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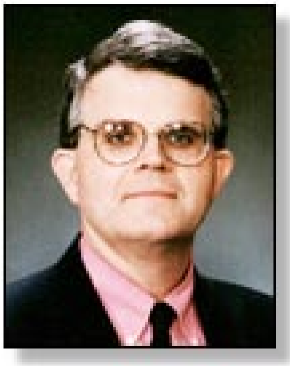

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Abstract

Graphic Arts professionals routinely choose the halftone screen frequency (LPI) to be used when reproducing photographs on various substrates with diverse printing processes. This choice involves numerous variables. Although decisions about most of these variables are mathematically based, some depend upon the end-use of the product and/or aesthetic considerations. One end-use concern is the distance between viewer and printed product: halftones viewed at a great distance can employ coarser halftone screens than images viewed up-close. Although the printing industry has traditionally employed rules-of-thumb regarding this variable, no empirically based study to relate viewing distance to LPI was found. This study fills that void and offers the graphic designer and/or prepress technician empirically-based data upon which to base LPI decisions.

Introduction

One of the most fundamental decisions to be made when preparing a photographic image for printed reproduction is the choice of the proper halftone screen. Whereas laypeople simply click "Print" and let their computer and printer driver make all the decisions, professional graphic artists—both designers and printers—must take into consideration halftone attributes that can contribute to, or detract from, the faithful reproduction of the image. Industrial Technology educators, especially those teaching print technology, teach students how to make decisions that will impact the effectiveness of printed halftones. Some of the decisions which educators often cover include: halftone type (amplitude- or frequency-modulated); dot shape (elliptical, square, round, and so on); screen angle(s); and screen frequency. The choice of screen frequency, known in the United States as lines per inch (LPI), is complex and based upon numerous aesthetic and mathematical considerations. Although halftone type, dot shape, and screen angle(s) are also important concerns, this article deals solely with LPI decisions. In particular, it is concerned with decisions that need to be made about LPI when reproducing images with amplitude-modulated (AM) halftones that will be viewed at varying distances. This paper provides Industrial Technology educators with empirically-tested answers to the question, "What LPI should be used when a halftone is viewed at a given distance?"

Screen Frequency Defined

Screen frequency refers to the number of lines, or rows, of halftone dots in one linear inch (LPI) or one linear centimeter (LPC). For example, in Figure 1, the halftone on the left is reproduced using a 35 LPI screen, while the photograph on the right uses a 133 LPI screen. Notice that the dots in the 35 LPI screen can be seen easily while those in the 133 LPI screen are almost invisible to the naked eye.

Figure 1. Halftones reproduced at 35 LPI screen (left) and 133 LPI (right).

Another way of illustrating frequency would be to consider the compactness of halftone dots within a square inch. Higher LPI screens have many more halftone dots in a square inch than lower LPI screens. For example, a 133 LPI screen has 17,689 halftone dots per square inch (133 × 133) while a 35 LPI screen has only 1,225 halftone dots per square inch (35 × 35). Some commonly used screen rulings include 65, 85, 100, 120, 133, 150, 175, 200, and 300 LPI.

Factors Affecting Screen Frequency

The choice of LPI is affected by numerous variables including: aesthetics, end-use requirements, the printing process, the substrate on which the image will be printed, the level of illumination under which the image will be viewed, and the resolution of both the output device and the digital photograph. The graphic artist must carefully consider each of these variables and determine which LPI best suits the constraints of each one. Oftentimes, the best LPI resolution for one variable is not suitable to another. For example, an output device may be able to handle a 150 LPI screen but the substrate may only accept a 50 LPI screen. The level of viewing illumination adds yet another variable. The appropriate LPI for a given job is the lowest appropriate to any of the variables.

End-use Considerations

Printed products are all designed and produced with a particular end-use in mind. For example, the product could be a fashion magazine, daily newspaper, direct-mail advertisement, invoice, letterhead, novel, textbook, art book, fine-art reproduction, point-of-purchase (POP) display, road sign, or billboard among thousands of different possibilities. Each of these items requires varying amounts of image detail. For example, consumers have come to expect a great deal of image fidelity in catalogs they use to make purchasing decisions. On the other hand, resolution of images in invoices is not of much concern as long as the amount due is legible.

One seldom-considered end-use requirement is viewing distance. Printed photographs on billboards viewed from a distance can use very low LPI screens because the dots are too far away from the viewer to be discerned. POP displays, in supermarkets, gas stations, and convenience stores, are viewed from a few feet away. So, to minimize the appearance of the halftone dots, POPs must be printed with higher LPI screens than billboards. Very high resolution is necessary for items such as art books. People look at photographs in such books closely—at perhaps a distance of six or fewer inches—to discern minute detail. Thus, these printed photographs require very high LPI screens to minimize the effect of the halftone dots on the image. Printing industry guidelines, such as the Specifications for Web Offset Publications (SWOP), the Specifications for Newsprint Advertising Production (SNAP), the General Requirements for Applications in Commercial Offset Lithography (GRACoL), and the Flexographic Image Reproduction Specifications and Tolerances (FIRST) all specify the *maximum* LPI that a given printing process and substrate combination can technically support. The highest LPI to be recommended by any of these guidelines is 175 if the job is to be printed on grade one or two premium coated paper using offset lithography. However, these guidelines do *not* specify the *appropriate* LPI for a given printed product. Instead, a wise graphic artist will choose the most *effective* LPI for a particular job. If 175 LPI is the finest screen recommended by printing industry guidelines, then the graphic artist must consider how to maintain that relative resolution as distance increases or decreases. Screen frequency can be decreased as viewing distance increases or increased as viewing distance decreases.

The resolution of an image has an impact on its file size. Higher LPI image files are logarithmically larger than smaller LPI files. Thus, to save hard drive space, speed up file processing in image-processing and page layout programs, and to decrease raster image processing (RIP) and output time, it is important to constrain LPI to a reasonable resolution.

Purpose

Many of the factors affecting the choice of LPI screen for a given reproduction are dependent upon mathematics or industry-sanctioned standards. For example, to prevent error diffusion, the output device's resolution, measured in dots per inch (DPI), mathematically fixes its maximum LPI according to the rule of 16's.

Output device resolution in DPI / 16 = Maximum LPI

2400 DPI / 16 = 150 LPI

The Nyquist Theorem fixes the proper relationship between image resolution, in pixels per inch (PPI), and LPI.

photograph resolution = *QCxlpixmagnification*
= *2 x 150 x 200%*
= *600*

In the Nyquist Theorem, "QC" stands for quality control factor and ranges from 1.5–2. In the above example, a factor of 2 is employed because it is the most common.

Printing industry guidelines, such as the SWOP (SWOP Incorporated, 2005), GRACoL (IDEAlliance, 2002), FIRST (Flexographic Technical Association, Inc., 2003), and SNAP (Newspaper Association of America, 2000) recommend the most effective LPI for varying substrates when printed with specified printing processes. A graphic designer or prepress technician need only consult one of these specifications to ascertain the appropriate LPI for a given process and substrate.

Of the factors affecting the choice of LPI for a given job, only two are not predetermined: aesthetics and viewing distance. Aesthetics are purely in the mind of the beholder and are, thus, subjective. On the other hand, the distance at which varying sizes of halftone dots is dependent on the human visual system and can be measured. Of course, not all humans possess the same visual acuity. However, a table of average human visual sensitivity to varying sizes of halftone dots would be of tremendous value to graphic designers and prepress technicians when photographs are prepared for print reproduction.

A thorough search of the Internet, as well as e-conversations with instructors and representatives of printing trade organizations and standards groups, failed to uncover an empirically-based LPI vs. viewing distance table or rule. The Specialty Graphic Imaging Association (SGIA) recommends using a heuristic "Rule of 240" when choosing the LPI for a given print application (Specialty Graphic Imaging Association, 2003). However, representatives from the SGIA indicate that the Rule of 240 has never been empirically tested.

Research Statement

The purpose of this study was to devise a test to determine human visual sensitivity to varying sizes of grayscale halftone dots at distances ranging from six inches through 20 feet and then administer it to a wide variety of subjects. After administration of the test, the results would then be analyzed and compared to directly- and indirectly-related LPI vs. viewing distance relationships that were gleaned from the literature.

Review of the Literature

Very little literature related to this study was encountered, even though a thorough web search was conducted and numerous printing industry authorities were contacted. In fact, only two types of relevant literature were discovered, and only one is directly related to printing and publishing. The first is an industry-recommended rule-of-thumb suggested by the SGIA. The second is related to the Snellen Chart used by optometrists to measure overall human visual acuity.

The Rule of 240. The SGIA recommends using the Rule of 240 when choosing the LPI for a given print application (Specialty Graphic Imaging Association, 2003). According to this rule-of-thumb, the optimal LPI for a given viewing distance is found by dividing 240 by the distance in question. Thus, if a halftone is to be viewed from a distance of two feet, the LPI would be:

240 / 2 feet = 120 LPI

SGIA bases the Rule of 240 on a reference 175 LPI screen. This screen ruling is the highest ruling recommended by any of the printing industry's guidelines and is based upon the *technical* capabilities of printing devices imaging varying types of substrates. "The rule of 240 comes from establishing premium quality as 175 lpi at 16.5 inches from your eyes (normal magazine high quality printing and viewing). If you extrapolate the 175 quality to a greater distance, you can use the number 240 and it will give you the distance in feet. Visually you will find that the dots will disappear at that distance. This is called 'dot diffusion.' The image looks like a continuous tone. Some people with very good eye sight or a good imagination say they can see the dots, but most people say they can't" (M. Ruff, RayHan PGF, e-mail communication, May 23, 2005).

Based on the Rule of 240, the appropriate screen frequency for a given print job can be determined from Table 1.

Distance	LPI
20 feet	12
18 feet	13.33
16 feet	15
14 feet	17
12 feet	20
10 feet	24
8 feet	30
6 feet	40
4 feet	60
2 feet	120
1 foot	240
6 inches	480

Table 1: Viewing Distance vs LPI using the Rule of 240.

The Snellen Test. The Snellen Test, more commonly known as the "Eye Chart," is used by optometrists to measure visual acuity. Although this test is not directly related to the present study, it is mentioned primarily because it is the only empirically tested methodology related to visual discernment that could be found in the literature. No direct comparison between the Snellen chart and halftone dot size is available. The relationship between them must be inferred.

The I-See Eye Charts (www.i-see.org, 2005) indicate that at 20 feet a person with 20/20 vision should be able to discern 43 point type in which the capital letters are 25 points (0.35") high. The specifications for the Snellen Chart, as given on the www.i-see.org website, are as shown in Table 2. Two additional rows were added to the bottom of the table taken from www.i-see.org. The letter ht (in) row was calculated by dividing the letter ht (pt) by 72 points per inch. The last row, letter ht (in) / 5

Distance (feet)	70	60	50	40	30	20	15	10	7	**4**
letter ht (mm)	31	27	22	18	13	9	7	4	3	2
font size (pt)	152	130	108	87	65	43	33	21	15	9
letter ht (pt)	88	76	63	50	38	25	19	13	9	5
letter ht (in)	1.22	1.06	0.88	0.69	0.53	0.35	0.26	0.18	0.13	0.07
letter ht (in) / 5	0.24	0.21	0.18	0.14	0.11	0.07	0.05	0.04	0.03	0.01

Table 2: Specifications of the Snellen Chart.

is the letter height in points divided by five as explained in the following paragraph. All calculations were rounded to two decimal places in Table 2.

The Snellen Chart is composed of only capital letters. Characters include Es, Fs, and other characters typically composed of five horizontal strokes (i.e., the three black and two unprinted horizontal strokes in a capital letter E). Dividing 0.35" by 5 results in a normal-sighted human's ability to discern an image approximately 0.07" at a distance of 20 feet. Similarly, a normal-sighted person should be able to see an image of 0.04" at 10 feet and 0.01" at four feet.

Methodology

To provide graphic artists and technicians with some empirically-tested guidelines related to LPI versus distance, a test was devised and viewed by students enrolled in GRTC 3350, 3351, 3352, 3353, and 4373 at the University of Houston. In addition, faculty and staff participated in the study, bringing the total involvement to 60 individuals. However, two subjects completed the test incorrectly, so their scores were discarded. Therefore, the *N* = 58. Subjects consisted of youthful teens through senior citizens. Those with self-reported 20/20 vision as well as those with corrective lenses were included in the study. Therefore, the results may be generalized to the general publication.

A color digital photograph was converted to grayscale using Photoshop's stan-

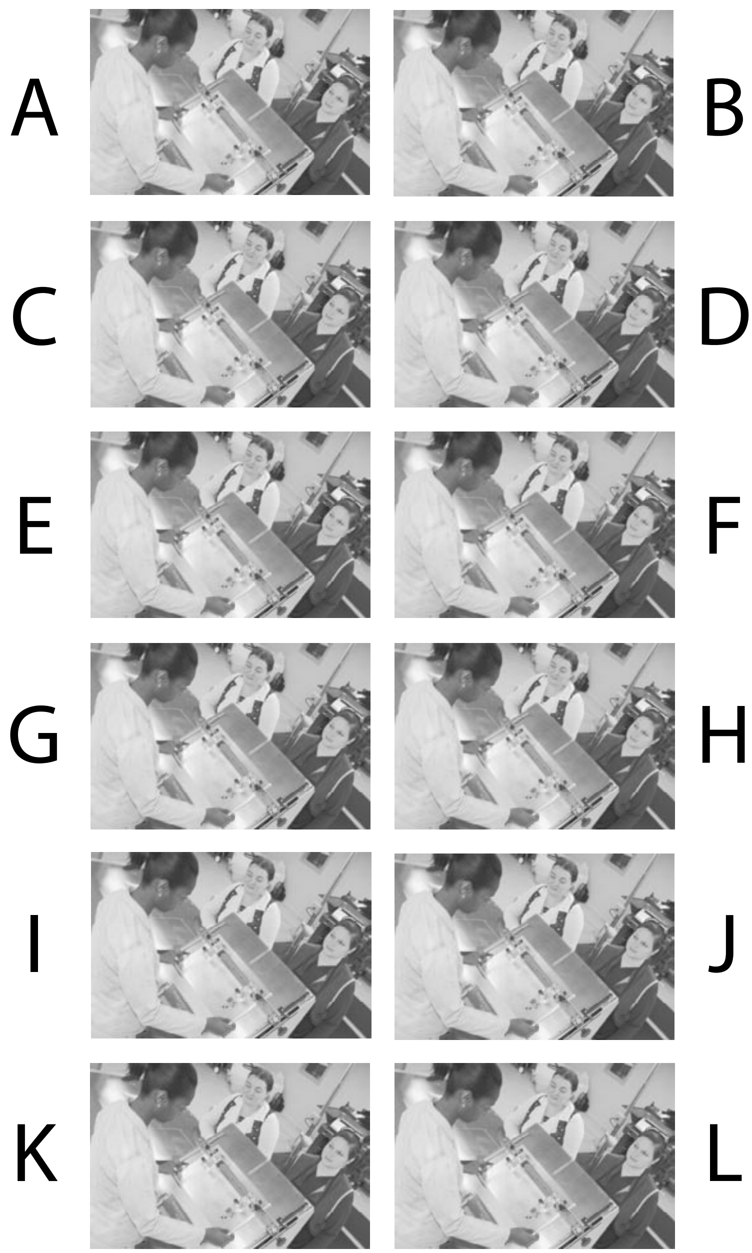

Figure 2. An illustration of the test target used in this study.

dard 20% dot gain profile. The resultant file was duplicated 11 times. Each of the duplicates was assigned one of the following LPIs: 5, 10, 18.75, 37.5, 50, 65, 85, 100, 110, 120, 133, or 150. The LPIs of 65 and above are those commonly used in offset printing applications. Screen rulings of 18.75 and 37.5 LPI relate mathematically to the output capabilities of 300, 600, 1200, and 2400 DPI marking engines. The 5 and 10 LPI samples were included so that the test proctor could explain to the subjects how to take the test: the dots in the 5 LPI sample were clearly visible at 20 feet, so the participants could be shown for what to look.

All 12 files were placed into an Adobe Illustrator document and output to a Mitsubishi Eco 1630 Platesetter. The Platesetter's Harlequin RIP was set to not override the halftone screen specifications embedded in the Illustrator file. The resulting plate was printed with a Ryobi 3302HA printing press on coated stock using GRACoL black-ink density standards. (See Figure 2 for an illustration of the test target.) Finished targets were hung on the wall in a well-lit area. Due to budget constraints, it was not possible to purchase a light meter to numerically measure the light intensity on the surface of the test target. However, all subjects viewed the test target under the exact same lighting conditions. This consistency established a level of control that was the best possible under the circumstances.

Subjects were then asked to view the print from varying distances that were clearly marked on the floor. These distances were: 20', 18', 16', 14', 12', 10', 8', 6', 4', 2', 1', and 6". Subjects recorded the distance at which they could first discern the individual dots in each sample on an anonymous record sheet prepared for the study (see Figure 3).

The distances at which each subject could discern the different halftone screen frequencies, as recorded on that subject's anonymous record sheet, were then input into a Microsoft Excel worksheet. Means, standard deviations, modes, medians, and other descriptive statistics were calculated once each subject's responses had been entered into the spreadsheet.

Findings

The results of the study are presented in Table 3. The tested LPIs are presented in the first column. The second column provides the mean distance at which the subjects could discern the dots. Column three presents the standard deviation of the mean for the entire population of

Figure 3. Record sheet used during this study.

UH Information and Logistics Technology Department
Graphic Communications Technology
Halftone Dot Discernability Study

1. Please assist Dr. Waite and Professor Oliver in completing this study by completing the following chart.
2. This test is voluntary. You will be given no extra credit and the test will not be "graded."
3. Stand at the masking tape marked 20', placing your toes on top of the tape.
4. Look at the Halftone Dot Discernability Test, and see if you can perceive the individual halftone dots that comprise the image in Samples A-L. Please place a check (√) in the box that corresponds to the first distance you are able to resolve dots in the image.
5. Move to the 18' masking tape and repeat the steps 3–4.
6. Continue until you have completed the chart.
7. Please complete only one chart and give it to Dr. Waite, Professor Oliver, or Ella O'Neal

	Please place a check (√) in the box that corresponds to the first distance you are able to resolve dots in the image.											
Distance	A	B	C	D	E	F	G	H	I	J	K	L
20'												
18'												
16'												
14'												
12'												
10'												
8'												
6'												
4'												
2'												
1'												
6"												

1	2	3	4	5	6	7	8	9
Sample	Mean	STDEVP	Mean-STDEVP	Mean+STDEVP	Min	Max	Mode	Median
150	0.08	0.22	-0.15	0.30	0.00	1.00	0	0.00
133	0.32	0.97	-0.65	1.29	0.00	6.00	0	0.00
120	0.67	2.06	-1.39	2.74	0.00	12.00	0	0.00
110	0.85	2.47	-1.61	3.32	0.00	14.00	0	0.00
100	1.17	2.74	-1.57	3.91	0.00	16.00	1	0.50
85	1.65	2.90	-1.26	4.55	0.00	16.00	1	1.00
65	2.56	3.24	-0.68	5.80	0.00	18.00	2	2.00
50	3.86	4.11	-0.25	7.97	1.00	20.00	2	2.00
37.5	5.84	4.39	1.45	10.24	1.00	20.00	4	4.00
18.75	11.10	3.99	7.12	15.09	4.00	20.00	10	10.00
10	17.14	3.07	14.07	20.20	6.00	20.00	20	18.00
5	19.90	0.78	19.12	20.68	14.00	20.00	20	20.00

Table 3: Distances at which viewers can discern varying LPI screens

subjects. Columns four and five present the range of distances that the majority of subjects could see the halftone dots. To calculate column four, the standard deviation was subtracted from the mean. Similarly, column five is the sum of the mean plus the standard deviation. Column six indicates the minimum distance at which a subject could no longer distinguish individual dots (the person with the least visual acuity) while column seven displays the maximum distance at which the observer with the greatest visual acuity could make out the dots for the given LPI. Column eight indicates the mode, or most often occurring distance at which an observer could see the dots in each sample. Finally, column nine indicates the median viewing distance.

Based on the results displayed in Table 3, it is clear that virtually all the subjects could easily discern the dots in a 5 LPI halftone at 20 feet. The mean viewing distance was 19.12 feet while the mode and median for this sample was 20 feet. Applying the standard deviation to the mean, 68% of the population is likely to discern 5 LPI dots between 19.90 and 20.68 feet. Only one subject could not make out the dots at 20 feet: instead that individual discerned the dots at 14 feet. Thus, 5 LPI dots should not be used unless the viewing distance is greater than 20 feet.

At the other end of the scale, the dots that make up a 150 LPI halftone could not be seen by the majority of people, even at a viewing distance of six inches. Only six people reported the ability to discern 150 LPI dots at one foot or less. The mode and median distances are both zero, meaning that the dots could not be seen at all by most people. However, applying the standard deviation to the mean, some people with above-average vision could discern the dots at about 1/3 inch. Since reading distance is about 14–18 inches, 150 LPI dots are, in effect, invisible. Therefore, these dots can be used for virtually any application.

Although 110–133 LPI dots are invisible to most people, adding the standard deviation to the mean viewing distance indicates that these dots will be visible to some people at 1.5–3.3 feet. Therefore, unless circumstances dictate otherwise, 110–133 LPI screens should not be used for materials to be viewed at reading distance. Instead, 150 LPI or higher screens should be employed.

To be most confident that the majority of humans will not be able to view a particular-sized halftone screen frequency, it is suggested that column five, mean plus standard deviation, be used. In practice, a graphic designer or technician, after being informed of the viewing distance for a given printed piece, should scan column five and find the closest distance. The *next higher* LPI should then be used. In this way, Table 3 may be used to determine the appropriate LPI screen for a given viewing distance. For example, if a convenience-store parking-lot sign is to be viewed at a distance of ten feet, it is safe to use a 50 or higher LPI screen.

Discussion

The present study resulted in LPIs that are generally more conservative (i.e. higher LPI number, smaller halftone dots) than those recommended by SGIA's Rule of 240 at longer distances. Conversely, this study recommends lower LPI screens for very close viewing distances. The Rule of 240 predicts that people cannot see a 12 LPI screen at 20 feet and the present study recommends a screen frequency higher than 10 LPI for that distance. These two recommendations agree. At midrange distances, however, the present study always recommends smaller halftone dots (higher LPI frequencies). For example, at a distance of eight feet, the Rule of 240 results in 30 LPI while the present study recommends 65 LPI or greater. Finally, this study recommends lower LPIs than the Rule of 240 for very close viewing distances. See Table 4 for other comparisons.

The discrepancies between the LPIs recommended by the SGIA's Rule of 240 and the results of the present study can be explained by the heuristic nature of the Rule of 240. The Rule of 240 is based upon viewing, at an arms-length of 16.5 inches from the eye, an optimally-reproduced image printed using the printing industry's highest recommended LPI screen (175) with the highest quality printing processes on the best paper. Questions abound. Why 16.5 inches? Do people with short arms have poorer eyesight than those with long arms? What, if any, is the relationship between the technically-based LPIs recommended by varying printing industry guidelines and discernment of halftone dots by people? Since the Rule of 240 has never been empirically tested, these questions go unanswered.

Although the Rule of 240 is a useful tool, it recommends excessively high LPIs for short distance viewing. For example, the Rule of 240 recommends a 240 LPI screen for a viewing distance of one foot while the present study recommends only 150 LPI. A 240 LPI screen far exceeds the recommendations in any of the printing industry's guideline books. In addition, a 240 LPI 5 × 7 8-bit grayscale halftone would consume 7.69 MB of disk space while the same image at 150 LPI would be only 3 MB. The additional RIPping time required to produce a publication with hundreds of 240 LPI images would, as a result, be substantially longer than the time it would take to process the same number of 150 LPI images. In addition, the Rule of 16's indicates that a 3840 DPI image- or platesetter would be required to output a 240 LPI screen while a 2400 DPI device could produce 150 LPI images. In effect, the Rule of 240 results in overkill at extremely close viewing distances.

Comparing the Snellen Test to the current study is complex because the Snellen Test does not directly address LPI. To make a comparison, the height of the capital letter that should be discerned at each distance was divided by five as explained in the Review of the Literature. That resulted in the width of a single stroke of the character that should be discerned at each distance. That width, however, cannot be directly related to LPI since the dot within each line of dots can vary from near 0% in area to 100%. If one considers a 150 LPI screen, the width of each 100% dot is 1/150". However, the majority of dots in a halftone are smaller than 100%. Thus, they are smaller in diameter than 1/150".

Distance	SGIA	Snellen	**Present Study**
20 feet	12 LPI	10 or greater	greater than 10 LPI
18 feet	13.33 LPI	10 or greater	18.75 LPI or greater
16 feet	15 LPI	10 or greater	18.75 LPI or greater
14 feet	17 LPI	18.75 or greater	37.5 LPI or greater
12 feet	20 LPI	18.75 or greater	37.5 LPI or greater
10 feet	24 LPI	18.75 or greater	50 LPI or greater
8 feet	30 LPI	18.75 or greater	65 LPI or greater
6 feet	40 LPI	37.5 or greater	85 LPI or greater
4 feet	60 LPI	50 or greater	100 LPI or greater
2 feet	120 LPI	65 or greater	133 LPI or greater
1 foot	240 LPI	110 or greater	150 LPI or greater
6 inches	480 LPI	150 or greater	150 LPI or greater

Table 4: A comparison of the present study results and recommendations gleaned from the literature.

For purposes of calculation, the diameter of a 10% dot was considered to be the smallest dot of interest. These dots, appearing in the highlight areas of printed halftones, are not the smallest that can be found in printed photographs, but are generally reproducible by most printing processes on most substrates. Therefore, they were chosen to represent the smallest diameter dot of interest to this study. If a person could see those dots at a given distance, the screen would be considered discernable.

A 10% halftone dot's diameter is, mathematically, 0.356 times the width of the halftone cell in inches. Thus, a 10% dot in a 1 LPI screen is 0.356" wide. Similarly, a 10% dot in a 10 LPI screen is 0.0356 LPI (0.356 × 1/10"). Widths of 10% dots in LPI screens of interest to this study are found in Table 5.

LPI	Width of 10% dot in inches
150	0.0024
133	0.0027
120	0.0030
110	0.0032
100	0.0036
85	0.0042
65	0.0055
50	0.0071
37.5	0.0095
18.75	0.0190
10	0.0356
5	0.0712

Table 5: Widths of 10% dots in inches for specified LPI screens.

To relate the discernability of 10% dots of the halftone screens of interest viewed at the distances used in this study to the Snellen Chart, it was necessary to extrapolate some distances not found in the Chart. Table 6 is derived from Table 2 and contains the specified distances and letter heights specified by the Snellen Chart as well as interpolated values (shown in *italics).* The fifth column in Table 6 indicates the LPI of the 10% dot that most closely matches the smallest visible size as predicted by the Snellen Chart. Normal-sighted individuals should be able to see dots of the size indicated in column five. Therefore, the next higher LPI (smaller dots) was used in Table 4 for comparison purposes.

Distance	Letter Height in Pts	Inches	Height in inches /5	**LPI of Closest 10% dot**
20	25	0.3472	0.0694	5
18	22.5	0.3125	0.0625	5
16	20	0.2778	0.0556	*5*
15	19	0.2639	0.0528	5
14	17.5	0.2431	0.0486	10
12	15	0.2083	0.0417	*10*
10	13	0.1806	0.0361	10
8	10	0.1389	0.0278	*10*
7	9	0.1250	0.0250	18.75
6	7.5	0.1042	0.0208	*18.75*
4	5	0.0694	0.0139	37.5
2	2.5	0.0347	0.0069	50
1	1.25	0.0174	0.0035	100
0.5	0.625	0.0087	0.0017	*150*

Table 6: Snellen Chart specified and interpolated (italics) letter heights and distances.

The present study resulted in recommended LPIs that are generally more conservative (i.e. higher LPI number, smaller halftone dots) in midrange distances than those extrapolated from the Snellen Chart. However, the Snellen Chart and the present study have similar recommendations at the closest and farthest distances. Both the Snellen Chart and the current study indicate that 150 LPI dots should be invisible as close as six inches. However, the present study indicates that much finer screens should be used for distances of one foot and above than the LPIs that would be predicted by extrapolations from the Snellen Chart. Interestingly, at 20 feet, both the Snellen Chart and the present study recommend 10 LPI screens.

Conclusions, Implications, and Recommendations

The present study empirically considered the relationship between halftone LPI screen frequency and discernability at varying distances. The results indicate the mean distance at which the dots in varying LPI screens become visible to the average person. Applying the standard deviation to the mean results in a range of distance at which the majority of people can see the dots in a given LPI screen. Using a halftone screen that is finer than the highest in this range will ensure that the halftone dots in a printed photograph will be virtually invisible to the majority of people.

The present study recommends halftone screens that often differ from those specified or inferred from other methods found in the Literature. In particular, halftone screens recommended by this study are different than those specified by the Rule of 240 or those that can be extrapolated from the Snellen Chart. The differences between the results of the present study and the Rule of 240 can be explained by the untested nature of the Rule. In general, the Rule of 240 recommends coarser screens for long viewing distances and finer screens for short distances than the present study suggests.

The Snellen test and the present study's results are similar for long and short viewing distances and vary greatly in the mid-range. It is likely that this discrepancy occurred due to the considerable interpolation that was used to convert viewing distances used in the study to the standard distances used by the Snellen Test.

Since this study is the only known empirically-tested method for choosing LPI based upon viewing distance, it is suggested that graphic artists employ its results when making screen frequency decisions. Its use will balance file size and RIPping time with the need for image fidelity at varying viewing distances.

It is recommended that further research be conducted to verify this study. In particular, it would be appropriate to ask participants to note when halftone dots *disappear* rather than when they *appear*. This would result in less interpretation than was necessary in the present study. In addition, it would be appropriate to study the relationship between viewing distance and color (rather than black-and-white) halftones to determine if the rosette pattern inherent in traditional color halftones affects halftone dot discernability.

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