Perceived Image Quality and Acceptability of Photographic Prints Originating from Different Resolution Digital Capture Devices

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Abstract

This research project attempted to understand how the imaging system parameter of resolution affected perceived image quality and how this perception changes as a function of a particular user classification scheme. During this experiment, a group of 108 participants were asked to indicate their expectations, rate the image quality, and indicate the acceptability of photographic prints created from digital sources. These participants represented three unique groups of individuals with varying experience with photography and computers. These groups were further subdivided into three subgroups, with each subgroup being told that the pictures they were about to view originated from different capture devices. Individuals in each subgroup were told that the pictures originated from either a one-time-use camera, a digital camera, or they were left to infer the source. During the experiment, individuals viewed and provided input for matched scenes originating from a variety of film and digital cameras. Resolution varied from 640 x 480 to 3060 x 2036. All scenes were printed on a photographic CRT printer to an optimal tone scale and color bias.

The results indicate that the resolution of the capture device is highly correlated with the perceived quality and the proportion of acceptable prints. Further, the participants' criteria was influenced by the indicated capture device only if the participants belonged to the group of participants, who were very experienced users of both photography and computers. This group of participants appeared to be more accepting of the photographs if they were told they originated from a digital camera and less accepting of the prints if they were told that the pictures originated from a one-time-use camera, or left to infer that the pictures originated from a film camera. Implications of this research for participant sampling and required digital image resolution are discussed.

Introduction

During the development of a new category of photographic products, it is often asked whether it is necessary for the new product to provide image quality that is comparable to a traditional photographic product. In recent years, this question may have been appropriately asked for digital cameras, as well as, one-time-use cameras (OTUCs), as each of these types of cameras have succeeded in capturing a reasonable sized market while delivering lower image quality than the typical photographic camera.

There are at least two possible reasons why these cameras may have gained success while providing lower image quality. The first is that the customer perceives this product as a different product and, therefore, their expectations of, and their acceptance for, the product's image quality may be different than their expectations of and acceptance for a traditional photographic product.

A second possible answer is that the user's expectations of the new product's image quality is not different than their expectations of the traditional product. However, since the product provides other utility (e.g., improved usability, portability, etc.) the user is willing to tolerate or reluctantly accept some loss in image quality in exchange for the increase in utility. It should be noted that only users who perceive this increase in utility will be willing to accept a loss in image quality.

Interestingly, the term "digital" has been recently applied to other types of systems to advertise these products as being higher in quality. One very prevalent example of this is the use of the term "digital" to represent sound recording and playback systems. These systems have succeeded in delivering significantly better sound quality than their analog predecessors. Therefore, it might be expected that a certain group of users may draw an analogy to "digital" cameras and expect higher image quality from these systems, than they would have expected from traditional systems.

This study was designed to determine whether different user groups have different expectations or define different levels of print acceptability. Further, this study was designed to determine if the indicated image source affects the user's expectations or acceptability limits for image quality. Finally, this study looked to further define the relationship between digital camera resolution and the perceived quality of digitally rendered 4 x 6 inch photographs.

Method

Participants

A total of 108 participants took part in this study. Participants were selected to represent three different market segments that were defined as follows:

(1) Advanced users of photographic and personal computer products. These users, henceforth referred to as advanced users, are individuals who are very involved in photography, often use personal computers, and who indicated that they are familiar with digital cameras.

(2) Medium users of photographic and computer products. These individuals, henceforth referred to as medium users, are people who take more than the average number of photographs each year, who are not interested in using images on a personal computer, but do use a personal computer and might use images on their personal computer if someone were to help them.

(3) Low users of photographic and personal computer products. These users, referred to as the low users, take fewer than the average number of photographs per year, they may have a home personal computer, but they are not interested in seeing their images on the personal computer.

It is acknowledged that these three groups do not include all potential users of either photographic products or personal computers. Instead, these three groups of participants were selected to span a wide range of both photographic and personal computer use. In addition to the user group requirements, each user was required to have a minimum corrected or uncorrected near visual acuity of 20/30.

Stimuli

Seven different digital and film cameras were selected to capture five matched scenes. The cameras were selected to produce a wide range of image quality. Three film cameras were used, including: a one-time-use camera (OTUC), a typical 35 mm reloadable camera, and a high-end single-lens reflex (SLR) camera. The images captured with these cameras were scanned to Photo CD and the 4 Base (1536 x 1024 pixel) image was used to create the images in this study. Images were also captured on four commercially available digital cameras, including cameras with resolutions of 3060 x 2036, 1536 x 1024, 800 x 600 and 640 x 480 pixels. Each of the digital files were hand balanced to provide near equal skin tone reproduction and similar gray scale rendition. The 5 scenes are shown in Fig. 1. Each of these prints were rendered on a 250 dpi CRT-based silver halide printer.

Viewing Environment

During the experiment, all pictures were viewed in a Macbeth light booth under D5000 lighting. Viewing distance was not constrained and the prints were arranged to force a response under single stimulus conditions.

Experimental Design

As stated earlier, this experiment had two primary goals. First, to determine if expectations or print acceptability were influenced by these groups of users preconceived impressions of the imaging systems. Second, to determine how image quality was influenced by digital image resolution. Given these goals, the experiment employed a mixed-factor design. The factors of Camera and Scene were manipulated as a within-subjects variables. By necessity, user type and Information (i.e., the indicated source of the image) were treated as between-subjects variables. The various levels of Camera and Scene were presented in a different random order for each participant.

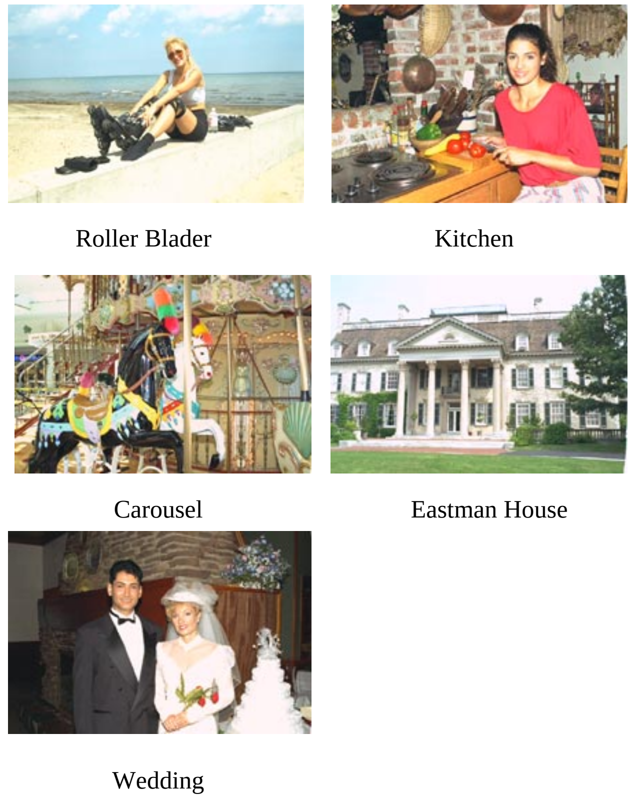

Figure 1. Low resolution renditions of the five scenes used in this study.

Within this design, the factors of camera, scene and user type should be reasonably self-explanatory with the types of users being described in the participants section of this paper and the cameras and scenes being described in the stimuli section. However, the factor of information has not been previously described. This factor was used to describe the information the user was given about the source of the images he or she would view during the experiment. It was hypothesized that if the user's expectations or acceptability of prints were not affected by their preconceptions of the systems they were told generated the photographs, then there would be no effect of this factor. Individuals within each user group were randomly assigned to an information subgroup with each subgroup being told that the prints they were to view originated from a one-time-use camera, a digital camera, or were told nothing and allowed to assume the origin of capture. The effects of User Type and Information were also combined to form a full factorial.

Therefore, a total of 9 user groups of 12 participants took part in this study.

During the study, the participants were asked to provide information on three dependent variables. These included; a categorization of their initial response to the picture into the categories of exceeded, met, or did not meet their expectation for the camera type described to them, a free-modulus magnitude estimate of the quality of the print, a categorization of their response to the acceptability of the print. Acceptability categories included the responses of acceptable, borderline, or not acceptable.

Procedure

Participants were recruited by telephone from around the Buffalo, New York area. Participants who fit the screening requirements and could be classified into one of the specified user groups were asked to participate in the study.

After completing a visual acuity test, participants were asked to read an appropriate set of instructions for the expectations portion of the experiment. These instructions informed the participants of the source of the pictures they were about to view. They were also provided task specific instructions and allowed to practice this task with a few prints. The participants were then asked to complete this task for the set of 35 prints (7 cameras by 5 scenes).

Once this task was complete, the participants were given another set of instructions and trained to use magnitude estimation to gauge the quality of each of the pictures. Once the users completed a short practice session using this procedure, they completed the magnitude estimation procedure for each of the 35 prints. For this phase of the experiment, the observer was asked to assign a number to the initial print and then to provide estimates of the quality of each print that were proportional to the quality of the first print.

Finally, the participants were instructed to categorize each of the pictures as acceptable, borderline, or not acceptable. This task was also completed for each of the 35 pictures. All responses were recorded by the experimenter.

Data Analysis

The data from the two questions that provided categorical information (i.e., expectations and acceptability data) were analyzed by combining the two upper categories and then collapsing across the five scenes to compute the percentage of prints that fell into these two categories. Therefore, the percentage of prints that met, or exceeded, expectations as well as the percentage of prints that were acceptable or borderline are reported in the results. Collapsing the data in this way, allowed the data to be subjected to ANOVA procedures. Chi-square analyses were also conducted, which explored changes in the distributions across the categories. However, these analyses indicated similar trends to the ANOVA results. The percentage data is shown here as it is simpler to present and understand.

The free-modulus magnitude estimation data were first scaled to reduce the intersubject variability that arises from the selection of different moduli by the participants in this experiment. This scaling procedure is adapted from Engen.[1] While this procedure reduces the intersubject variability, an artifact of this scaling procedure is to eliminate any variance in between-subject variables. Therefore, the free-modulus magnitude estimates are used only to discuss the perceived difference in quality between scenes and between cameras. Once the data were scaled, they were subjected to ANOVA procedures. Simple-effect F tests were used to test the two-way interactions and Student Newman-Keuls post hoc tests were used to test simple effects.

Results

Print Expectations

The print expectations data indicated a statistically significant effect of Camera ($F(6, 77) = 70.6$, $p = 0.0001$). No other significant effects were noted for the expectations data, indicating that neither User Type or Information had a significant effect on the proportion of prints that were rated as meeting or exceeding expectations.

The effect of Camera is depicted in Fig. 2. As shown, the proportion of prints classified as meeting, or exceeding, expectations covers a very wide range, such that these values increase from less than 20 percent to greater than 80 percent from the camera with the lowest quality to the camera with the highest quality. That is to say, that as few as 20 percent of the prints were rated as meeting, or exceeding, expectations for the 640 x 480 resolution digital camera and as many as 80 percent of the prints were rated as meeting, or exceeding, expectations for the images originating on the SLR film camera.

Student Newman-Keuls post-hoc tests were used to test for statistical differences between proportions of prints that met, or exceeded, the customers expectations. The proportions of prints that met or exceeded expectations from the OTUC and the 1536 x 1024 digital camera were not statistically different. The proportions of prints that met or exceeded expectations from the reloadable film camera and the 3060 x 2036 resolution digital camera were also statistically equivalent. The proportions of prints from each of the remaining camera combinations were statistically different from each other.

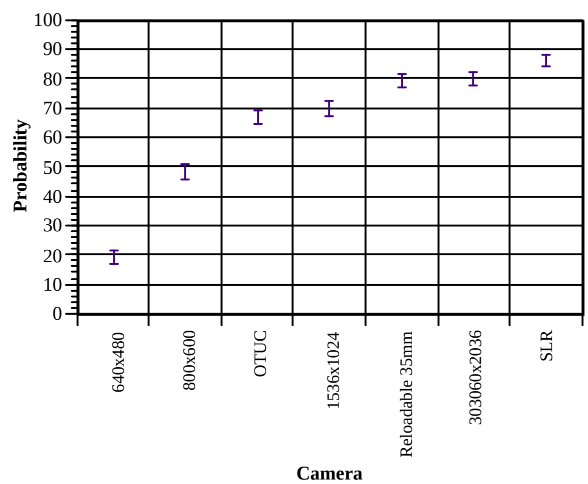

Figure 2. Effect of camera on user expectations.

Magnitude Estimation Data

The ANOVA indicated statistically significant main effects of Scene (F(4, 385)=11.23, p = 0.001) and Camera (F(6,385) = 180.08, p = 0.001) for the magnitude estimation data. This ANOVA also indicated the presence of a two-way interaction between Scene and Camera (F(24, 385) = 6.69, p = 0.001).

The effect of Scene is depicted in Fig. 3. As shown in this figure, the Roller Blade, Wedding and House Scenes were rated statistically lower than the Carousel or Kitchen scenes. This indicates that the participants perceived a range in quality even within a single-capture device.

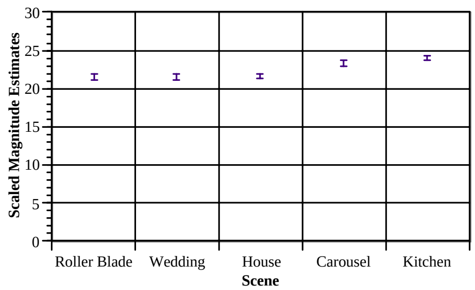

Figure 3. Effect of scene on image quality magnitude estimates. Error bars indicate plus and minus one standard error of the mean.

As shown in Fig. 4, the scaled magnitude estimates generally increase with increasing digital camera resolution. The scanned film images generally compete with the higher resolution digital camera images. Prints from the one-time-use camera and the 1536 x 1024 pixel digital camera were not statistically different. The magnitude estimates for prints from the reloadable film camera and the 3060 x 2036 pixel resolution digital camera were also not statistically different from each other. The scaled magnitude estimates from each of the remaining camera combinations were statistically different from one another.

Print Acceptability Data

When analyzing the print acceptability data, the ANOVA indicated a statistically significant main effect of Camera (F(6,77) = 68.89, p=0.001), as well as, a main effect of Information (F(2, 12)=3.93, p=0.0216). A statistically significant two-way interaction was also present between User Type and Information (F(4,24)=2.521, p=0.0418).

Figure 5 shows the effect of Camera on the probability that a print will be rated as borderline or acceptable. As could be expected, the rate of acceptability generally increases with increasing digital camera resolution. Student Newman-Keuls post-hoc tests were used to test for statistical differences between these probability values. The probability that a print will be rated as acceptable or borderline from the reloadable film camera was not statistically different than the probability that a print from the 3060 x 2036 pixel digital camera would be rated as borderline or acceptable. However, these probabilities were statistically different for all remaining camera combinations.

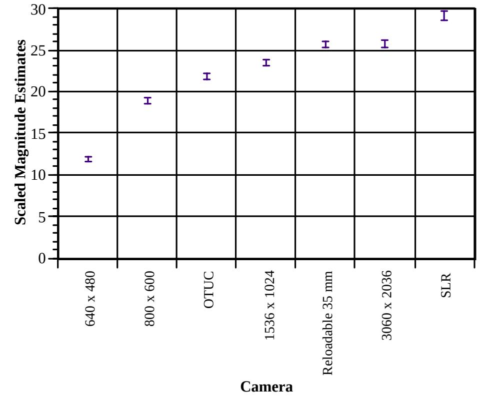

Figure 4. Image quality magnitude estimates as a function of camera.

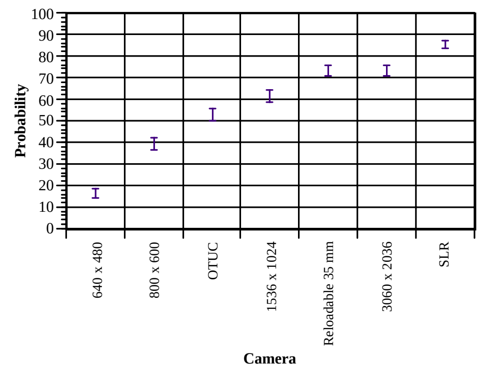

Figure 5. Probability of a print being rated borderline or acceptable as a function of camera.

Figure 6 shows the effect of information on the probability that a print would be rated as borderline or acceptable. Post-hoc tests indicated that the probability of a print being rated borderline or acceptable was lower when people were told that the prints originated with the one-time-use camera than they were when the participants were told that the prints originated with a digital camera. There are no other statistically significant effects of information. However, information was also involved in a two-factor interaction, so it is important to analyze this effect in light of the higher-order interaction.

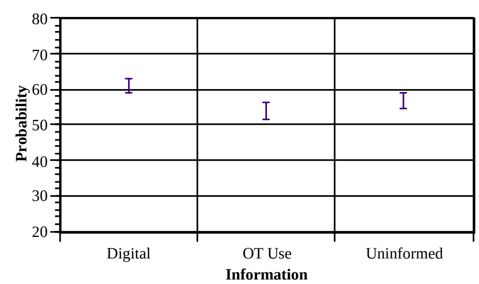

Figure 6. Probability of a print being rated borderline or acceptable as a function of the indicated camera type. Error bars indicate plus and minus one standard error of the mean.

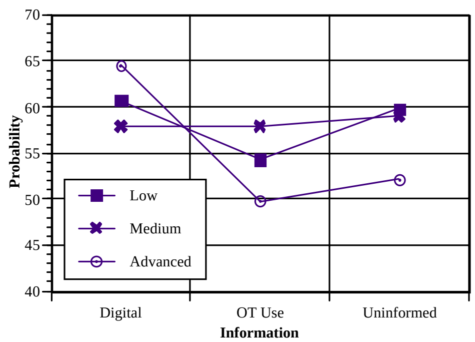

Figure 7. Two-factor interaction of user type and information on print acceptability.

The two-factor interaction of User Type and Information on the probability that a print was rated as borderline or acceptable is shown in Fig. 7. Simple-effect F-tests indicated that within this interaction the effect of Information was only significant for the Advanced User Group ($F(2, 154) = 6.56$, $p < 0.01$). Student Newman-Keuls post hoc tests further indicated that when the participants from the Advanced user group were told that the prints originated from a digital camera they found significantly more of the prints acceptable than when they were told that the prints originated from a one-time-use camera, or when they were allowed to infer the origin of the pictures. Therefore, it would appear that the effect of Information is due solely to the fact that the advanced user group accepted more prints when they were told these prints were generated from a digital camera than they did for the other information conditions.

When this interaction is further decomposed to investigate the effect of User Group for a given set of Information, simple-effects F-tests indicated that User Group was near significance when the user group was either told that the pictures came from a one-time-use camera, or when they were uninformed of the capture device. While not statistically significant at the 0.05 level, it would appear that this effect is due to a lower level of acceptability for prints by the advanced user group.

Discussion

The results showed that the factors of user type and information had no effect upon the user's stated expectations. Instead, the users indicated that they expected the same image quality regardless of the image source. However, these two factors did combine to have an effect on print acceptability. This data appears to indicate that there was no effect of either of these factors on print acceptance for the medium and low users. When the advanced users were told they were viewing prints from a one-time-use camera, or when they were left to infer the source of the prints, they accepted a smaller proportion of the prints than the medium or low users. However, when told that the same pictures originated from a digital camera, this group tended to be more forgiving, accepting a larger proportion of the prints than the medium or low users. This data would appear to indicate that this user group does, indeed, place a higher utility on digital cameras for features other than image quality and are willing to accept lower quality to obtain this added utility. The same cannot be said for the other user groups who do not inherently place a higher utility on these unknown or undesirable digital camera features.

Interestingly, while the medium and low users did not place greater utility on the digital prints, they also do not appear to expect higher quality from a digital camera. As stated in the introduction, one might suppose that users expectations of digital products may have been altered by the use of the term "digital" to market higher quality audio systems. We did not observe any increase in user expectations, due solely to the use of the term "digital" within the more unaware user groups.

Finally, we can use this data to better understand the resolution necessary to deliver an acceptable photographic print. Figure 8 expresses the data shown in Fig. 5 in terms of digital camera resolution. As this figure shows, the probability that a print will be rated as being borderline or acceptable by an average customer in this study is about 62 percent when the camera has a resolution of 250 pixels per inch. This value increases to about 73 percent when the resolution increases to about 500 pixels per inch.

Looking at Fig. 8, it can also be seen that the slope of the curve relating resolution in pixels per inch to the percentage of prints rated as borderline or acceptable is much lower between 250 and 500 pixels per inch than it is between lower pixel resolution values. This result generally agrees with Ohno, Takakura and Kato[2] who recommended a digital camera resolution of approximately 300 pixels per inch for hand-held prints. However, it is also important to note that the acceptability of the 250 pixel per inch film scan from the reloadable 35 mm camera provided roughly the same acceptability as obtained from the better than 500 pixel per inch digital camera when the images from these cameras were printed on the CRT printer used in this study. Further, a larger percentage of prints were rated as borderline or acceptable when the image was captured on a 35 mm SLR film camera, scanned, and printed at 250 pixels per inch than when the image was captured with a digital camera resolution of 500 pixels per inch.

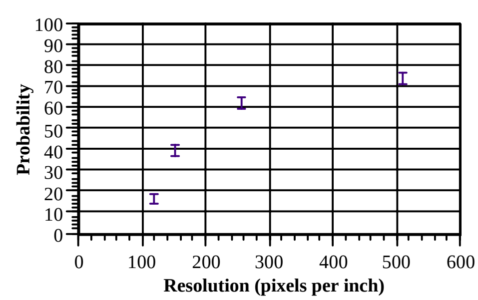

Figure 8. Percent of acceptable images and image quality rating as a function of camera resolution expressed in pixels per inch.

It is generally believed that the differences between the images captured on film cameras and the images captured on digital cameras tended to originate from resolution limitations, color filter errors, and the limited dynamic range of the digital cameras. The quality of the images captured on film cameras varied significantly even though each was scanned to the same resolution digital file. This change in image quality reflects the performance of the camera's exposure system and the modulation transfer function of the camera's optics.

Conclusions

Different user groups were shown to indicate different acceptance levels for pictures generated from products with different characteristics and potential uses. In particular, users knowledgeable of digital cameras were shown to accept lower quality images from a digital camera than from a traditional photographic product, while persons not knowledgeable of digital cameras did not express different levels of acceptance for these two classes of photographic products.

Not surprisingly, the perceived image quality of pictures generated from different cameras was shown to be highly correlated with camera resolution, when care was taken to match the color and tone of matched scenes from those cameras. The proportion of acceptable images also increased with increasing resolution. The image quality of a 1536 x 1024 resolution digital camera was shown to be roughly equivalent to the image quality of a picture generated from a one-time-use film camera, scanned to a 1536 x 1024 digital file and printed on the same silver halide printer. The image quality of a 3060 x 2036 digital camera was shown to be roughly equivalent to the image quality of a picture captured on a typical 35 mm point and shoot camera, scanned to a 1536 x 1024 pixel resolution digital file, and printed. The image quality produced by capturing an image on a 35 mm SLR film camera, scanning these images at a resolution of 1536 x 1024 pixels and printing them was found to exceed the quality of an image captured with the 3060 x 2036 pixel resolution digital camera.

Acknowledgments

The authors would like to recognize Novia Weiman for her valuable contribution to this work.

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