
Susan Farnand
Staff Scientist, Chester F. Carlson
Center for Imaging Science
Rochester Institute of Technology

A Research Monograph of the
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Abstract

In recent years, digital print engines have made marked strides in increasing their level of image quality. What was once a ragged, de-saturated, and uninspiring color document can now be made sharp and vibrant. The difference between the image quality of digital printers relative to offset lithographic presses is shrinking—but just how big is this difference? What particular image quality parameters contribute most to this difference? And how much does this difference matter to the end user?

The objective of this research was to answer these questions by evaluating the image quality gap between digital print technologies and offset lithography and determining the importance of this gap to end users. It was found that there were significant differences in perceived value of prints made on digital versus offset printing equipment, with the prints on coated media from offset equipment being generally preferred and the prints on uncoated media from digital printers being generally preferred.

Introduction

Little more than a decade ago, the introduction of the Xeikon and Indigo printers ushered in a new era of print possibilities. These machines offered reasonable image quality at high enough speeds that short-run, on-demand print runs became a possibility. While typical offset presses required upwards of half an hour for make-ready, economically precluding runs of less than a few thousand, this new equipment required minimal set-up time, making runs of even one print feasible. With the addition of variable data printing (VDP)—in which each document in a print run can contain different information allowing personalization of documents—life in the printing world became considerably more interesting.

In the past decade, the equipment has evolved, offering increased reliability and the capability of printing on a wider range of substrates. But—what about image quality?

Certainly, the wider range of substrates has helped. Other technological advances have boosted the quality of the images being generated on digital printing equipment to the point where some might argue that it is now in the realm of offset. Henry Freedman of Technologe Watch™ (2004, 2006a, 2006b) has demonstrated that higher-end digital printers such as the Kodak NexPress 2100 and the Xerox Docucolor 8000 can be set up to produce image quality comparable to that of offset lithography. While Freedman has shown that it is possible to achieve image quality comparable to offset on high-end digital printing equipment, it is telling that there exists a great deal of information on "designing for digital." Googling "designing for digital print" results in about 209,000,000 hits, including whole books on the topic as well as websites and articles.

The goal of this research was to examine the current gap in image quality between high-end digital printers and offset lithography and to develop an idea of how important or relevant this image quality difference is to the end user. An investigation into image quality parameters that are particularly relevant in comparing print systems technologies was also conducted.

Background

Much work in evaluating digital print quality has been undertaken by researchers in technical, marketing, and academic milieus. A number of these efforts have focused on printing digital photographs; this is an application where image quality is of particular concern. In one of these studies, Swanson (2000) found four "significant issues" in assessing image quality: "color reproduction, uniformity, resolution, and artifacts."

The same issues are among those listed by the INCITS W1.1 Image Quality for Printer Systems *ad hoc* committee working to establish a standard for perceptually measuring image quality (INCITS, 2004). (The INCITS W1.1 committee was established by W1, the Office Equipment subcommittee of INCITS. This is also the ANSI Technical Advisory Group for ISO/IEC Joint Technical Committee 1, which is responsible for the standardization in the arena of Information Technology.) This committee has identified gloss, color rendition, uniformity, text and line quality, and sharpness and effective resolution as the essential characteristics for measuring image quality on prints.

In their study on digital print quality, Chung and Rees (2006a) generated lists of attributes of interest in evaluating image quality for both digital and offset print. Most of the print attributes identified as being of key concern in evaluating digital images, including color rendition, resolution, text quality, and artifacts, also appear on the offset list. However, Chung and Rees point out that, "while many of the attribute names are shared, the difference in the two technologies results in different visual appearances." It is this difference in the visual appearance that is of interest in this study. While efforts have been made to evaluate the measured differences in such items pertaining to print appearance as solid area density, dot gain, colorimetric values, and color gamut volume (Xu & Kellogg, 2007), it is the focus of this research to evaluate actual perceived differences in the quality of prints produced on high-end digital printing equipment relative to those printed via offset lithography.

Experimental Method

To answer questions around image quality differences, it is essential to first establish an image set that will be effective for evaluating image quality. This can often be the most difficult part of a productive image quality evaluation. The set must comprise images that will provide a measurable signal of the difference that exists between technologies. The set should also be representative of various types of images that may be encountered.

To address this, images representing the four categories included in Frey, Christensen, and DiSantis' (2006) monograph were used: direct mail, marketing and promotional materials, business communications, and photo books. Six test images were created (shown in Appendix A). In the marketing and promotional materials category, a brochure, entitled "Train," created as part of the Technology Practicum printing course offered each spring at the Rochester Institute of Technology, was used. In the direct mail category, a mailer obtained from the Village Sports center was used. For photo books, two photo pages were created, one entitled "Sarah" and one entitled "China." The latter image includes vacation-type photos and Chinese text as well as copyright text. For business communications, a text and graphics document was created and IS&T's NIP23 Print Gallery image was used.

With the image set in hand, prints were made on high-end digital equipment, including an HP Indigo 5000, a NexPress 2100, and an iGen3. Prints were also made on the Heidelberg Speedmaster 74 sheetfed press in the Printing Applications Lab at RIT. An image of the text print on uncoated paper on a desktop color printer was also included.

Two substrates were used on each device, one coated (Titan Plus Dull *digital* 100lb. cover) and one uncoated (HP Indigo printing paper 80 lb premium cover) cover stock. The text image on the coated stock was not used in the experiment. Two prints, one from early in the run (typically the fifth print) and one from later in the run (typically the ninety-fifth print), were used for each printer on each paper for each image. With two prints on two papers of five images on four printers plus two prints of one image on one paper on five printers (though only one print from the desktop printer), the complete test set consisted of 89 prints.

With the print database generated, psychophysical experimentation was conducted that examined effective image quality differences; essentially, the impact of any apparent differences on perceived quality or value. The experiment was initiated by showing the participant prints of the Print Gallery image made on the desktop printer and the Heidelberg Speedmaster sheet-fed press. These prints represented a clearly visible range in image quality. Various aspects of image quality that the participants could use in making their print quality decisions were described. The participants were specifically instructed not to consider hue shifts in their decisions on print quality. The rationale for this comes from three factors: Freedman has shown that printing equipment can be

set up to match in color; the images used had little high chroma content (and therefore gamut mapping was not an issue); and color management did not function adequately during the execution of the print runs.

After speaking with each participant briefly regarding image quality, the participants were shown the prints in sets, where each set consisted of the prints made on either coated or uncoated paper for each image. For example, one set would be the prints of the Village Sports brochure made on coated paper on each of the four printers. At the start of the evaluation of each set, the participant was told of the purpose of the document.

For the photo book pages, the participants were told that the prints represented photo book pages of pictures that they may have taken on vacation and that were for their personal use to share with family and friends. For the Village Sports brochure, each was told that he or she was the owner of Village Sports, and that this was a mailer that had been commissioned to send to prospective customers. For the Train brochure, each was told that they were the owner of Georgetown Loop Railroad, and that the prints represented sales brochures used to generate business. For the text document and the Print Gallery page, the participants were told that these were business communications documents that would be used within an office environment (perhaps to be sent to a supervisor or another company), and that, although the main purpose of the document was to convey information, the documents still needed to be presentable.

To address the question of impact, the observers were questioned regarding what they would be willing to pay for a given print. For each set, one of the prints made on the Heidelberg Speedmaster 74 sheet-fed press was selected to be the reference print. When the participants were shown the first reference print, they were told that they paid a dollar for this page. The participants were given the following instructions: for each of the comparison prints, if the quality was sufficiently higher than the reference to justify paying more for the document, they were to specify how much more they would be willing to pay. If the quality was sufficiently worse than the reference (so that they would not want to pay as much for the document as they had for the reference), they were asked to tell how much less they felt it was worth. If they thought the quality was essentially comparable (even if the prints looked quite different), they were to state that it had the same value as the reference. With this explanation, the first comparison print of the first set was presented, and each participant proceeded through the document sets in random order.

The experiment was conducted under D50 lighting conditions within the Vision Lab of the Color Science building at RIT. Thirty-eight people of varied backgrounds participated, including twenty-five students from an undergraduate psychology course. The students' majors ranged from Computer Science and Liberal Arts to Photography and Biotechnology. The remainder of the participants consisted of Imaging Science and Color Science undergraduates, graduate students, and faculty. Eleven females partici-

pated along with twenty-seven males. At least three participants had color vision anomalies; this was self-reported, so others may have been present. The age range of the participants was approximately 20 to 50 years of age. None of the participants were involved in any way with the printing industry.

Results and Discussion

In the summary of his paper on measuring digital image quality, Swanson (2000) states that "the consumers of digital imaging output are as varied as their definition of image quality." It seems a comfortable extrapolation to include all printed output in this statement. This is one of the reasons that participants with varied backgrounds were sought out for this experimentation. The results would indicate that this effort was successful., as opinions on the quality of given prints varied widely. Standard deviations on the responses to the digitally produced prints ranged from about 9¢ for one of the Village Sports mailers on coated paper to over 44¢ for one of the China photo pages on uncoated paper. The difference in responses for a single print ranged from 50¢ for a Village Sports mailer on coated stock, for which the pickiest participant assigned a value of 70¢ and the most delighted participant felt it was worth $1.20, to a $2.30 difference for one of the "Sarah" photo pages on uncoated media, for which one disgusted participant offered 20¢ and another impressed participant assigned a value of $2.50.

The correlation coefficients of the individual responses with the mean response for each of the comparison prints averaged approximately 0.6 and varied from approximately 0.24 to 0.8. Interestingly, the three participants who reported color vision anomalies all had correlation coefficients that were higher than the average of 0.64, 0.68, and 0.68.

Most of the participants having lower correlation coefficients tended to either have relatively flat responses – they tended to assign values around $1.00 for all of the comparison prints as shown in Figure 1 – or they had one or two responses that did not fit in well with the majority of their responses, as shown in Figure 2. In the case of the participant having the lowest correlation coefficient (and for a few other participants), both of these things occurred. However, removing participants whose responses correlated poorly with the mean responses or the few outliers had little impact on the results. Therefore, all of the results were retained in the analysis.

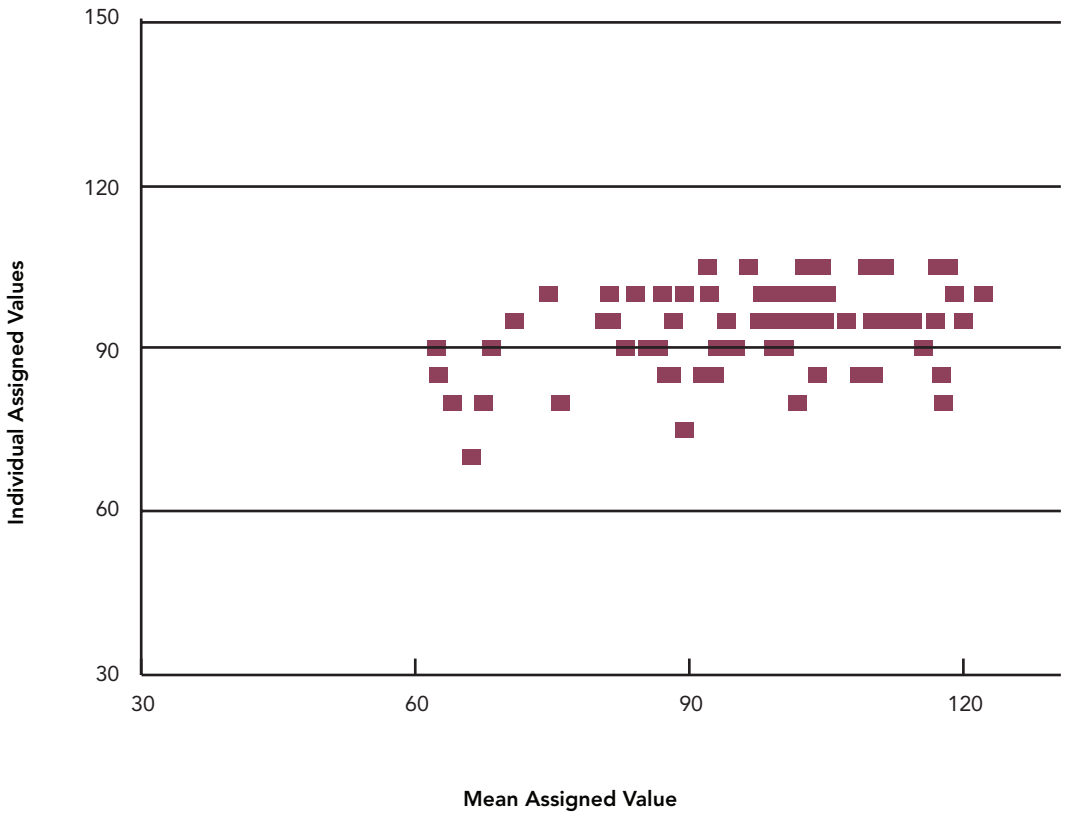

Figure 1. Data for a participant who exhibited a relatively flat response

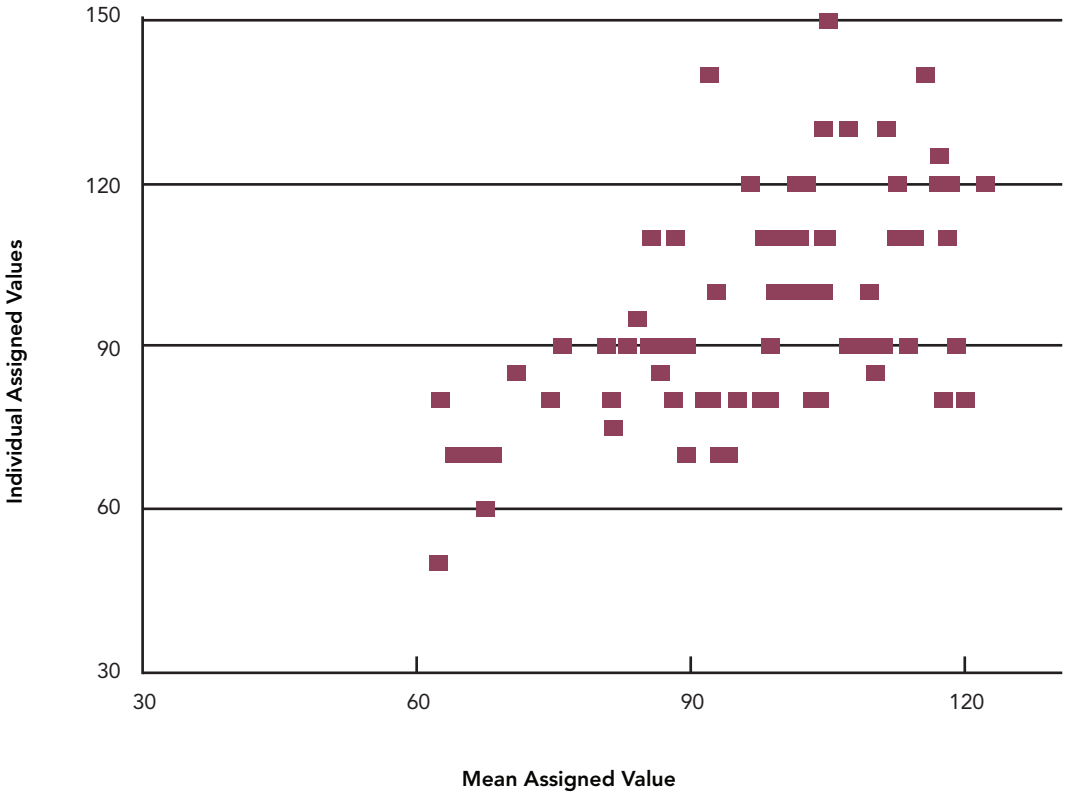

Figure 2. Data for a participant who exhibited a few outlier responses

An example of the ratings for the comparison prints for one test image, the "Sarah" photo book page on coated media, is shown in Figures 3 and 5. Figure 3 is a histogram depicting the number of ratings at various levels for all of the participants and all of the comparison prints. Figure 5 shows all of the ratings for the comparison prints in ascending order. The high degree of variability among participants is evident. The curve in Figure 3 for the Heidelberg prints features one tall, narrow peak at the $1.00 to $1.10 level, while the curves for the other printers are much flatter with shorter and broader peaks. The peaks for Printers 1 and 3 cover the range from $.70 to about $1.10, while Printer 2's curve is more of a plateau, covering the region from 0¢ to 90¢. Figure 5 shows that the "Sarah" photo book page comparison print on coated media for Printer 3 was assigned values ranging from 0¢ to $1.50. The standard deviation for this set of images was about 20¢. The variability for the uncoated version of the "Sarah" photo book image is even higher, with a standard deviation for the set of almost 26¢. The responses for this print are shown in Figures 4 and 6 as a histogram and in ascending order, respectively.

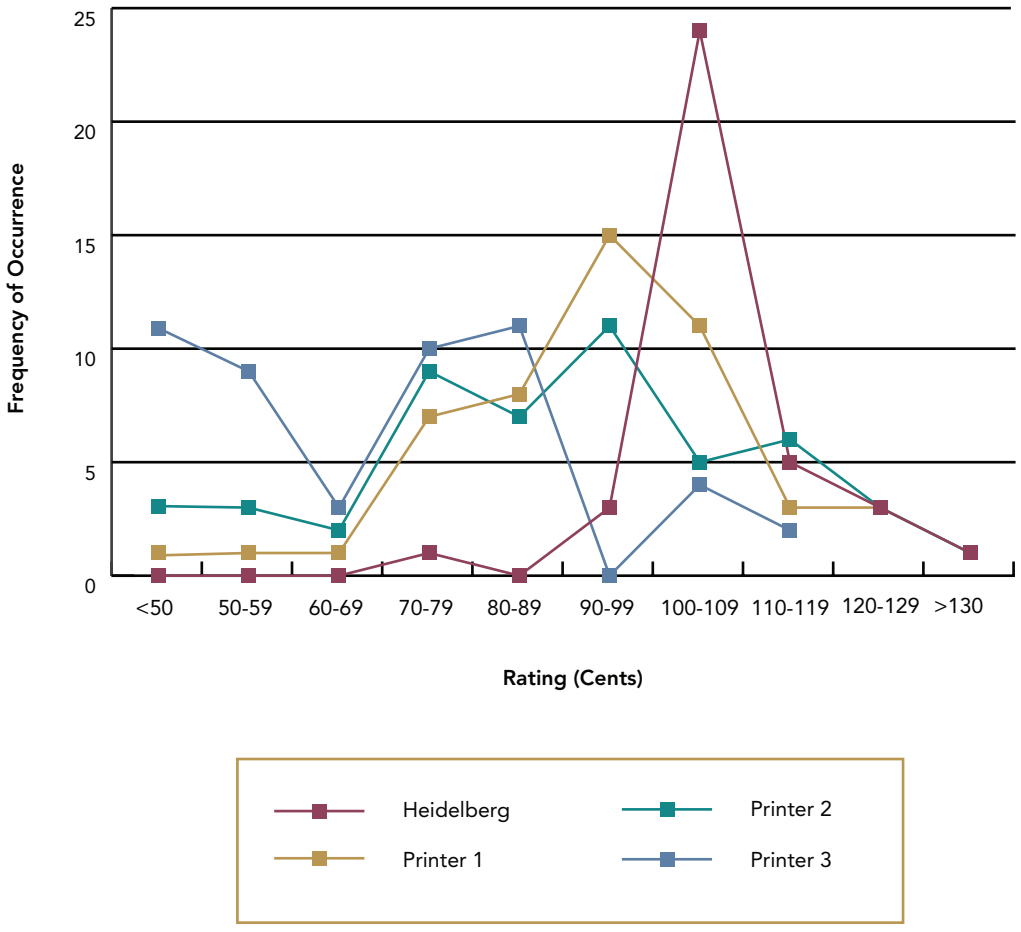

Figure 3. Number of values assigned by the 38 participants for the comparison prints of the "Sarah" photo page image set on coated media

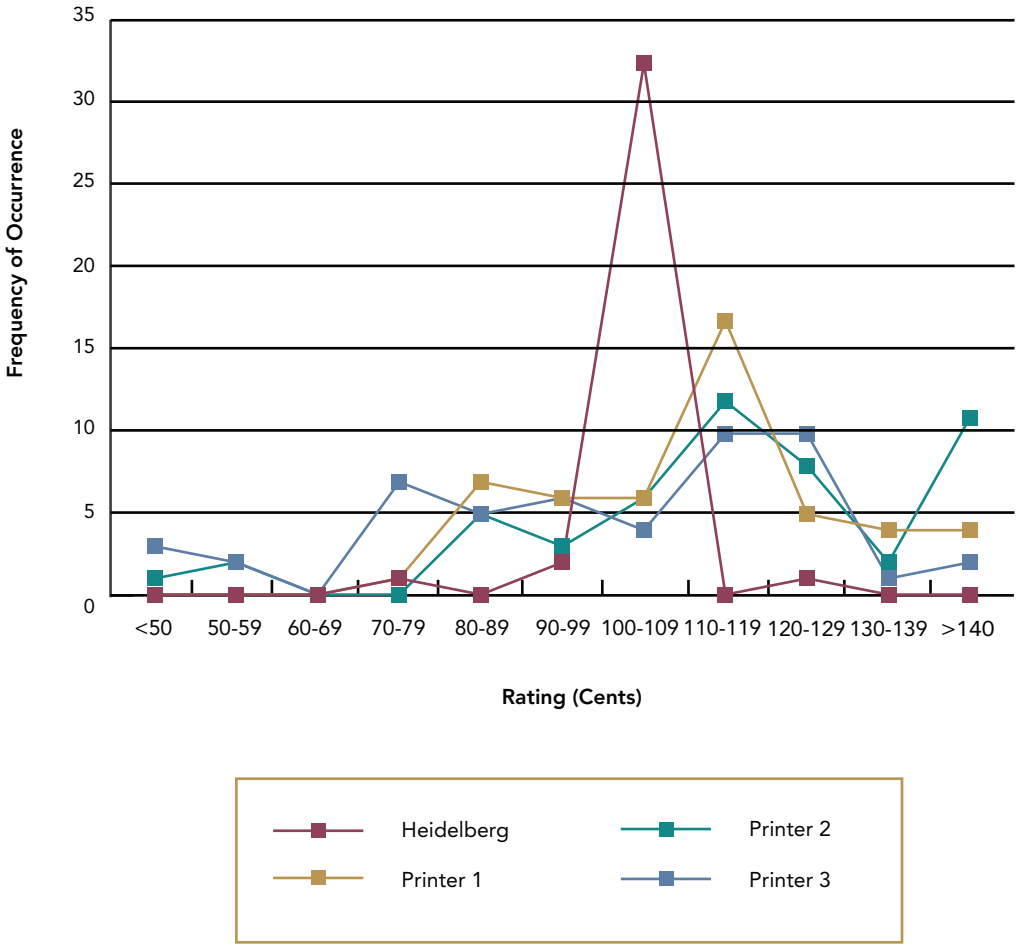

Figure 4. Number of values assigned by the 38 participants for the comparison prints of the "Sarah" photo page image set on uncoated media

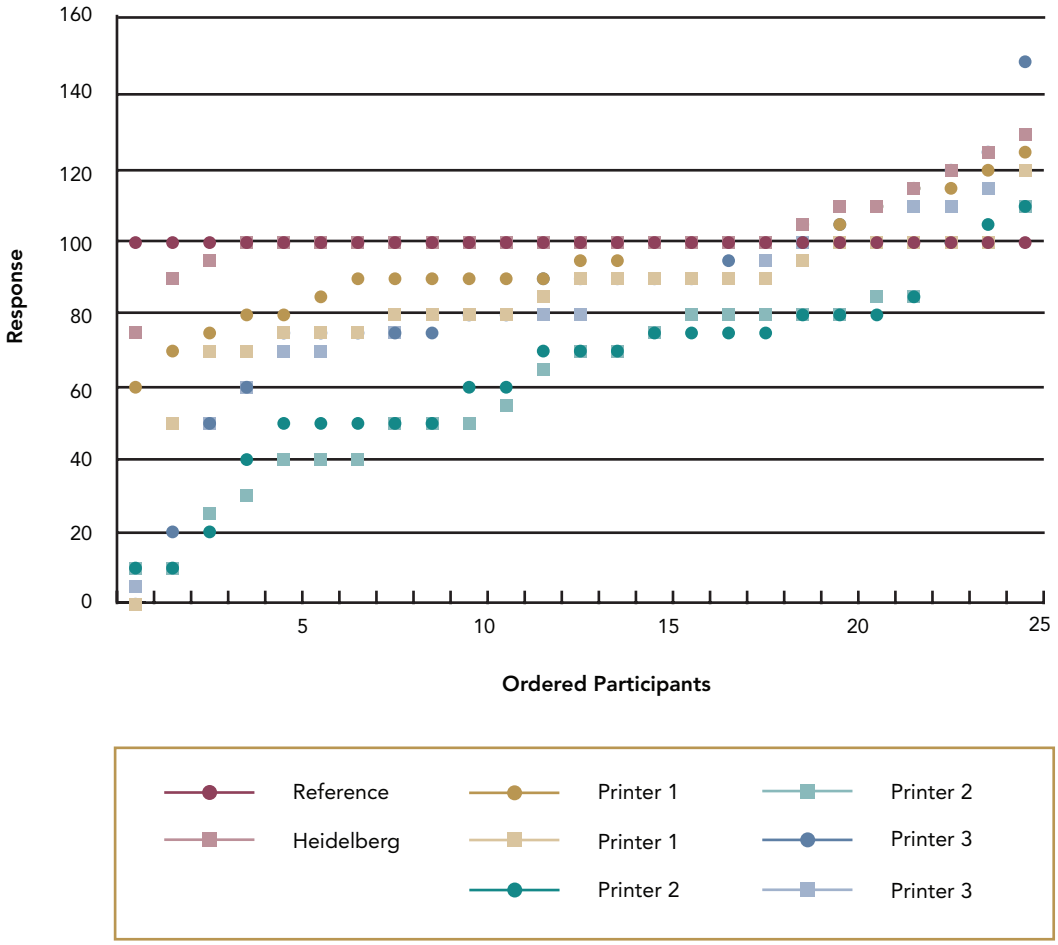

Figure 5. Values assigned by the 38 participants for each of the comparison prints in the "Sarah" photo page image set on coated media, shown in ascending order

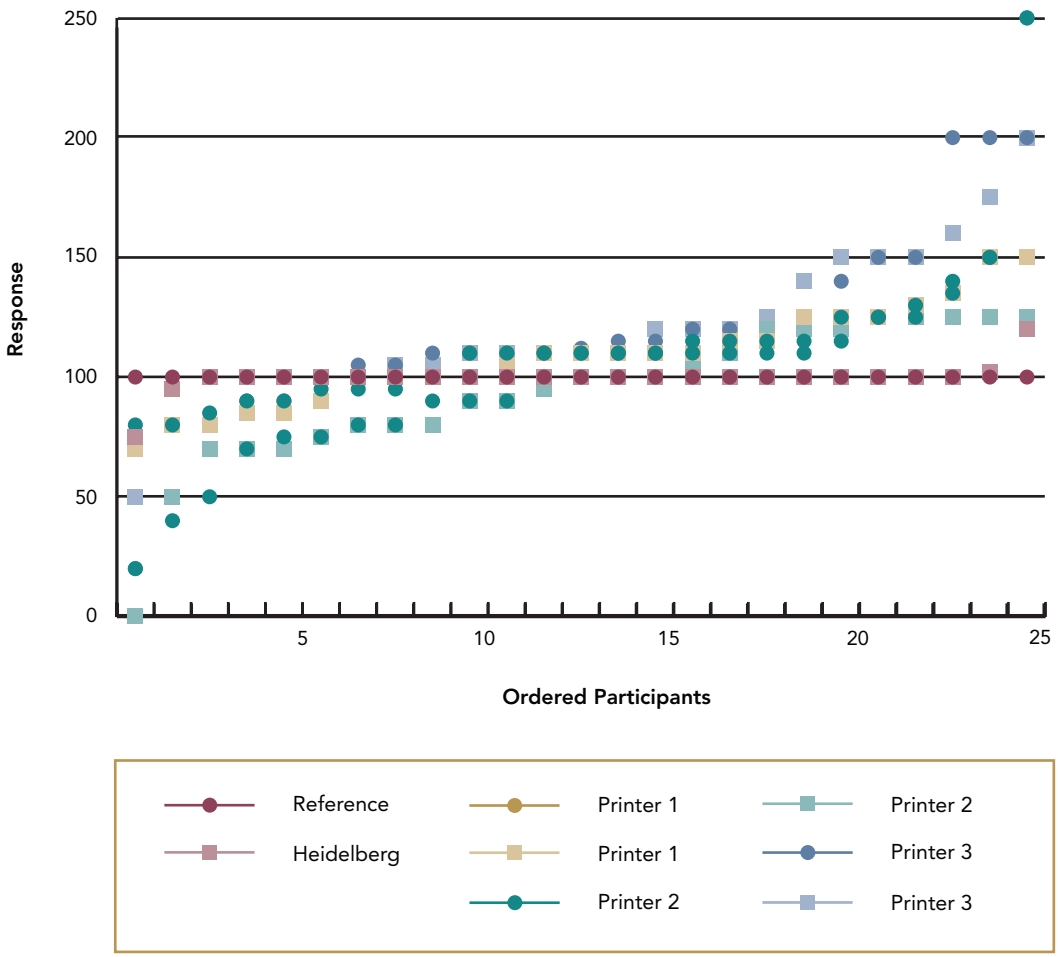

Figure 6. Values assigned by the 38 participants for each of the comparison prints in the "Sarah" photo page image set on uncoated media, shown in ascending order

Figure 7 shows that the uncoated media had higher variability than the coated media for the train brochure and the Village Sports mailer as well. For the remaining images, the variability is essentially the same between the coated and uncoated media sets. Figure 8 shows the variability by printer. Variability is highest for Printers 2 and 3 on uncoated media.

The exact reason why the assigned values had increased variability on uncoated stock is uncertain. However, the differences between the reference and comparison prints were more apparent for the prints on uncoated media than those on the coated media, just as the prints on the digital prints had much greater differences than those made on the Heidelberg Speedmaster. As the difference from the reference increased, so did the variability in how the participants valued those prints; some thought the differences were inconsequential, some found they added to the value, and others occasionally felt the differences rendered the prints worthless.

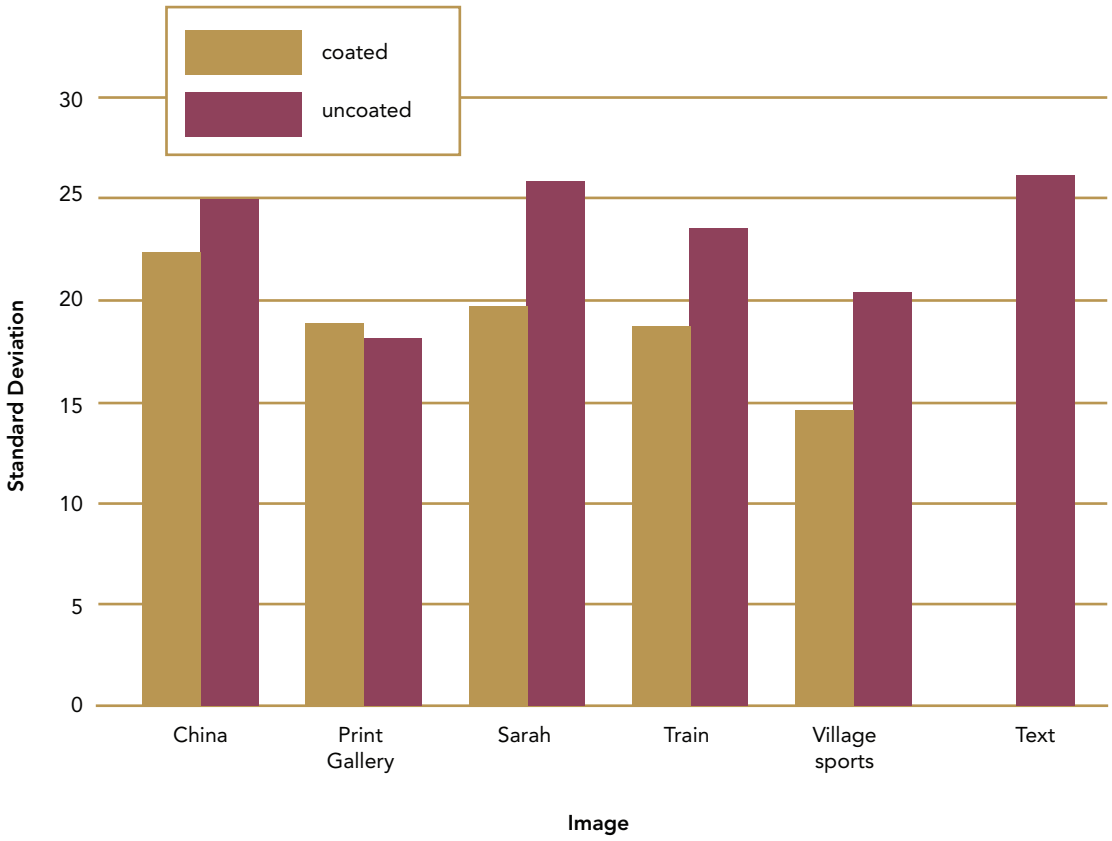

Figure 7. Standard deviation values for each of the image sets on coated and uncoated media averaged over all images

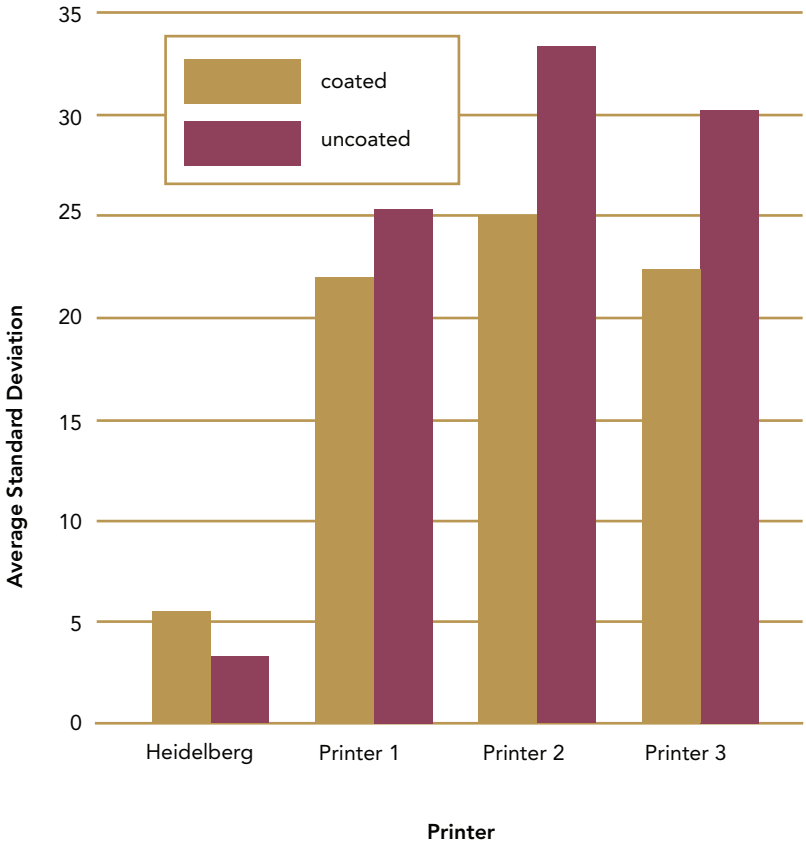

Figure 8. Standard deviation values for each of the image sets on coated and uncoated media averaged over all the printers

Further investigation reveals other interesting differences between the coated and uncoated media sets. For the coated media, the offset prints are consistently rated higher than the digital prints for all images, as shown in Figure 9. Only the "China" images from Printer 3 and the "Train" images from Printer 1 are rated approximately the same as the offset reference for coated media. This was also evident in Figure 3, which shows that the majority of the responses were below the $1.00 value of the reference print for all of the other printers. Also, as shown in Figure 5, a clear majority of the responses for the "Sarah" photo page are below the $1.00 reference print value. However, for the uncoated media, prints produced on the high-end digital printers often rated higher than the offset prints on average, as shown in Figure 10. Many of the prints made on Printers 1 and 3 were rated at a higher value than the offset reference. The train brochure, the Village Sports mailer, and the photo book pages show this shift to higher perceived quality for digital printers 1 and 3. Figure 5 shows that the response peaks for uncoated media shifted above the $1.00 reference print value when compared to the coated media, while Figure 6 shows the responses as more evenly distributed above and below the $1.00 reference print value. Figure 11 shows the comparison of the coated and uncoated media by printer averaged over all of the image sets.

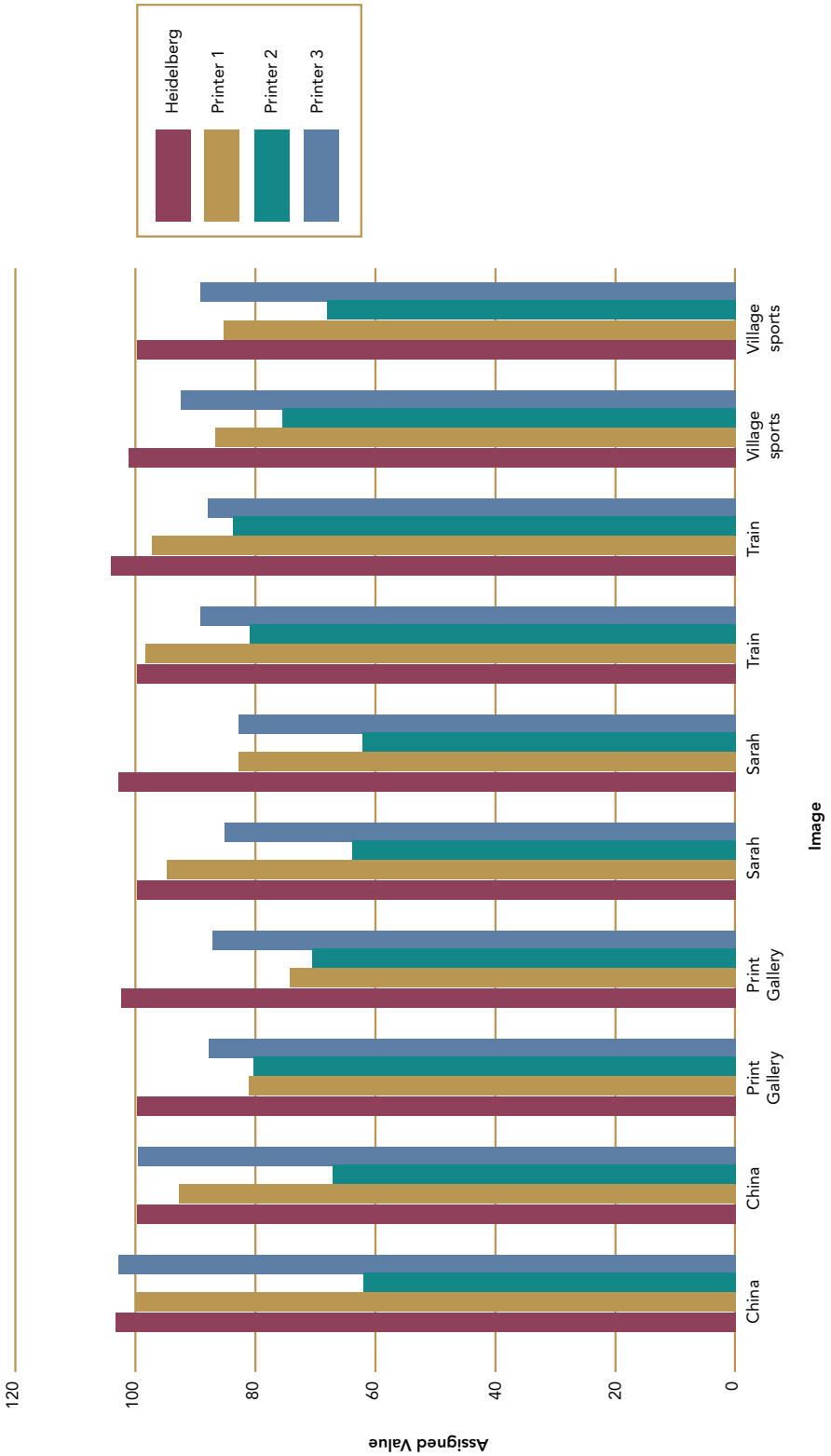

Figure 9. Average assigned value for each image on coated media, shown by printer

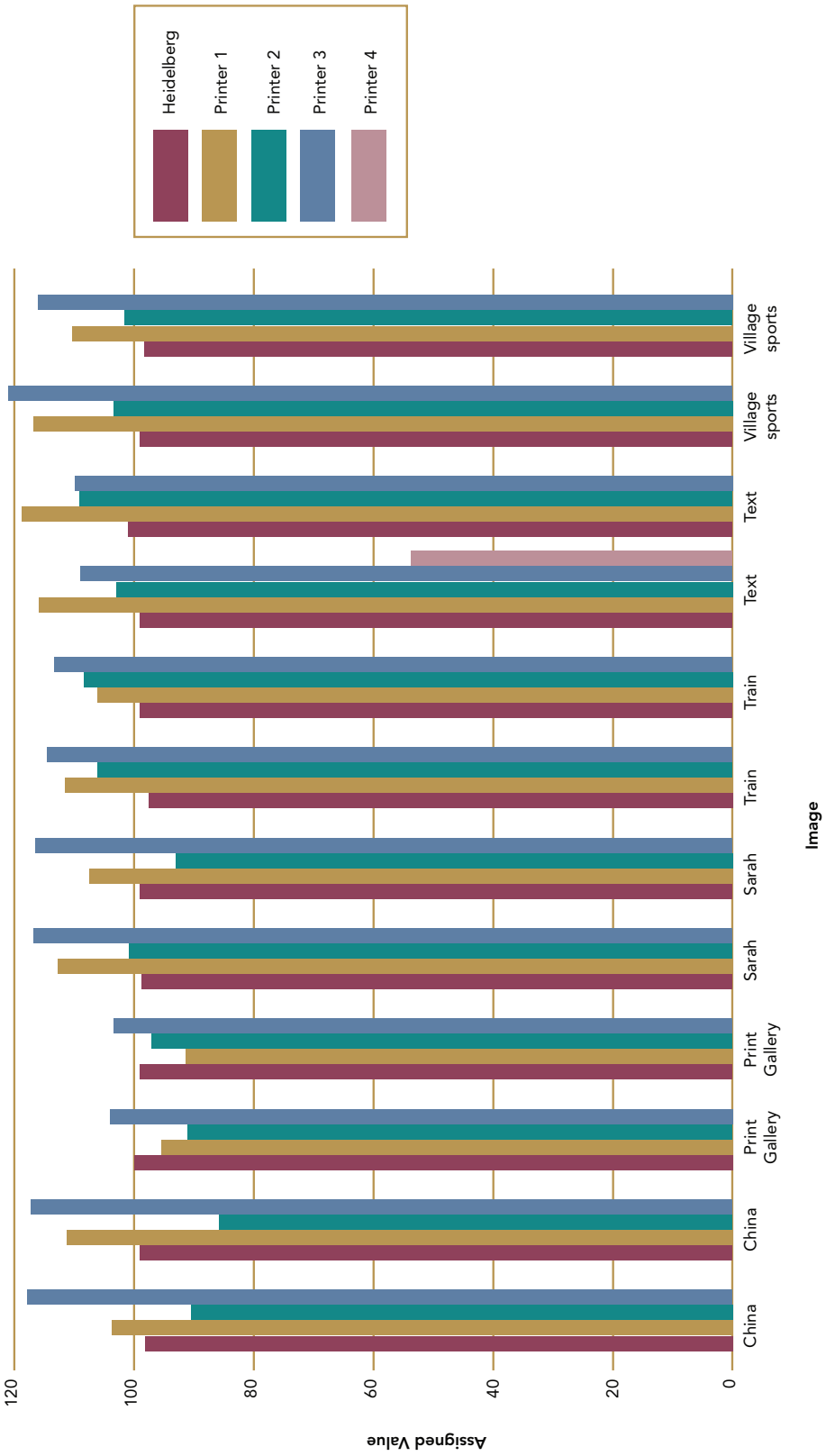

Figure 10. Average assigned value for each image on uncoated media, shown by printer

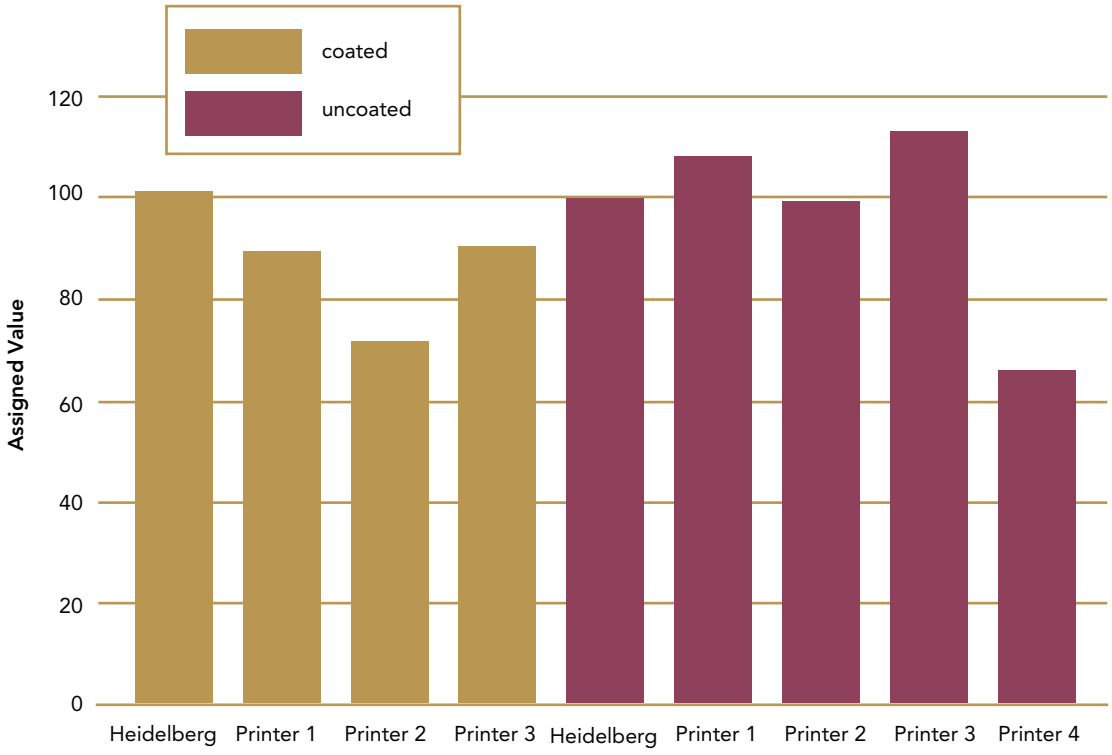

Figure 11. Mean assigned values for the images on coated versus uncoated media for each printing device

Given the high variability of the participants' responses, it would be reasonable to ask whether or not any of the differences exhibited in Figures 9 and 10 are significant. For the coated images, a difference of about 14¢ would be needed to be significant at a 95% confidence level. With this requirement, all of the prints made on Printer 2, the Print Gallery, Village Sports, and one of the "Sarah" prints made on Printer 1, and the "Sarah" prints made on Printer 3, are significantly worse than those made on the Speedmaster.

For the uncoated images, a difference of about 18¢ would be needed to be significant at a 95% confidence level. With this requirement, the photo book pages and Village Sports brochures made on Printer 3 and the text images and one of the Village Sports brochures made on Printer 1 were all rated of significantly higher value than the prints made on the Speedmaster. The single text print made on a desktop printer was not considered to be of comparable quality level as the prints made on the offset press or the high-end digital printers.

It is interesting to note that there were two instances where one of the two prints of an image on a given media made on Printer 1 was significantly different and the other one was not. Further investigation revealed that Printers 1 and 2 showed more variation between the two prints of a given image on a given media within the run (about 5¢ on average) than did either Printer 3 or the offset press, which showed an average within-run difference of about 2¢. While the levels of variation were too small to be statistically significant (although the "Sarah" photo page on coated media for Printer 1 had a

difference between the mean responses for the two prints of 12¢ and was close to being significant), the run lengths were relatively short. The increased variation for two of the digital printers may signal that within-run variability is an important factor to monitor.

The data indicate that statistically significant differences between prints made on digital equipment and those made on an offset press existed in this experiment. What factors led to these perceived differences in print quality? The comments made by the participants as they made their assessments are instructive.

The three most common comments dealt with uniformity, including things like grain, banding, and smooth gradations; contrast; and text and line quality, especially when regarding arcs and white text. Lack of uniformity was the most common complaint for the prints made using digital equipment, with concerns regarding text and line quality ranking second. However, many participants preferred the higher contrast of the digital printer output, especially for the photo book pages and marketing material on the uncoated media. Although there were few comments specific to gloss, it seems reasonable to posit that the higher gloss appearance of the prints created on the digital equipment added to the perception of higher value on the uncoated media. Certainly, the higher gloss added to the higher contrast and the higher color saturation of these prints, which was appealing to many participants.

Asian and European participants were among those who seemed to exhibit a preference for higher contrast, more highly saturated images. The ratings for these participants were examined relative to those produced by American-born participants. Different, higher printing standards have been in effect in the past in European and Asian countries. Questions have arisen periodically about whether different results would be obtained in image quality assessment experiments with Asian or European observers relative to those born in the United States.

In this experiment, significant differences between the European and Asian-born observers (n=10) and those raised in the United States (n=28) were seen for two digital printers for the "Sarah" photo book image on coated media, for the "China" photo page and the Village Sports brochure on uncoated media, and for one of the digital printers for the Print Gallery image on coated media. Interestingly, in each of these cases the European and Asian participants rated the prints more highly than the U.S. participants.

The mean rating results for all of the test images are shown in Figure 12, with the U.S. ratings being plotted relative to the Non-U.S. ratings. The blue diamonds depict the one-to-one relationship of the Non-U.S. ratings relative to themselves. There are generally more U.S. ratings values below this line than above it. The higher ratings by the Asian and European participants could be attributed to their apparent preference for the higher contrast and saturation of the digital printers. It may be that these participants were more lenient on other image quality problems (such as lack of uniformity and lower resolution) as they weighed the relative effects on overall quality of different aspects of the comparison images.

Color is an image attribute for which regional differences have been shown. In a survey conducted on ink jet image quality, Gast and Tse (2001) report differences in color preference between Asian and American participants, but not in other aspects of image quality. Fernandez and Fairchild (2002) report regional differences in color preference as well. Although participants in this experiment were instructed to overlook shifts in hue to the best of their ability, differences in color saturation may have had an impact on their ratings, leading to the regional differences in image quality detected.

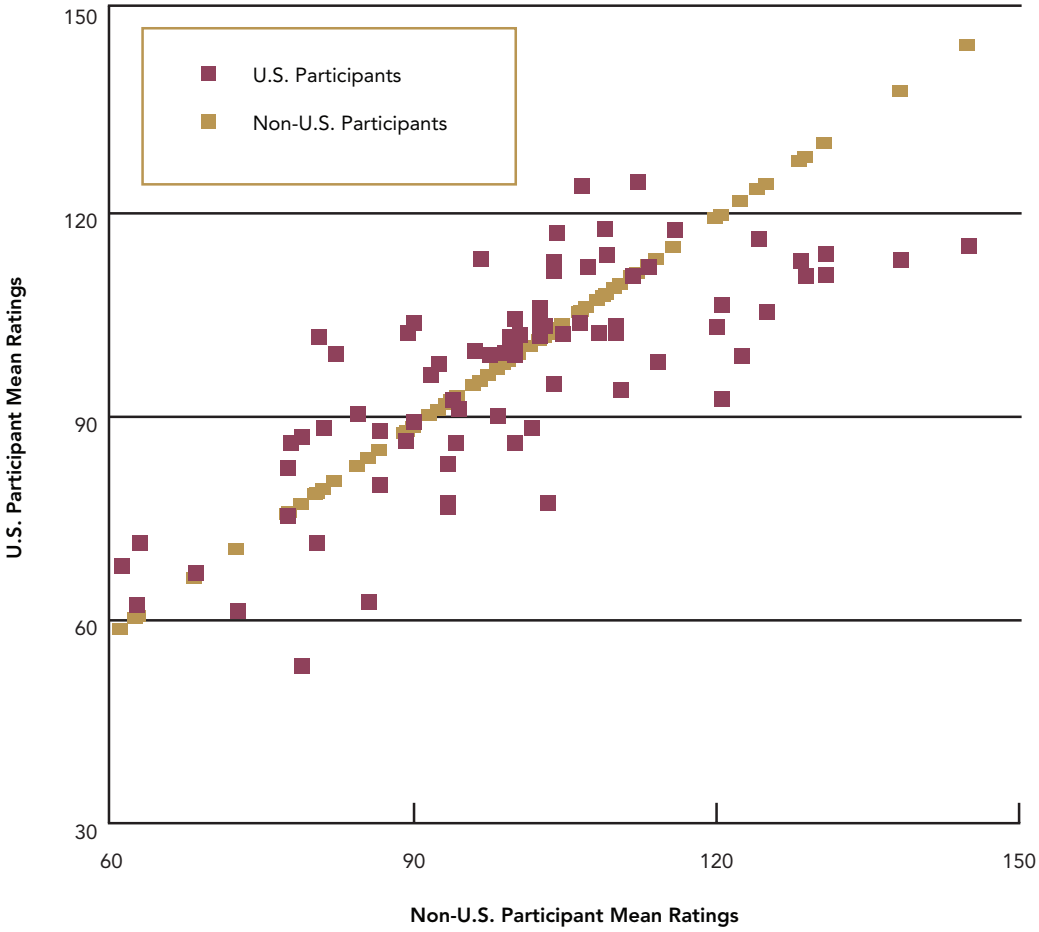

Figure 12. Mean ratings for U.S. versus Non-U.S.-born participants

In their work on digital and offset print quality, Chung and Rees (2006a) report that the problems with offset printing relate to issues with the materials used while the problems with digital printers relate to the technology and lack of standards making the "use of formal quality assurance procedures difficult." The results of this survey seem to support this conclusion. The main problem with the offset prints seemed to relate to the uncoated media used. The prints on this media generated by the offset press used in this research were lower in contrast and gloss, giving them a flat, dull appearance. Conversely, the digital prints had problems with uniformity and, to a lesser extent, text and line quality, that were the result of technical constraints and limitations.

Conclusions

It is important to remember that prints were made on only one offset press and only one machine for each of three different high-end digital printer vendors. Different results may be obtained using different equipment, even if it is from the same vendor and has the same model number. Different results could be obtained on this same equipment run by different people or on different days. Therefore, drawing conclusions from this work must be done with some caution. In all actuality, the best that can be hoped for is a better understanding of existing trends.

For this set of participants with this set of images, it was found that the offset press produced prints on coated paper that had comparable or higher perceived value for all of the images tested. On uncoated paper, the story was somewhat different. On uncoated media, some of the prints from two of the digital printers—especially those of the photo book pages and marketing materials—were found to be of higher value. Participants generally liked the uniformity and high quality lines and text of the offset prints, while they tended to prefer the higher contrast of the digital prints—at least for some applications—on the uncoated paper. These results are in general agreement with Chung and Rees' (2006a) findings that offset printing image quality issues tend to be related to materials problems, while image quality issues for digital printing equipment tend to involve technical limitations of the equipment.

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Appendix A: Images Used in Research

Village Sports Mailer

Energetic staff, unique sports experiences, and incredible themes and activities. 5 acre indoor/outdoor sports center. You'll find it all at the Village Sports Just For Fun Sports Camp. Designed for boys and girls ages 5 – 12, the camps add unusual twists to standard sports to create fabulous, fun activities. Basic skills related to the sport are taught by a team of experienced coaches. Each session emphasizes teamwork, sportsmanship, safety, and most of all FUN! Our coaches are carefully selected based on their experience in the specific sport to provide your child with the ultimate summer sports experience. Facilities include: Air Conditioned Turf Field, Ice Rink, Water Wars, Adventure Challenge Maze, and a large outdoor activity area. Let the games begin!!!

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Creative games, encouraging kids to have fun with sports, and helping them learn through play are the goals of our program. All coaches are experienced with Red Cross training certification. They're fun, involved, talented young people who enjoy working with children to help them learn and grow while emphasizing safety and fun.

Just the facts

10 one week sessions run Monday through Friday. Complete and mail the registration form, or drop it off at our front desk. Parent or guardian must sign liability waiver on the registration form. Please complete a separate registration form for additional siblings.

Camp Costs

$99 per session 9:00 am - noon
$180 per session 9:00 am - 4:00 pm
$199 per session for extended day (7:30 am - 6:00 pm)
Lunch is available for $25/session or bring your own.

All summer Sports Camp activities take place at our newly renovated and expanded Village Sports, 5 acre indoor/outdoor facility, featuring:

- Indoor Turf
- Ice Skating Rink
- Mini-golf
- Basketball Area
- Outdoor sports fields
- Adventure Challenge obstacle course
- Water Wars
- Pirate Pete Surf n' Slide
- Active care center with crafts, computers and other educational opportunities

"Just For Fun"
Summer Sports Camp

10 Weeks of Great Summer Sports Fun

June 25 1. Lots of Lacrosse
Guest appearance by a Rochester Knighthawk

July 2 2. Star Spangled Sports
(Pro Rated for Holiday week-no camp July 4th)
An "All American" Sports spectacular with a variety of awesome sports and games

July 9 3. Super Soccer
Led by U of R goalie coach John Spuhler

July 16 4. Extreme Hockey
Play with Boston Bruins Prospect Chris Collins

July 23 5. Summer Super Bowl (Football)
SUNY Brockport football grad Brock Thrasher will lead the march to the Super Bowl

July 30 6. Wild World of Sports
A crazy and exciting week of sports you've heard of and some you haven't.

August 6 7. Hockey! Hockey! Hockey!
Play with local hockey stars. A great week for the young hockey fan!

August 13 8. Soccer Insanity
Coach John teams with local soccer players to work on skills and have a blast!

August 20 9. Sports Spectacular
If you love sports, this ones for you. We'll play them all!

August 27 10. Summer All Stars
This week we play all the favorite games from the previous 9 weeks. This is all star games week. Always a favorite!

Village Sports Registration
SUMMER SPORTS CAMP 2007

Child's name _____ DOB_____
Address _____
City/State_____ Zip_____
Parents_____
Phone (home)_____ (work/cell) _____
E-mail_____
Emergency contact _____
Phone_____

Choose Your Session & Options:

Sessions	$99 9-12 morning	$25 lunch*	$180 9-4 full day	$199 7:30-6 extended
1. June 25-29	☐	☐	☐	☐
2. July 2-6 closed 7/4	☐	☐	☐	☐
3. July 9-13	☐	☐	☐	☐
4. July 16-20	☐	☐	☐	☐
5. July 23-27	☐	☐	☐	☐
6. July 30-Aug 3	☐	☐	☐	☐
7. Aug 6-10	☐	☐	☐	☐
8. Aug 13-17	☐	☐	☐	☐
9. Aug 20-24	☐	☐	☐	☐
10. Aug 27-31	☐	☐	☐	☐

*lunch includes choice of pizza or soft sandwich, chips, drink, fruit and cookie

METHOD OF PAYMENT
☐ Check made out to Village Sports
☐ Credit card (circle) Mastercard Visa Discover Amer. Exp.

Card #_____
Name on card _____
Total Amount$_____ Exp. Date_____
Signature _____

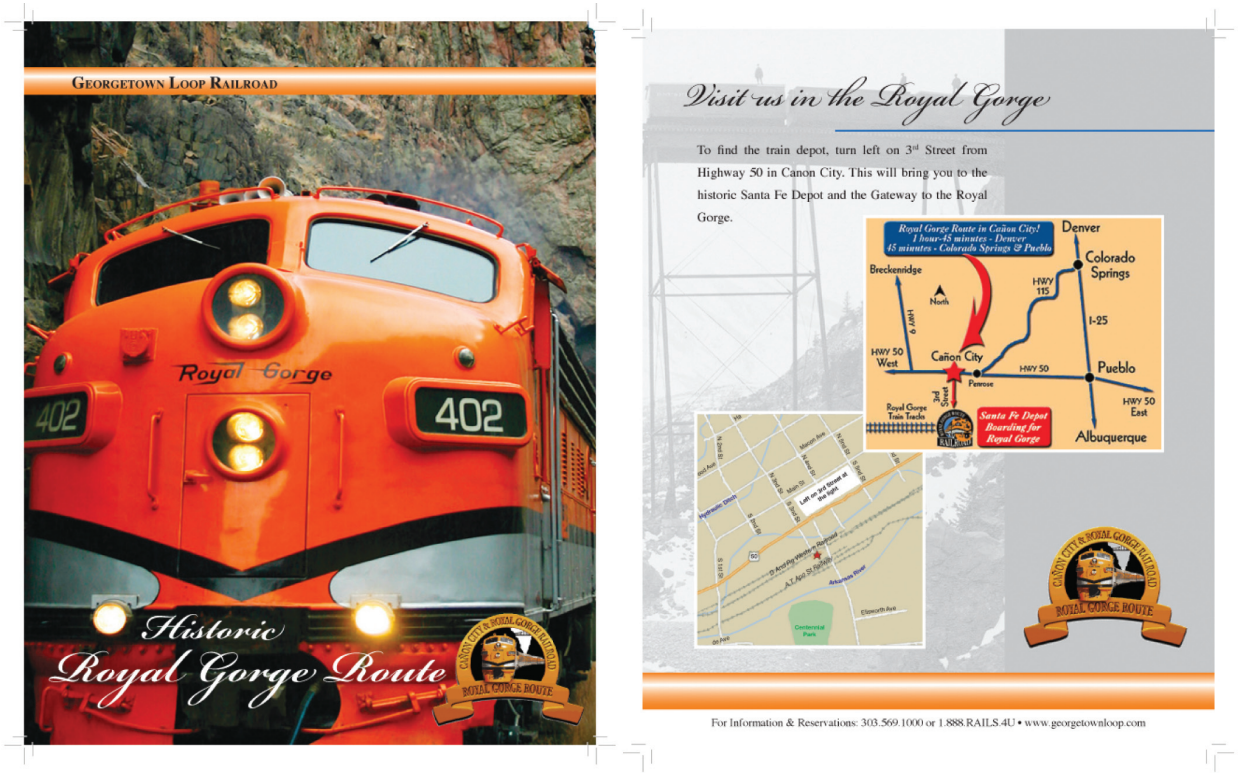
Liability waiver: the participants and guardians agree Village Sports coaches, staff, and instructors will not be held responsible for any incidents or loss, however caused, and agree to release program directors and proprietors of Village Sports from all claims or damages which may arise as a result of any such accidents or loss.

Signature _____ Date_____

To register by mail, send to: Village Sports, attn: Summer Kids Camp, 2830 Baird Road, Fairport, NY 14450

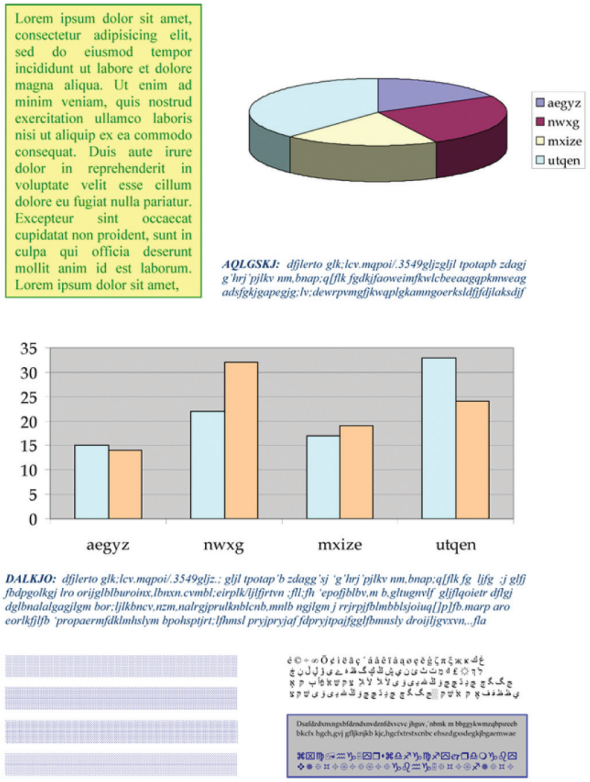
"China" Photo Page

"Train" Brochure

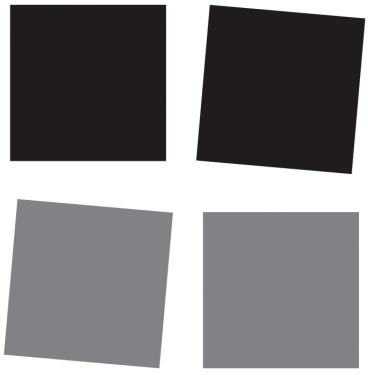


"Sarah" Photo Book Page

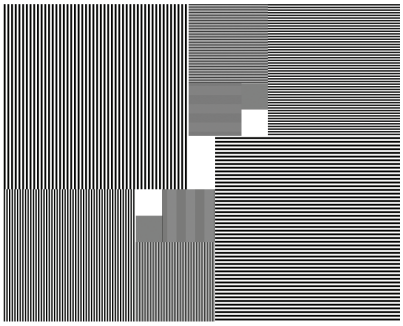
"Text" Business Communications Page

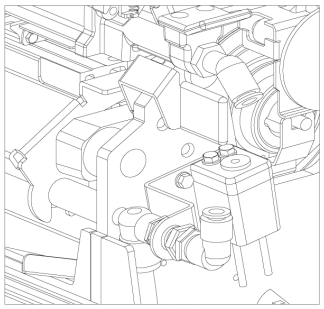


NIP 23 Target



NIP 23 target
(ez/dt 2007)





Rochester Institute of Technology
College of Imaging Arts and Sciences
55 Lomb Memorial Drive
Rochester, NY 14623
Phone: (585) 475-2733
http://print.rit.edu