6-1-2013

The Influence of media displays and image quality attributes for HDR image reproductions

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The Influence of Media Displays and Image Quality Attributes for HDR Image Reproductions

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A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Science in the School of Media Sciences
In the College of Imaging Arts and Sciences
of the Rochester Institute of Technology

June 2013

Primary Thesis Advisor: Professor Bruce Leigh Myers, Ph.D.
Secondary Thesis Advisor: Professor Michael Riordan

Acknowledgements

Thank you to Professor Bruce Myers. Your support and guidance over my graduate career is immeasurable. Your encouragement to focus on subject matter I was passionate has been rewarding on many levels.

Additionally, thank you to Professor Michael Riordan and Dr. Patricia Sorce for your continued encouragement, assistance, guidance and willingness to take on a challenge.

A special thanks to all the staff and faculty that I have had the pleasure of knowing at Rochester Institute of Technology. Your continued support during the completion of my graduate research pushed me farther then I thought I could go.

Lastly, thanks to those, both professional and personal, that took the time to assist in the stages of my research, involving aspects ranging from photo shoots, construction of display setups, software troubleshooting and late night brainstorming.

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Abstract

High Dynamic Range (HDR) photography has been in existence at least since the time of Ansel Adams, with his experiments using analog film and darkroom techniques for the production of black and white prints in the 1940's (Ashbrook, 2010). This photographic method has the ability to provide a more accurate representation of a scene through a greater range of the light and dark areas captured in an image. In the mid-20th century HDR Photography it has continued to grow in popularity among those interested in photography wishing to optimize their resulting image beyond a more commonly used technique. Presently, the limitations of commonly available reproduction technologies can lead to unpredictable output results through media such as monitor displays and inkjet prints.

The purpose of this research was to determine the influence of quality attributes and image content on the preference of display media for HDR image reproductions. To achieve this purpose, a psychophysical experiment was conducted of 38 observers with previous imaging related exposure. This part of the study consisted of HDR comparisons across both a monitor display device and inkjet prints. Through qualitative and quantitative methods, common trends were identified among observer responses.

The results show that for inkjet prints are the most preferred for the output of HDR images, specifically when printed on a metallic substrate. Additionally, the content of displayed images can directly impact display preference depending on the viewer's

perception and relationship formed with the photographic image. When evaluating HDR images across two media platforms, quality attributes comprising of a strong influence towards preference are sharpness, naturalness, contrast and highlights while artifacts, physical qualities and shadows were found to have barely any influence. Within the attributes related to HDR, relationships between attributes are found to be significant regarding image evaluation, leading to areas of further research.

Chapter 1

Introduction

Much of the research done on HDR photography often focuses on the application of algorithms and advancement of current technologies, however an influential component of photography is the relationship between an image and the viewer's perception of an image. Research often overlooks the subjective viewpoint of characteristics represented by HDR, as viewed by photo enthusiast, classified as a prosumer, with limited knowledge of technical processing methods. Provided with basic knowledge of HDR constructs, such as common behaviors and qualities, photo enthusiasts can become more efficient in their evaluation of image properties. Informed decisions can be made regarding display technologies and post-process workflows, which can further improve the intended applications for photography across multiple medias.

Topic Statement

This research examined the information necessary to enable users to have a greater understanding of certain quality attributes affected in HDR image rendering to make the most advantageous choices in this domain. The study used controlled conditions and an established psychophysical method to elicit relevant observational responses pertinent to the information required by HDR practitioners involving image

content and display technology considerations. Specifically, the study involved a dual media comparison designed to ascertain if there is an impact on the visual perception of HDR image reproductions due to display media, image content, and specified image quality attributes.

Background and Significance of Topic

HDR imaging is a specialized area of photography that has received greater interest in recent years. This is evidenced by the 80,000 plus members in the HDR community on the photography website Flickr.com, as well as the over 20,000 titles relevant to the topic from Amazon.com, intended for avid photography enthusiasts and professionals alike.

The digital equivalent to conventional film based HDR photography began development around 1994 in response to photographers' desire to capture the scene as accurately as possible with consideration to matching the quality provided by traditional analog photography (Isis, 2006). These types of images give a great range of light between the darkest and brightest areas of an image. The dark and bright area of a scene can be recorded at the same time into a single image, avoiding under and over exposed areas. Therefore, a greater amount representation of detail can be observed (Artusi, 2009). However, most output media is limited to an approximate 400:1 dynamic range: this contrasts with normal human vision, where perceivable dynamic range can exceed a 1,000,000:1 (Meyer, 2004).

While emerging high-end display technologies are breaking barriers in terms of reaching a closer parallel for the output of HDR images in regard to simulating accurate human vision, they do not cater to the commercially available prosumer level products. Due to the limitations of typical prosumer monitors and printers, HDR image compression is essential. Examples of areas where necessary compression is applied include: image capture, image output and a viewer's visual perception.

To approximate the output of an HDR image through a given display output, the image must be color managed and allow for steps in establishing a consistent workflow, such as calibration and profiling for display devices. Isis (2006) states: "HDR imaging deals with a new concept for established color management systems known as scene-referred, which represents the original scene values of captured light" (p. 6). Scene-referred images are viewed based on how an image appeared when it was initially captured, while most color management systems deal with output-referred images, which are viewed based on the specifications of the media being used to display it. The techniques involved in HDR imaging are such that the process is able to produce an image capable of capturing a range of information outside the spectrum that most commercially available devices can capture or display. Although technologies offer solutions to work around the issues, there is still a void for an entry-level device offering direct capabilities. When reproduced, some of the characteristics and qualities of the HDR image need to be sacrificed to optimally render the image on a desired output technology

Bit depth is one aspect of imaging that is pertinent to the discussion of HDR image reproduction due to the capability of providing the maximum dynamic range of an image. Bit depth can be used to describe the number of colors a device can capture and store in a file. Most HDR images are captured in a dynamic range of 32 bits, meaning that the number of colors available can exceed 10 million (Carr, p. 6).

With no entry-level technology capable of producing HDR results at full capacity, prosumers would commonly rely on their home-owned display technology to provide similar results. When using technology incapable of displaying a large dynamic range, the image becomes converted to a 16 bit to be displayed by a monitor, which is then typically converted to an 8 bit to be subsequently output to a printing device.

Issues here are compounded, as both monitors and printers compress the image differently and can make the process of producing HDR images unpredictable from soft proofing[1] to a hard copy. Currently, there are no direct solutions for prosumers due to obstacles of: display monitors specialized in HDR being out of a prosumer level price range and the absence of a printing device able to print high dynamic range imagery to full potential. This leaves photographers and viewers with significant concerns regarding HDR reproduction methods and what differences lay between the two common media display choices, monitor display and inkjet print. Differences can include changes in image quality characteristics, such as color, contrast, detail, tone values, and photographic artifacts further explored in this study. Considering the difference in output capabilities as a result of image compression and display, perception of an HDR image can be impacted through the way they are viewed.

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[1] For the purpose of clarity in this definition, *Color and Its Reproduction: Fundamentals for the Digital Imaging and Printing Industry* expands on soft proofing as follows:

"A soft proof is the intangible image displayed on a color monitor. A soft proof is derived from digital image data but has an analog structure on the screen. The [variables] that determine the image elements may be infinitely varied between limits. These proof images are called soft because, unlike all other kinds of proofs (e.g. hard proofs), they do not exist as a tangible object. Soft proofs are also referred to as real-time proofs because they can be formed almost at the same instant that the original image is input or that a modification has been made to the image data.

Electronic proofing devices are the color monitors that form an indispensable component of image processing systems. The monitor displays a color image that simulates the color properties of the printed sheet. The surface characteristics and image structure of the printed sheet cannot, however, be satisfactorily simulated on a color monitor" (Field, p. 279).

The literature indicates that widely available, entry-level image display reproduction technologies, specifically display monitors and printers, are usually not capable of fully displaying the range of true HDR images. Therefore, HDR practitioners need to make informed decisions about how to best optimize their images for subsequent display.

Reason for Interest

As HDR photography continues its upward climb in popularity, those involved in the imaging process and workflow are realizing obstacles and inconsistencies as they produce and compare images to both how the scene was viewed and stored in memory, to how the image looks through a screen or on print. Although most seem to settle with blaming available technology for the obstacles they encounter, some embark on the path necessary to understand the process the images go through before they are sent for output. Through this encounter, one can better know and use their own technology and available imaging programs to create consistent and accurate images that perform to the best of their ability.

The researcher is personally interested in this study due to her lifelong passion for photography and her background in studies for her Bachelor of Fine Arts degree in Visual Media, focusing in photography and print. As a photographer, the researcher continues to have an interest in increasing the efficiency of the image processing workflow and gaining further understanding towards the impact of both print and monitor display in an industry continually moving forward with digital dominance.

With many digital devices being presently available and convenient for a wide variety of audiences, a constant pattern found on photography forums and blogs has been a question concerning which method is best for displaying portfolio pieces for a particular audience, monitor or print. Similarly, the researcher has often produced photographs for a variety of individuals with the intention of producing the best quality without knowledge of an individuals intended display method, leading to an interest in the advantages of knowing the behaviors of selected devices.

In addition, the researcher has an interest in using imagery from this study to demonstrate advantages to both screen and print in hopes of challenging the preconceived notions viewers may have on either display method. In addition, she implemented the exploratory methods of this study to gain a better understanding in image display preference and affecting attributes in regard to image quality characteristics for HDR images, which is one of the many specialized photography methods she has explored.

Definition of Terminology

Due to the abundance of published work on this topic, there are several applicable definitions for terms used throughout this study. The definitions for the terms were selected based on their relevance to the research as well as their parsimony. Therefore, Carr (2009), Field (2004), and Bunting (2005) were the sources of the definitions provided.

AEB: "Auto Exposure Bracketing is a camera feature that automatically adjusts the exposure for a series of photos, resulting in a set of at least three photos" (Carr, p. 266).

Aperture: "The size of the opening in the lens that focuses light past the open shutter and onto the sensors inside the camera. A larger opening lets more light in and a smaller opening permits less light in. It is express as an f-number" (Carr, p. 266).

Bracketing: "The process by which at least three different photos, two of which are bracketed around the central exposure. This process can be done manually or using auto exposure bracketing" (Carr, p. 266).

Calibration: "Modifying or adjusting the behavior of a device to a desired state" (Bunting, p. 493).

CIE LAB: "One of the two main color spaces proposed by the CIE to attempt a perceptually uniform color space (Also known as L*a*b*)" (Bunting, p. 72).

CIE XYZ: "Defines colors in terms of three theoretical primaries, X, Y, and Z, that are based on the CIE research into human color response. Used commonly in ICC-based color management" (Bunting, p. 69).

CMS: "Color Management System. Software dedicated to handling device-to-device conversion of colors" (Bunting, p. 494).

D50: "One of the CIE standard illuminants. Specification of daylight with a correlated color temperature of 5000 K" (Bunting, p. 497).

Device Dependent: "The property of a color model whereby the exact meaning of a set of numbers depends on the specific device" (Bunting, p. 498).

Device Independent: "The property of a color model where the exact meaning of a set of numbers is unambiguous and does not depend on any specific device" (Bunting, p. 498).

Dynamic Range: "The ratio between the smallest and largest possible values of a changeable quantity. In photography, it is the difference between the brightest and darkest values the camera can record. Dynamic Range can be expressed as exposure value stops or contrast ratio" (Carr, p. 267).

Exposure Value: "The relationship between exposure, shutter speed and f-stop number. It is a working number that allows the altering of shutter speed and aperture on the exposure to be quickly and easily compared" (Carr, p. 9).

Exposure: "How much light reaches the camera's sensor during a single photography" (Carr, p. 267).

F-stop: "Numerical representation of the effects of aperture on exposure to be expressed between focal lengths" (Carr,p. 8). This can be used in HDR to keep a constant depth of field across bracketed images.

Gamut: "The range of colors and density values reproducible on some output device such as a printer or monitor. This is sometimes split into the color gamut – the range of colors limited by the primaries used- and the dynamic range- the range of brightness levels from the darkest black to the brightest white of the device" (Bunting, p. 501).

HDR Photography: "High dynamic range photography is a discipline and software process that captures high-contrast scenes using exposure bracketing techniques and processes them to keep details from being lost in shadow or blown out in highlights" (Carr, p. 267).

IT8: "One of a family of targets used for calibration and profiling of scanners and printers for output" (Bunting, p. 502).

Luminance: "The amount of light energy given off by a light source, independent of the response characteristics of the viewer" (Bunting, p. 138).

Photomerge: The process of using software to combine multiple exposures for the creation of a single image.

Post Processing: "Referring to any manipulation occurring after an image is taken" (Carr, p. 269).

Profile: "A file that contains enough information to let a CMS convert colors into or out of a specific color space" (Bunting, p. 507).

RAW: “A term used to describe proprietary camera file formats that store data direct from the camera sensor. They are not directly editable and require a raw editor to process through formats for post-processing” (Carr, p. 269).

Saturation: “The property of the light from a surface or light source by which we perceive the purity of the light” (Bunting, p. 35).

Single Exposure HDR: “HDR created from one camera raw file, rather then multiple images. This method does not capture the same dynamic range as multiple bracketed exposures are able to” (Carr, p. 269).

Soft Proofing: “Using a monitor as a proofing device- displaying a simulation of how a document will appear when printed” (Bunting, p. 508).

Tonal Compression: “The remapping of tonal values from a wide dynamic range to a narrower one” (Bunting, p. 74).

Tone Mapping: “The process of condensing the dynamic range of a 32-bit HDR file onto a lower dynamic range, 16-bit file that you can view, edit, and print from standard image-editing programs” (Carr, p. 269).

Tone Range: “The ratio of the luminance of the brightest color (white) to that of the darkest color (black) that the system is capable of producing or viewing” (Carr, p. 266).

Tone Reproduction: “A term that relates the density of every reproduced tone to the corresponding original density. This relationship is best described by the use of graphical techniques” (Field, p. 440).

Visible Spectrum: “Part of the spectrum containing the range of wavelengths visible to the eye, approximately 380-720 nanometers” (Bunting, p. 7).

Workflow: “A term used to describe work or processing order. An HDR workflow should promote creative flexibility and timeliness without unnecessarily compromising data integrity” (Carr, p. 269).

Chapter 2

Review of the Literature

Overview

Within the last decade, HDR imaging has grown in popularity. Factors contributing to the increased adoption are applications and programs that allow image manipulation and experimentation easier to handle and understand. It is a surprise to many that the HDR image concept predates digital photography. One of the first widely known photographers to implement this idea was Ansel Adams. Through his use of dark room techniques, such as burning and dodging, and his formulation of the Zone System, he was able to expand on the dynamic range of scene using film-based technology (Ashbrook, 2010). The advent of digital cameras with CRT/LCD monitors and digital printing offered opportunities to continue to expand the amount of dynamic range that could be captured and displayed. Although the output of HDR images has much improved, there are still gaps between the paralleled systems of output from accurate soft proofs to print.

Literature relevant to the topic of HDR can be categorized as those related to the photographic industry, HDR imaging workflow, color management practices, image quality models and the understanding of judgment for comparison of images.

Imaging and Photographic Industry

Industry Status and Application of HDR

The graphics industry is continually evolving with multiple applications utilizing digital imagery. As time continues, so does the trend of pushing boundaries for the use of producing and displaying higher resolution images. Reinhard states: “Although the trend towards high-resolution images is apparent, there is a major shift in thinking about digital images that pertains to the range of values that each pixel may represent” (p.1). With the idea that the range of values for images will continue to increase, it is recognized that this condition may challenge the present technology capabilities available, in which case the understanding of impactful qualities and characteristics and their behaviors in regard to available technology becomes vital.

Common applications of HDR processes can be seen largely in the video and image science with a focus of high-speed video capture, development of tone-mapping algorithms, virtual reality, and assistance in technical and medical fields. “Studies on image quality are important because much industrial effort is dedicated to producing and reproducing images,” states Dijk (2004, p. 11). Changes in the output process, such as adjustments to displays or inks within printers, can directly affect the end result of an image. Understanding the technology used to produce imagery can assist in the evaluation of image quality of HDR as time progresses.

Limitations for HDR

A challenge for the graphics industry is the limited dynamic range of imaging and display technology. Presently, there are displays ranging from advanced, high-end devices with a high cost and experimental benefits, and displays with capabilities close to HDR if time is taken to develop methods and workflows. There has been much research done in regard to addressing the limitations of displays, however, conventional media displays continue to be insufficient in creating the “optical sensation” of viewing the scene in person, even though the use of programs and tools can assist in make HDR images appear pleasing (Seetzen, 2004).

Image Workflow

Camera System

The camera device is the first step to capturing the scene of an HDR image. Individuals using digital cameras are limited to an averaged or compromised exposure when relying upon a single photograph and normal processing techniques to capture and present all of the data (Carr, p. 4). Due to the human eye having the capability to see greater dynamic range then can be captured by a camera, HDR imaging requires that multiple exposures of scene be taken to account for all the light and dark areas in the scene being captured. Even with multiple exposures, the camera covers less than half of the chromaticity that the eye can see.

An aspect of tone reproduction can be noticed when dealing with the captured, original image as it is exported to another device. When exported, the image that was once the original on camera now becomes the new original image on the display media. Field (2004) states: “The two aspects of tone reproduction are the tonal compression for a given original and the tonal adjustments due to the [output] conditions” (p. 206). Due to the wide variety of detail in an HDR photographs, it is important to understand the limitations on color for the scene being captured and determine how much editing software plays a part in recovering or replacing colors. The range of factors that reduce a camera sensor’s dynamic range include electron noise, which interferes with a senor’s ability to record extremely low levels of light, to pixel size and sensor efficiency (Carr, 2009, p. 5).

The quantification of color is manifested in work done by the CIELAB color space. In regard to the image capture tool, the camera consists of an RGB sensor that can be converted to X, Y and Z, by means of following a linear equation, to be compatible with the color space values of output devices[2]. However, a second conversion to a

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[2] While an extensive analysis of CIELAB, RGB, and XYZ are beyond the scope of the presently proposed research, Mark Fairchild (2005) provides a brief explanation, declaring:
“The CIE system is a well-established, international standard for color specification and communication. The general use of chromaticity diagrams has been made largely obsolete by the advent of the CIE color spaces. These spaces extend colorimetry to three-dimensional spaces with dimensions that approximately correlate with the perceived lightness, chroma and hue of a stimulus; this is accomplished by incorporating features to account for chromatic adaptation and nonlinear visual responses.
The CIE (L* a* b*) color space, abbreviated CIELAB, was developed as a color space to be used for the specification of color differences. L* represents lightness, a* approximate redness-greenness, b* approximate yellowness-blueness. These

visually uniform color space, such as CIELAB, is required so that meaningful color quality decisions can be made based on the camera measurements (Connolly, p. 16). Using the variables involved in HDR imagery and preference in addition to the values examined using the CIELAB color space; further observation can be made in the evaluation of the HDR image workflow.

Tone Mapping

When an HDR image needs to be processed for optimized subsequent output, a method known as tone mapping is typically utilized. Tone Mapping is a method to approximate a high dynamic range image to a much lower dynamic range that can be displayed and printed on different output devices. Without tone mapping, an HDR image cannot be displayed on a screen accurately because it can have a tone reproduction and distribution beyond the screens capabilities (Steinmueller, 2007). This method is vital to HDR workflow and caters to each HDR image independently. Meyer (2004) states that devices used to display images do not offer an accurate representation of a full HDR image. If the desired outcome is to output an HDR image on paper or display, the wide dynamic range must be converted to the lower range that is supported by the selected display technology (p. 1).

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coordinates are used to construct the color space. In the equations used, X, Y, and Z represent the tristimulus values of the stimulus. Given tristimulus values for the stimulus, other data regarding the viewing environment, can be considered in order to predict color appearance (p. 78).
The CIELAB formula takes the XYZ tristimulus values of a stimulus and the reference white as input and produces correlates to lightness, chroma, and hue as output. Thus CIELAB is a simple form of a color appearance model" (p. 189).

It is relevant to distinguish between the concepts of tone mapping and gamut mapping: tone-mapping deals with the luminance from the real-world scene and gamut mapping can also be used for reproduction on a device of limited a limited color gamut. Gamut mapping considers mapping colors mostly from one device to another in a comparable dynamic range dealing with display-referred images, while tone mapping deals with scene-referred images, which does not need to compress the contrast to fit the range that is available on the output device (Reinhard, 2009, p. 227).

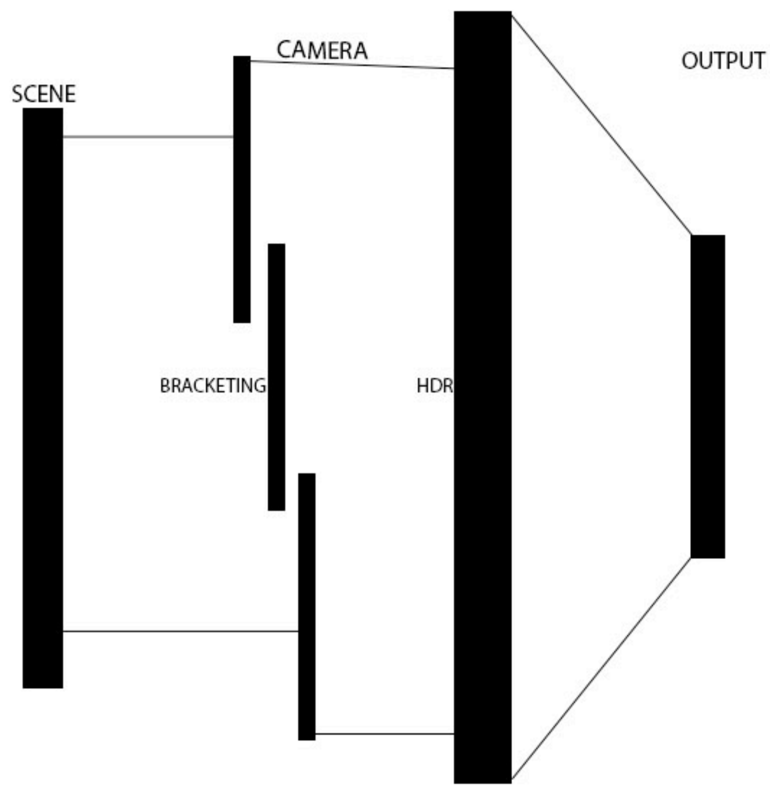

Figure 1: HDR Mapping Process: Compression of file from original scene to Output

The goal of tone mapping is to deal with limitations inherent to certain imaging capture and devices. In the image capture stage; the camera sensor has a limitation on how much light passes through to be able to capture the detail of a scene. Capturing multiple images of the scene under different exposures and then condensing them to be a single HDR image is a primary method of HDR image capture. The second limitation deals with the display device, as mentioned within earlier research, and reproducing the dynamic range captured on a low dynamic range device. These limitations can be a hindrance on the dynamic range of an image, as seen in Figure 1. The details in the highlights and the shadows of the image must still be accurately viewed on prints and standard monitors despite the limited dynamic range of those prints and monitor displays. The goal of tone mapping is to reproduce the composite appearance of the original image captures in media such as prints and monitors (Mantiuk, 2008). Often times a tone mapped image is confused with an HDR image, however this is not the case. A tone-mapped image reproduces the dynamic range captured on standard monitors or prints, while the HDR image represents the original values of light captured. Understanding human perception in regard to how HDR images are viewed can be an important factor in the display and output process.

Color Management

Overview

Color management is a technique that is intended to assure that the color observed in an image is the same that others will see as well as what will be seen on other devices

(Steinmuller, 2007). HDR images introduce a challenge for color management systems due to the difference compared to relatively lower dynamic range images. As a result of the wide tonal range, shadows and highlights can appear oversaturated (Stack, 2012). A tone mapping application, as explained previously, must also be done before being able to view the image on the monitor for color management.

Softproofing

Soft proofing is an important element in the processing and workflow of HDR, including elements of understanding bit depth and color management. Soft proofing is defined by Bunting, Fraser & Murphy (2005) as using a monitor to display a simulation of how an image will appear when printed.

One element related to soft proofing and the effects of HDR is bit depth. Bit depth relates to HDR in terms of the limitations of how much dynamic range you can represent. Certain devices, such as monitors and printers, usually have a set maximum bit depth that they can output. According to Steinmueller's (2007) methods: "To determine this number for any x-bit image use 2^x, where x refers to the bits per pixel." This method is illustrated graphically in Table 1.

Bits	**Contrast Ratio (Available Colors in RGB)**
2	4:1
4	16:1
8	256:1
16	65,536:1
32	>10,000,000:1

Table 1: Bits to Contrast Range

Tone mapping combined with bit-depth scaling is a method for mapping the pixels representative of the scene to the device's gamut. A tone map to compress a 32-bit HDR image to 8-bits is necessary if it is the eventual goal to produce a print of that respective image (Isis, 2006).

Using the Photoshop image editing software, tone mapped HDR images can be imported to adjust elements for compliance with the medium used for display. Fairchild (2005) states: "It is more intuitive for untrained users to manipulate the colors in images along perceptual dimensions such as lightness, hue, and chroma, rather than through device coordinates such as CMYK. A good color [management technique] can improve

the correlation between tools intended to manipulate these dimensions and the changes that users implement on their images" (p. 310).

Colorimetric Rendering Intent

Colorimetric rendering intents and working color spaces responsible for the way a color gamut is handled and visually represented on an output device, and therefore vital to HDR. The gamut allotted for specific devices rarely matches that of standard color spaces; therefore the mapping of colors becomes necessary to maintain subtle distortion and shifts in an image (Reinhard, 2008, p. 838). Two commonly used rendering intents for photographic reproduction namely, perceptual and relative colorimetric. Differences between the two are: perceptual will compress and remap available colors of an image with the intention of preserving pleasing relationship while relative will attempt to maintain the accurate color values with slight corrections based on selected media. Presently, relative colorimetric is the default rendering intent on most systems and applications. Besta (2011) argues that the relative rendering intent would be complimentary of HDR images because with the advanced printer technologies of today, some colors that overlap into the ProPhoto RGB color space can be printed on select substrates, therefore providing a better representation of a scene (p. 1).

RGB Color Spaces

Color spaces are an important aspect of image processing and the relationship of image evaluation with human vision. The advantages of color spaces allow the definition

of a color gamut based on a particular image's color and tone range (Rodney, 2006, p. 9). With relation to HDR imagery, it becomes important to use the largest possible color gamut. While sRGB and Adobe RGB are the most commonly used RGB color space used by the target audience of this research, ProPhoto RGB has the capability of producing a largest range of color information (Buckley, 1999, p. 2).

Importance of Calibration and Profiling

In order to obtain accurate image outputs, the process of calibration and profiling output devices can be performed using industry recommended software and instruments. These processes are an application of measured settings to change the behavior a specific output device. Calibration is a way to map the visual display of a system according to user specified settings. Creation of a profile is manifested from the based on the provided settings, which can be used to represent a current behavior of a given display as accurately as possible (Bunting, 2005, p. 126-133). Suitable to viewing HDR images across multiple displays, calibration and profiling secure the reliability in viewing images, which would otherwise contain varying characteristics if no controlled variable was utilized.

A better understanding of the differences in image characteristics can be achieved through understanding of importance of color management and the direct result of the process on the output of HDR images. Aydin (2008) argues that, "the key issues in image reproduction is not obtaining an optical match, but rather plausible reproduction of all important image features and persevering overall image structure" (p. 1).

Output for Print

Within the realm of print production, the communication of how an image has or will be changed from one version to another becomes a vital in the accuracy of the image reproduction; information about changes in tonal value becomes key. Fink (1992) states: “Value changes occur in subjective image editing, color correction, color modification, and dot gain compensation. Whether [individuals] wish to add impact to a black-and-white image, modify one or more color-separated components of a color image, or simply you’re your image look its best on a given press run, [individuals] rely on essentially the same type of tonal information” (p. 10). Through print production, this information can be impacted through compression of an image for printer compatibility, substrate selection, and viewing conditions of the image.

Communication of tonal values is detrimental when an exported image is output to print. When sending an image from a monitor to the printer, to be compatible with the management of digital inkjet printers, images larger than 8 bits must be compressed to an 8-bit image. Bamberg (2012) argues that if one has a necessity to print 16-bit prints, they need to be prepared to use the appropriate printer and software tools capable of transmitting a large image. Today’s frequently utilized digital printers tend to have a smaller gamut of colors that are reproducible compared to a monitor’s gamut (p. 308). If the desired outcome is to output an HDR image on paper or display, the wide tone range

in the image must be converted to the lower range supported by the display and print device (Meyer, 2004).

Viewing prints on certain substrates can affect the human perception when dealing with the reflectivity of the paper, which can in turn affect the luminance and contrast of an image. Reflective print media is mostly made for low dynamic range images. It is recommended that one be aware of the printer they are using to output HDR images. This can help delineate the types of inks and formatting applied to the print, in addition to what substrate would generate the best results. “The best papers for HDR printing are those that don’t reflect light”, states Bamerg (2012, p. 134).

When viewing images, a particular consideration to observe are the viewing conditions surrounding the print and observer. This is due the various appearances an image can have with the changes in viewing conditions. Field (2004) explains: “in order to minimize variations, the graphic arts viewing standard should be used when evaluating printed results or when making comparisons between an original and reproduction. The international standard that covers viewing in the graphic arts is ISO 3664:2009. The standard’s specifications for color temperature, rendering, and environmental conditions within the viewing booth are essentially fixed, and such, should exert a consistent effect on the viewed images” (p. 30). In regard to this research, cross-media comparisons between monitor displays and printed images will continue to be problematic despite attempts to standardize the viewing conditions. Field (2004) states: “In order to accurately capture differences in appearance, it becomes necessary to consider the influence that the viewing field has on the appearance of areas within the image” (p. 36).

Consideration of the consistency of image size when producing the HDR sample images, in addition to the aforementioned obstacles, are variables taken into consideration for the output of an HDR image.

Image Quality Models and Perception of Photographic Images

The following sections discuss criteria pertinent to the evaluation of photographic images in the context of image quality models.

Human Visual System

The human visual system can be considered the motivation for the reproduction of HDR images based on the desire to replicate a scene with in a way consistent with that of the human visual system. It is understood that, as previously stated, the human visual system can perceive a dynamic range more than one hundred times large than a printed page. Dark and light tonal adaptation provides the mechanism that allows the human vision to distinguish content at different parts of the dynamic range captured (Isis, 2006). Any given individual's eyes are able to see a large tonal range depending on lighting conditions, while digital imaging systems tend to capture much less. According to Stack (2012): "typical human eyes differ in two vital ways: adaption and non-linear response. With human vision, adaption allows the eyes to adjust to different lighting conditions as well as be able to adapt to extreme situations, such as glaring at the sun or maneuvering through the dark; Non-linear response deals with the accommodation of drastic changes in sensory output without overloading the brain" (p. 1). In summary, the human visual

abilities are more flexible than digital sensors and devices in terms of capturing and processing visual information from wide ranges of light.

The visual system is an important factor to consider when viewing HDR images via output mediums. When viewing images on a monitor display, humans typically adapt to the lighting conditions of our viewing environment as well as the monitor itself, both of which can be very different from the lighting conditions from which the image is intended to be viewed. As a result, our perception of photographs depends directly on the environment and applications in which they are displayed (Akyuz, 2005).

Judgment of Image Quality

Overall image quality of a photograph can be evaluated through multiple subjective and objective methods. Reinhard (2006) states: "human observers are very good in immediate judgment of image quality, even without any reference image" (p.436). When evaluating image quality, observers often use subjective measures to draw conclusions as to whether a reproduction is considered to be a good representation of the original or not. Within the spectrum of assessing quality, Engledrum (1999) suggests that the subjective evaluation is most important because observers are viewed as the "customer" of images, and therefore that is the viewpoint that should be taken highest in consideration (p. 252).

Observers use common characteristics from memory to evaluate if an image appears natural or is an accurate representation without seeing the original scene (Dijk, 2004, p. 13). However, to draw further conclusions between subjective and objective

evaluations, quality attributes can be introduced to assist with observer perception of an image. Quality attributes also have the ability to reduce the complexity of possible characteristics observed with image quality and further contribute to a more efficient overall image evaluation (Pedersen, 2008).

Content of an Image

Consideration is also given to judgment based on the content of an image. On a perceptive level, the visual content of an image plays a fundamental role in the information viewers receive due to the subjective nature of interpretation. Keelan (2002) suggests: attributes that determine preference can always be found in an image. However, preference depends on the perception of the viewer and the content of an image (p. 6). If an individual prefers high-key images, while another prefers dark, shadow heavy images, the attribute of contrast will be interpreted on two different scales.

Recognition of content is based on the perception of the viewer and their experience. Alberto Del Bimbo (1999) distinguishes the perception of image content to be a variable of two concepts, pre-attentive and attentive. “Attentive similarity has to do with interpretation. It usually involves previous knowledge and a form of reasoning. Pre-attentive similarity is simply based on the perceived similarity between stimuli, with no form of interpretation” (Del Bimbo, 1999, p. 30). Therefore, an observer of an image may discern between quality attributes based on the content of an image simply due to an interpretation independent of image quality.

Image Quality Model and Associated Quality Attributes

Peter Engledrum (2000) defines an Image Quality Model as: “a fragment of a mathematical or formal theory if (visual) perception that enables a prediction of image quality” (p. 252). This model functions by assessing an images attributes to predict the judgment of image quality based on an observers preference (Engeldrum, 1999, p.452). Further, the models form trends about the relationships among quality attributes.

A first step with image quality models is that quality attributes must be identified. According to the literature, multiple attributes have be considered and investigated in relation to image quality evaluations. Pedersen (2009) states: “quality attributes should be based on perception and account for technological printing issues. The quality attributes should be general enough to be evaluated by observers, and in order not to exclude novice observers the attributes should be somewhat straightforward to evaluate” (p. 205). The framework for the present study is based on the image quality model, proposed by Bartleson (1982) and conducted by Pedersen (2010), which approached the evaluation by identifying important attributes associated to quality, determining the relationship between subjective and objective measure, and analyzing output values to predict overall image quality. The purpose of the selected framework was to show influence of commonly understood attributes.

Many studies have been conducted with the intention of evaluating attributes related to the performance of overall image quality. Pedersen (2010) performed several studies involving the identification of important attributes for color prints. Based on literature and evaluation by observers, the research focused on six quality attributes

(color, lightness, contrast, sharpness, artifacts and physical parameters) with additional observation of "subcategories" classified under the specified attributes (hue, saturation, colorfulness). The group of attributes was responsible for a large amount of influential preferences and relationships to image quality.

Reinhard (2008) finds attributes including hue, saturation, Artusi (2009) evaluated overall image qualities of HDR specific images involving brightness, contrast, color, and detail attributes based on the application of tone mapping operators measured by a rating scale. Further, Kuang (2007) evaluated eight tone-mapping methods and had observers rate four specific attributes perceived in the image; namely global contrast, colorfulness, shadow detail and sharpness. Additionally, numerous researchers investigated image quality attributes such as tone reproduction, blur, naturalness, color rendition, details, noise, clue and lightness.

Evaluation of Quality Attributes

Although necessary, the selection of specified attributes has a direct effect on the evaluation of the image quality. Pedersen (2009) identified vital issues that must be weighed when selecting quality attributes, found in *Table 2*.

Origin of Quality Attribute	The purpose behind selecting specified attributes
Intended Use	How the attributes will be formulated to gather results
Dimensionality	The number of quality attributes to be used
Independence	The clear identification between attributes
Quality Attribute Sample Size	The range of values associated with the interpretation of defined quality attributes and further observations

Table 2: Purpose behind quality attributes selection. Adapted from Pederson (2009).

The first step in selecting quality attributes is to identify attributes relevant to the area of research. After a survey of the existing literature, many sets of quality attributes were established. The attributes selected were found to be suitable for image quality metrics to address the intended objective of evaluating HDR imagery.

The attributes selected for this study were chosen to be concise and comprehensive descriptors consisting of artifactural characteristics (degrading quality if noticed) and preferential characteristics (always visible in an image and have preferred positions) (Topfer, 2002).

Color Judgment

It is widely recognized that individuals perceive color differently. Most observers of color in images, unless expert in the particular type of image, are left to interpret the image without insight into the artistic intent or production methods used. Gamm (2011)

states: “the act of liking or disliking an image is an intuitive, yet complicated process that is taken for granted. The task becomes considerably more difficult when asked to explain why an image is liked, or, as in the case of image quality research, why one image is of higher quality than another” (p. 20). Although results can vary, it becomes important that the individual viewing the image can understand what variables they are evaluating and how much of their personal opinion should be weighed. When conducting a psychophysical experiment involving color, Banterle (2011) suggests, “participants should be chosen with normal or corrected-to-normal vision and carefully instructed about the task that has to be performed” (p. 177).

Although it is recognized that all individuals perceive color differently due to a number of factors, certain individuals differ from what is widely considered to be abnormal color vision, typically known as “color blindness.” This color vision abnormality can prove to be a hindrance if color is a factor in the decisive area of image quality, causing questionable reliability in accuracy. Fairchild (2005) states: “given the fairly high rate of occurrence of color vision deficiencies, it is necessary to screen observers prior to allowing them to make critical color matching judgments. Screening with a set of [commonly administered tests] should be considered a minimum evaluation for anyone carrying out color judgments” (p. 33). Since HDR images are designed to produce a wide gamut of color through their capture, it would be important to be aware of the status of a viewer’s color vision.

Method of Comparison

The use of a pairwise comparison method, with ranking and rating based measurements, can provide substantial data in the evaluation of perceptual preference and subjective variables. This method involves the comparison involving a reference in which an image satisfying a set group of criteria. Involved in this method can be the use of ranking, in which participants must make a decision based on a series of variables, and rating, in which a participant would rate perception of attributes based on a scale (Banterle, 2011, p.177).

A broader understanding of comparison methods can be explained by L.L. Thurstone's Law of Comparative Judgment. The Law of Comparative Judgment founded a concept which allowed the measurement of psychophysical experiments to be based on perception rather than physically measureable scales. The law suggests an observer will give "different comparative judgments on successive occasions about the same pair of stimuli based on higher or lower degrees of excellence (Thurstone, 1927, p. 269). The use of these methods is vital to observers comparing multifaceted variables within an experiment.

Conclusion

According to the literature, there are proven limitations to reproduction characteristics for HDR photography with output mediums available to the suggested audience. These barriers are continued today with prosumer level inkjet printers and display monitors. The human visual system remains a much more complex system then

any prosumer level technology can aspire to be compared. Narrowing the vast amounts of workflows and prosumer technology to which could best represent the unique qualities of HDR images would only encourage the experimentation and available resources for further aspirations. Assisting the prosumer market in understanding the effect of compression on tonal reproduction can aide in the common mistakes made when attempting to accurately reproduce an HDR image.

Chapter 3

Research Objectives

This exploratory research was designed to demonstrate the perception of HDR image reproductions across two media platforms, namely monitor display and inkjet print outputs. The focus of this study involves the evaluation of primary predictor variables for display preference: image content and quality attributes. The research seeks to analyze these variables using a psychophysical study to collect both qualitative and quantitative data from an established population. Literature indicates that optimized display preference has been the focus of previous research; however, no found publications have established a similar foundation with the techniques of HDR imaging. This study will provide further insight by examining the following research questions:

1.) What is the preferred output media of HDR images between monitor display and inkjet prints?

b.) How does image content impact the visual perception of HDR imagery?

2.) Which image quality attributes are most influential when viewing HDR images across different media platforms?

a.) What relationships exist between individual quality attributes?

Chapter 4

Methods

Overview

This study used a multi-media setup, consisting of a monitor display device and inkjet prints, to conduct a psychophysical experiment developed for the prosumer population interested in HDR. An experiment was designed to determine preferred display output and influential quality attributes of HDR imagery. Observers were asked to simultaneously view a printed image (the reproduction) and a monitor display image (the reference) to evaluate how pleasing the reproduction appeared on a 5 level rating scale. Additionally, a qualitative analysis of visual perception was used to investigate trends between qualifying criterion.

Image Processing

The following sections discuss criteria pertinent to the image processing methods and procedures utilized during the course of this study.

Procedure

The first step of the image processing was to capture image samples used during the visual comparison portion of the experiment and determine what types of image content would be most successful during HDR processing. In addition to image capture, a

secondary component was to define a consistent workflow used during the development of the image process.

Image Capture

The images utilized for this experiment were captured by the researcher using a 21.1 megapixel, full-frame sensor Canon 5D Mark II camera. Using the HDR bracketing technique, images were captured in a series of three exposures taken consecutively on manual mode. This captured the same scene represented across normal, over and under exposed ranges to further assist in the HDR creation. Scenes represented in the images were taken in varied locations surrounding Rochester, NY, Buffalo, NY and Leicester, VT. Specifications of image capture can be found in *Appendix C: Image Samples and Metadata* and *Appendix K: Image Capture: Breakdown and Organizatoin*. Additional tools and settings that contributed to the capture process included: low ISO settings, a Sekonic light meter for proper exposure, a shutter release to ensure clarity, and a Manfroto tripod for stability.

Image Sample Size

Ten different image classifications, consisting of unique content in varying environments, were selected for use in the study. The Image selection process, conducted by the researcher, is visually represented in Figure 2. The images contained two different origin directions with the representation of six landscape (horizontal) and four portrait (vertical) images. Nine of the images were displayed in color while one image was

displayed in black and white. During the duration of the experiment, participants observed a total of twenty different samples encompassing both print and monitor displays.

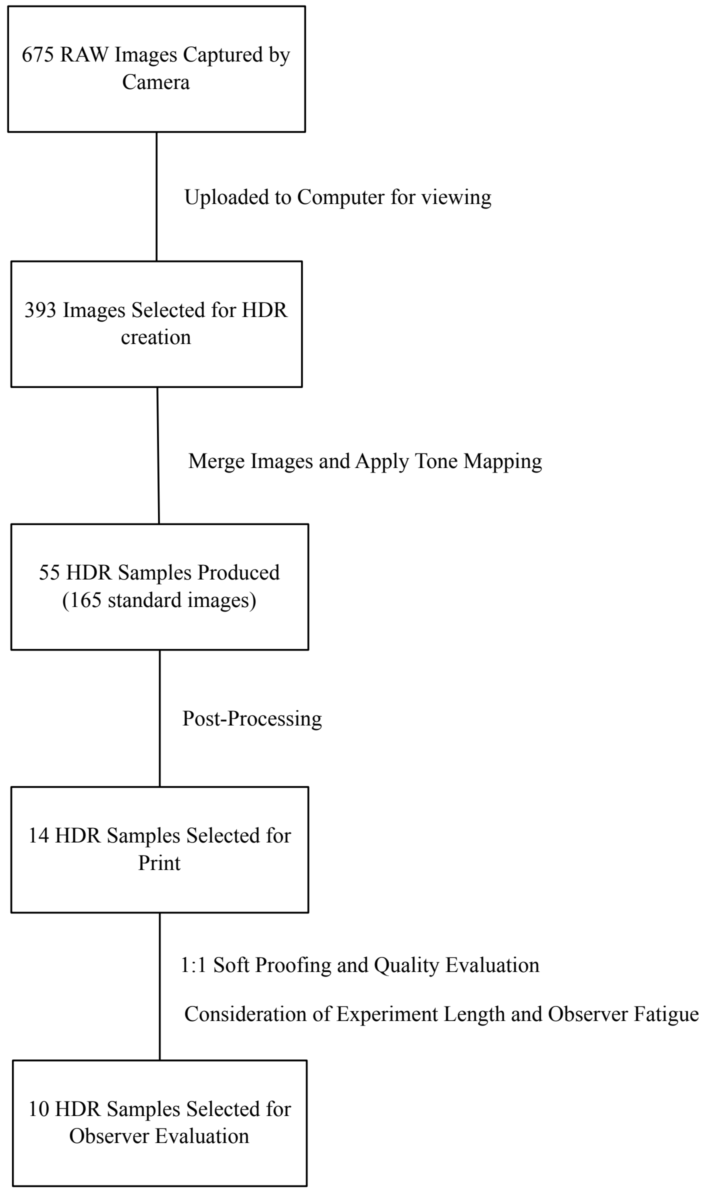

Figure 2: Numerical breakdown of image selection during the HDR process

Criteria

The content within the images, which determined image classification criteria, were chosen during image capture at the discretion of the researcher based on location, weather and personal aesthetic. To establish what image contexts were best fits for this study, set of objectives were created prior to image capture.

Image Content Objectives
Vary: Objects, Time of Day, Location, Perspective
Represent range of quality attributes
Local Locations for representation of
Offer diverse viewing experience
Appropriateness for Study
Ability to identify images easily, without confusion or abstract descriptors

Table 3: Objectives used as a guideline when preparing for image capture and development of HDR

Image samples content were classified both to amplify the interests of viewers and evaluate impactful interactions had by a connection formed by the selected samples context. By appealing to a viewer's emotion, judgments of images can be affected both negatively and positively depending on the level of association (Engledrum, 2000, p. 25). The purposeful intention of using differing images was to lessen potential bias across participant evaluations. Likewise, tone mapping can often bring out attributes in images that may not have been originally noticeable, therefore assigning image classifications

were best set forth when all the images had completed HDR processing and the assessment of existing quality attributes was made.

Image #	Color/Monotone	Description	Classification	Subcategories
1	Color	Red trailer in grass field with large sky	Emphasis	•Memory Colors
2	Color	Bridge on canal with blue sky	Natural	• Perspective • Focus
3	Color	Night image with brightly lit building	Variation of Lightness	• Cool Hue • Tone Variation
4	Color	Sunset on lake	Color Transition	• Saturation • Tone Variation
5	Color	Indoor gallery hallway	Variation of Color Temperature	• Warm Hue
6	Color	Outside façade of barn	Texture	• Texture
7	Color	Greenhouse with supplies	Fine Detail	• Fine Detail
8	Color	Door of greenhouse with bright light	High Key	• Variation of Light •Quality of light •Tone Variation • Dramatic
9	Color	Tractor against grey sky	Saturation Variation	• Perspective • Low Key
10	Monotone	Tall building	Monotone	• Tone Variation • Perspective

Table 4: Layout of selected image details, classifications and associated subcategories for identification

Using descriptor words, image classifications and subcategories were created based on noticeable spatial configurations. Engledrum states: “when scaling image quality, it is important to include image classes that are familiar to, or requirements of, the target focus” (2000, p. 26). The significance of classifications further emphasized quality attributes found the images as well as identified commonalities within associated subcategories. Classifications and subcategories were not disclosed to observers during the experiment and can be comprehended through the visual representation of *Table 4*.

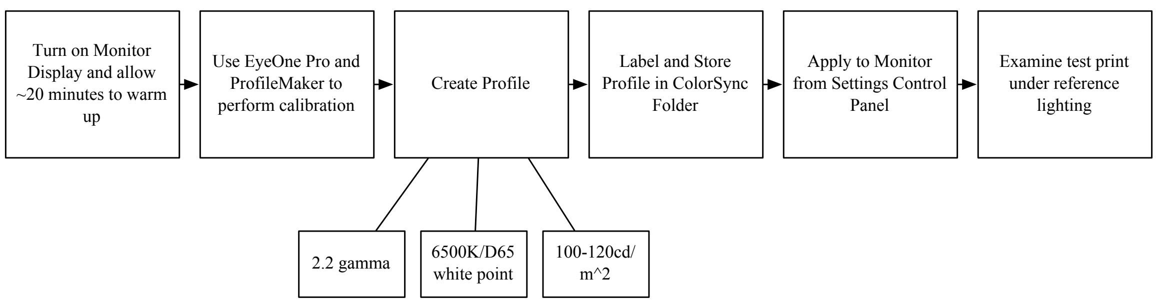

Figure 3: Process of monitor calibration and profile with appropriate settings

Output Displays

Choice of display used for the control portion of this study was the Apple iMac 30” Mac Apple Cinema display. An Eizo ColorEdge CG242W, located within the GraphicLite GTI viewing booth and connected as an extension of the Mac Display, was used for the display portion of images for this study. Preceding image processing, calibration and profiling were performed on the monitor displays to confirm the given device would behave in an optimal state. Steps were taken using the EyeOne Pro calibration instrument and ProfileMaker software. The monitor calibration process can be

seen in Figure 3. Due to the required amounts of time taken to complete the experiment, in addition to the machines being located in a centralized area, the displays were checked and re-calibrate, if necessary, before each use to ensure accuracy.

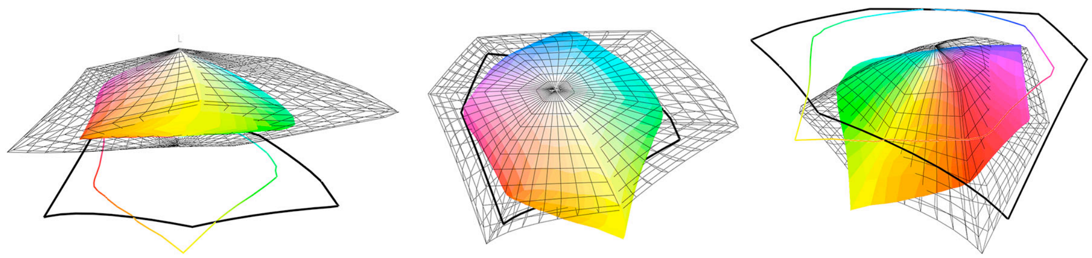

Figure 4: Three different perspectives of the Output Display Gamut used for this study. Monitor (wireframe) clearly has a larger amount of capabilities then the Printer (solid color).

HDR Workflow

Procedure

Although many varieties of processing software and techniques for HDR images exist, the researcher focused on a method using commonly available software with the intention of applying basic principles intended to be repeated by HDR enthusiast for further interest and experimentation on the topic. The leading processing software programs used for this study consisted of: Adobe Lightroom, HDRsoft's Photomatix, and Adobe Photoshop CS6.

Adobe Lightroom

The first step of the process workflow involved importing captured images from a 16 GB compact flash card into Adobe Lightroom to be catalogued and analyzed. Each

scene was evaluated in groups of three images, representative of a two exposure value range difference (EV +/-1). The images were imported in RAW format, a native Canon file type, with no in-camera processing. Images were discarded altogether if there were noticeable blurring, interfering objects, or other visual perceived flaws. To prepare the appropriate images for export, they were assigned an ID number according to a pre-determined file-naming scheme, creating corresponding image sequences. Adobe Lightroom also provides the metadata to each image to help detect numerical differences in images if an exposure value could not be distinguished.

Using Adobe Lightroom, the researcher chose methods of converting the RAW images to 16-bit TIFF files with a ProPhoto RGB color space, no compression at 350 pixels per inch (PPI); then exporting the files to a new folder, creating source images necessary for the HDR processing software. Prior to the executive decision of converting the RAW images, the researcher experimented with processing HDR's by directly importing un-assigned RAW formatted exposures into the software. It was concluded that converting the images to TIFF early in the image processing allowed for preservation of the selected color space of the source files and the prevention of true values from the source file and the prevention of clipped colors, otherwise noticed in the piloted HDR's created with RAW files. HDRsoft, creator of HDR processing software, further states on their resource website:

> "Photomatix processes the values of your source images directly, without converting them to another color space. This means that the resulting images produced by Photomatix will be in the same color space as the one specified by the ICC color profile of your source images" (2013).

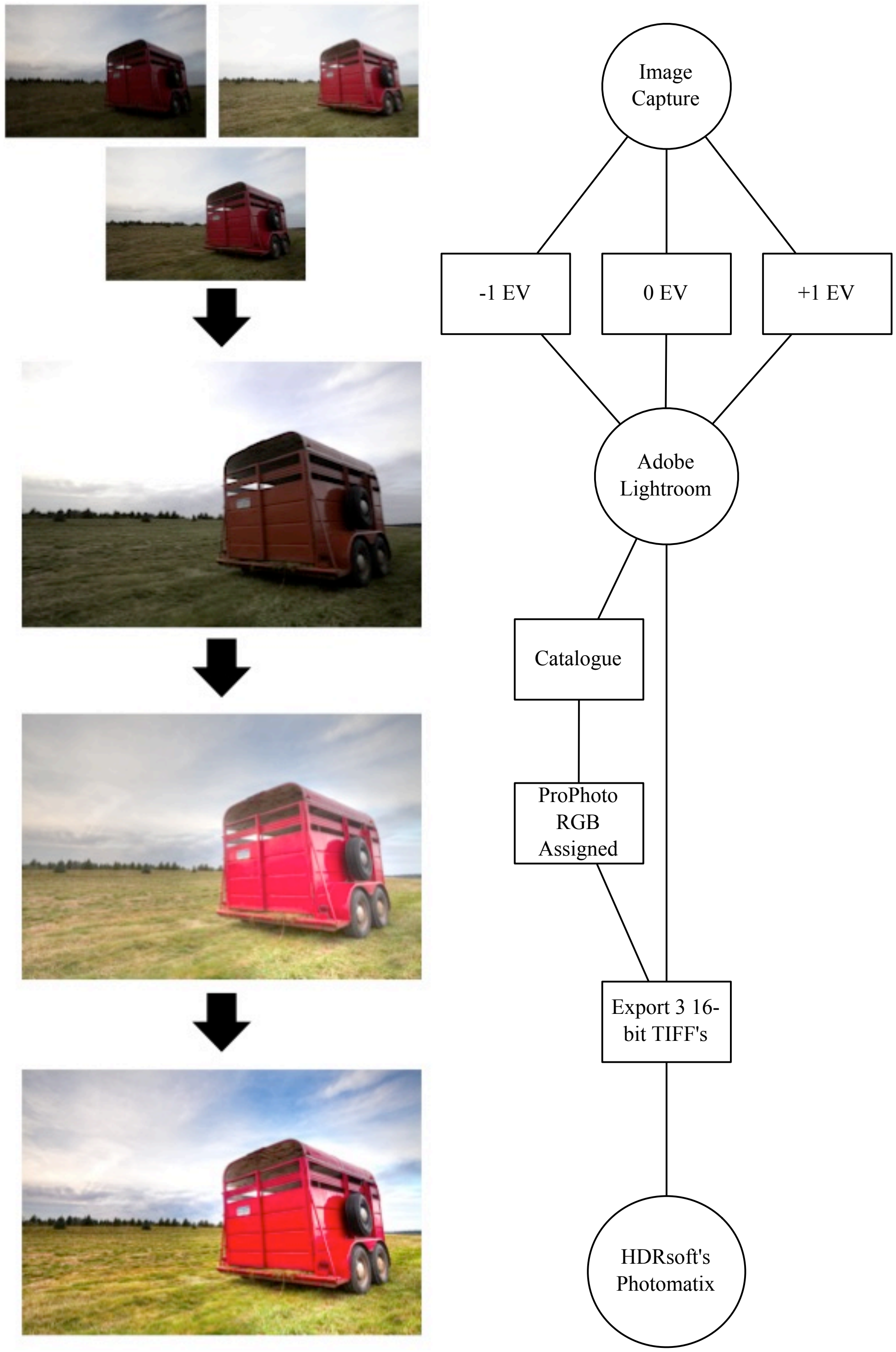

Figure 5: Workflow of HDR image from capture to HDR processing (right) and stages an image goes through to become an HDR (three exposed images, one true HDR file, tone mapped image, output ready)

HDRsoft's Photomatix

Secondly, images are imported to HDRsoft's Photomatix software, designed to handle the unique characteristics of HDR imagery. The software tool was used to merge bracketed exposures together and apply tone mapping to a file to create an HDR image visible on a monitor display. The file formats accepted for processing are JPG, PNG, PSD, TIF (8-bit, 16-bit and Floating Point), Radiance RGBE and OpenEXR. It is suggested that an HDR originating from 3 or more bracketed exposures is appropriate to achieve high quality. The files were selected, aligned and batch processed to result in a single 32-bit that appeared inaccurately exposed and unfinished. Due to the compilation of three sets of information from the bracketed images, dynamic range of an image is increased and therefore cannot be accurately displayed on a monitor. Resolution was found by application of tone mapping, which visually created clarity and distinction of image context.

Tone Mapping

The researcher chose to use Photomatix's tone mapping controls for the modification of the HDR file. HDR specific software is optimized for the purpose of bringing out details and features of images, and therefore automates majority of the process through adjustable sliders to achieve results. Tone Mapping can occasionally cause a "surreal" impression to image context; however the desired result utilizing the technique for this study was to give dimension to images, increasing overall appeal.

Attributable to the image dependent nature of its application, tone mapping is often viewed as an experimental approach. Adjustment sliders most often used for an image to appear at an optimized state were: strength, micro contrast, smoothing, luminosity and gamma. Using a manageable file format, images were saved as 16-bit TIFFS, resulting in 10 individual HDR's.

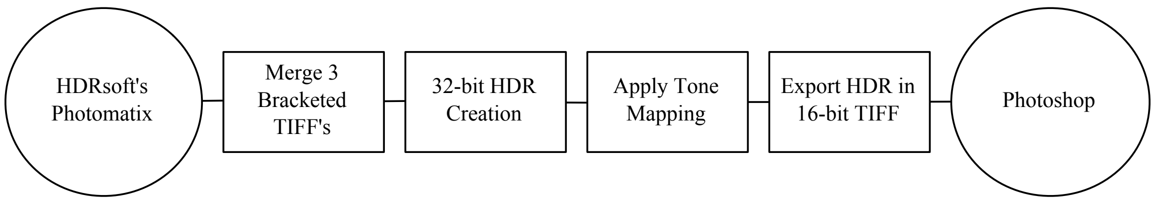

Figure 6: Workflow of HDR processing software

Adobe Photoshop CS6

The final step in the image process utilized Adobe Photoshop CS6 for image preparation, manipulation and output to both media displays. The single TIFF HDR was opened in Photoshop with the ProPhoto RGB color space and relative colorimetric rendering settings applied.

Color Settings

Prior to images processing, proper color settings were enabled to ensure a consistent working space. Options were changed from default settings to the following:

Working Spaces:	
RGB:	ProPhoto RGB
CMYK:	U.S. Web Coated (SWOP) v2
Gray:	Gray Gamma 2.2
Spot:	Dot Gain 20%
Color Management Policies:	
RGB:	Preserve Embedded Profiles
CMYK:	Preserve Embedded Profiles
Gray:	Preserve Embedded Profiles
Conversion:	
Intent:	Relative Colorimetric

Table 5: Custom Color Settings applied for post-process in Photoshop

Settings were applied with anticipation of color management, rendering intents, and RGB behaviors towards photographic inkjet printing. ProPhoto RGB was used most consistently amongst workflow applied for this study for the purpose of providing the widest possible color gamut, accommodating the large range of HDR. Relative colorimetric rendering intent was chosen as the manner in which out of gamut colors, colors that are present in a source image but unable to be reproduced by an output device, were to be handled for display output. Attributable to the importance of HDR, the selection of the given rendering intent and was made based on two components:

1.) In conjunction with the ProPhoto RGB working space, there was a possibility of representing a larger gamut of colors with Relative as opposed to Perceptual.

2.) The relative rendering intent is currently a Photoshop default and therefore would be more applicable for a workflow to pertain to a prosumer or HDR enthusiast.

Photoshop Adjustments

Using Adobe Photoshop Adjustment tools, editing techniques were applied to each image, however the level of application was image dependent based on characteristics presented within the processed HDR. All images appeared to be hazy or have an overall halo due to the tone mapping application, resulting in perceived soft edges of objects in the image. To compensate, a high pass sharpening was applied with the purpose of sharpening the edges within the image and avoiding noise and unwanted pixels. Both global contrast and saturation adjustments were also applied for corrections in areas of image temperature and added stylistic intents.

Output from Adobe Photoshop CS6

Photoshop was used to facilitate the output of both monitor display and inkjet prints used during this experiment. All image files were resized to 4200 by 2800 pixels, which translate to 12 inches by 8 inches, with a resolution of 350 dots per inch (DPI). Size was pre-determined based on available surface area within the viewing booth setup, used by observers to assess image pairs. With the appropriate color settings applied, images were positioned on the Eizo ColorEdge in an allotted frame identical to the size and shape of the printed reproductions.

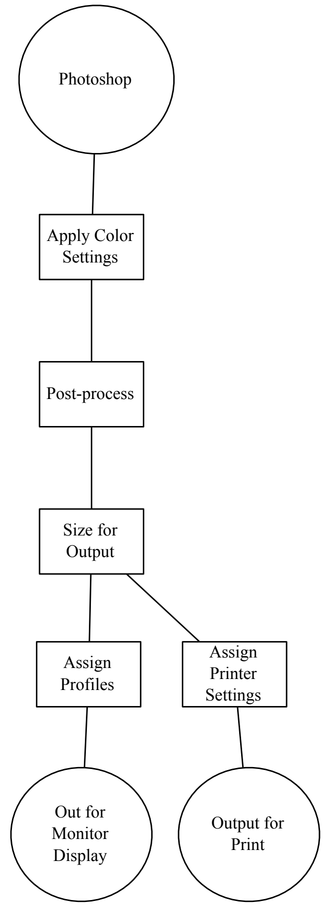

Figure 7: Workflow of image process from Photoshop to desired output

To output for the inkjet prints, Photoshop's print settings were augmented to export the file to the Epson Stylus Pro 4000. Behaviors of the print device were discovered through the creation of profile, suited to the characteristics of variables such as paper and output intent. Application of a customized printer profile was chosen from drop down options in addition to the selection of a relative rendering intent in correspondence with previous applications. Color Settings were turned to off for "no color adjustment". To better simulate the behaviors of commercially available devices

for the target audience, measures were taken in applying settings capable of simple duplication.

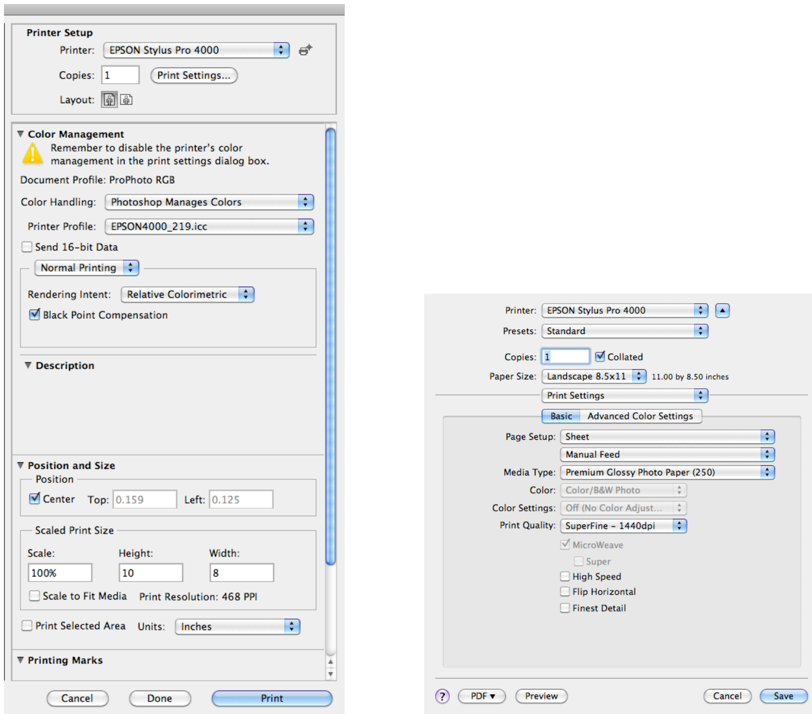

Figure 8: Screen shots of settings applied to enable communication to the printer device

Output from Epson Stylus Pro 4000

Using the EyeOne Isis and iProfile Maker instruments, a custom printer profile was created specifically for the Epson Stylus Pro 4000 based on the selected substrate: Red River Polar Pearl Metallic 12x18 in 60 pound weight. The particular substrate utilized was recommended by Besta (2010) and Bamberg (2012, p. 314) for use with an Epson printer to produce high-quality HDR prints. It is important to note, the researcher first applied the generic profile supplied by the supplier to use for image output.

Evaluated on a 1:1 test, the custom profile supported a higher quality image output when compared to the generic profile. Specifications of the substrate used can be found in *Appendix H: Summary of Substrate Characteristics and Recommendations*. Application of the profile was moreover used with each proof setup for the images exhibited to observers. When applied, the profile confirmed that both displayed images would be valid by reason of consisting viewing conditions. With the aforementioned target audience, a commercially available inkjet printer was chosen for the hard copy output.

The Epson Stylus Pro 4000 consisted of an 8 color ultrachrome ink system and was found to be compatible with the chosen substrate through the supplier's website. The substrate was chosen due to the surface capabilities of producing prints with bold color, large exposure range, and added depth. Containing qualities that would benefit HDR imagery reproduction, consideration of was given to producing the highest quality HDR prints possible, while remaining in the confinements set forth by output device capabilities. The prints were cut and hand trimmed, with no border, according to the 12 inch by 8 inch size.

Experiment

Pilot Test

Following the groundwork of the display setup, a pilot test was conducted for readability of the structured questionnaire, understanding of terms used to describe images, and fluidity of image transitions for a cohesive viewing experience. Results of the pilot tests were used to adjust the display setup finalize question formatting and

develop a more efficient image transition method for each matched pair of print and monitor display so observers were not distracted by unrelated variables.

Survey Administration

The foundation of this research is characterized through the use of an exploratory psychophysical experiment. The purpose of administering a preference-based survey consisting of rating and open ended questions was to gather information based on observer preference and perception of displayed HDR images. All participants completed the survey utilizing Polldaddy, a survey application, through an iPad device on an iOS 6.1.3 platform. All surveys were completed in the presence of the researcher. For a complete summary of survey questions, please refer to *Appendix A: Experiment Survey*.

Experiment Procedure

A total of 38 observers participated in the visual assessment and completed an electronically administered survey. The observers consisted of RIT affiliated Undergraduates, Graduates, Alumni, Faculty and Staff. All observers were verbally clarified of the volunteer nature of their participation as all as given an electronic confirmation of content button prior to the start of the survey. The experiment took approximately 35 minutes for each observer to complete. Participant's responses were submitted via the iPad while a separate document was kept to transcribe oral dialogue and conversations.

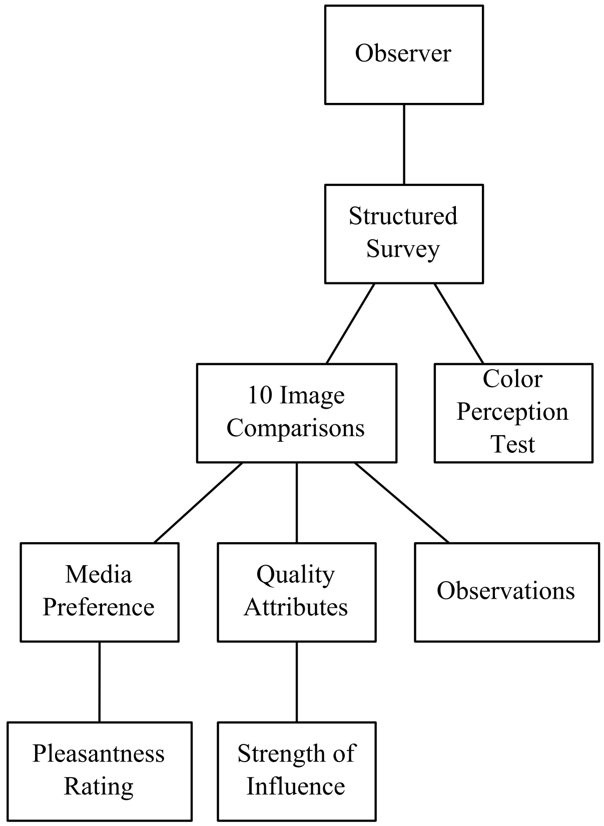

Figure 9: Overview of Psychophysical Experiment Tasks

Location of the experiment took place on a one to one setting in a room specifically designed for critical color analysis; prior research found the room to be compliant with the industry standard according to ISO 12646:2008, '*Graphic technology – Displays for color proofing- Characteristics and viewing conditions'*. To follow the specifications of ISO 12464 for soft proofing display surroundings, the room was kept dark with minimal interference of outside ambient light.

The experiment consisted of two parts. First, the observer was asked to take an electronic version of the Ishihara Color Perception test. Literature suggests that the

Ishihara test is one of most easily available and simplest to perform (Reinhard, 2008, p. 306). Commonly, the test is performed using physical pseudo isochromatic plates; however further evaluation of color perception exceeds the scope of this research. At the completion of the test, observers would promptly receive a score out of 100%. The purpose was to test for color deficiencies, related to the accuracy of observers' evaluations regarding the color attribute associated with image quality.

Second, the observer would view ten image pairs side by side. One image was displayed through the Eizo ColorEdge monitor screen, while the inkjet print was temporarily mounted with t-pins against a standardized grey panel in the same orientation. A set of three questions were consistently asked per each image pair. The first instructed the observer to compare the two displayed images while emphasizing image quality of the printed reproduction, verbally establishing that the monitor display would be considered the reference for their evaluations. They were asked to rate how pleasing the printed reproduction appeared on a scale of 1-5, where 1 represented significantly less pleasing and 5 represented significantly more pleasing.

Scale	Evaluation	Condensed Evaluation
5	Significantly More Pleasing	Preferred Printed Reproduction
4	More Pleasing	
3	No Change	No Preference
2	Less Pleasing	Preferred Monitor Display
1	Significantly Less Pleasing	

Table 6: Rating scale used in experiment to determine preference of media display

Immediately following, observers were instructed to focus on individual image quality attributes. Instructions were given to indicate the level of influence nine pre-selected attributes had on their opinion of the printed reproduction's quality. The nine attributes used in the experiment were considered by observers to have a strong influence (favoring the print), lesser influence (favoring the monitor) or no influence. To further assist with the reliability of the data, descriptions and definitions of the quality attributes were posted in two visible areas within the experiment location. The definitions and presentation can be viewed in *Appendix B: Accessible Definitions for Observers During the Experiment*. Lastly, the observer was presented with an optional open-ended response inquiring to whether they had further remarks or observations about the image pair. The researcher would manually change the viewed image pairs when the observer indicated they had been given enough time to record their answers.

All observers were informed, prior to their participation, about the commitment involved in the experiment. As an added incentive, every participant was rewarded a travel coffee cup containing a dollar off token to Java's, a local Rochester coffee shop. After the completion of the experiment by all 38 observers, data was exported to statistical software to be explored.

Experiment Sample

There were 38 observers, in total, that participated in this experiment. All observers were administered the same structured questionnaire and pair-wise comparisons during their participation in the study.

Due to the location of the experiment being conducted on the campus of Rochester Institute of Technology (RIT), a bias in regard to the observer criteria for the sample is acknowledged. Selection standards for participants were created by the researcher based on the level of image knowledge required for efficient evaluation of HDR imagery and processes; the standards were as follows:

1.) An interest or previous exposure to color photography
2.) Basic knowledge of objectively viewing image
3.) Higher level of understanding in regard to an image workflow (capture, edit, display)
4.) Normal Color Vision

Participants were primarily extracted from upper level, advanced color management and imaging processing courses based in the School of Media Sciences at Rochester Institute of Technology (RIT).

Limitations

While relevant precautions were taken, parameters inherent in this study may have been cause for potential errors:

1.)The image workflow used for this research is not to be considered as the only method in the process and creation of HDR images. The chosen value of the procedure was to benefit a large population of users under the assumption that the software and processes would be widely available and easily understood. Results may have varied if alternative workflows were implemented.

2.)The location of the study, specifically available equipment, resided in a public area and therefore a large effort was made by the researcher to maintain viewing conditions and setting. Due to the stationary position of viewing setups paired with relatively tight confines of the room, observers were advised to use a marked area on the floor to move within to diminish chance of glare from the prints, due to the recognition that the prints exhibited a slightly glossy surface. Due to varied heights of observers, viewing angles differed per participant.

3.)Displays used for this study were chosen based on availability of industry accepted instruments that were commonly available to prosumers. Due to the comparison method necessary for the experiment, the proofing setup previously established was considered most effective. Attempt to uniformly calibrate both monitors proved to be difficult due to differing characteristics in make, model and capabilities. Images used for the experiment were originally edited on the Mac display, therefore when the images were displayed using the Eizo ColorEdge, key aspects were not

parallel. Using two different viewing specifications on the monitors occasionally presented differing results between an image when moved from one screen to another, despite appropriate profiles and adjustments being applied. This challenge is confirmed by Reinhard (2008) suggesting that "even if the display device and viewing environment have been appropriately characterized and corrected for, the image may not appear as intended" (p. 827). It was discovered that the Eizo ColorEdge display required hardware calibration adjustments independent of the graphics card. It is important to note, the researcher conducted multiple tests of calibration to achieve a best possible match. Show the comparison of the two profiles.

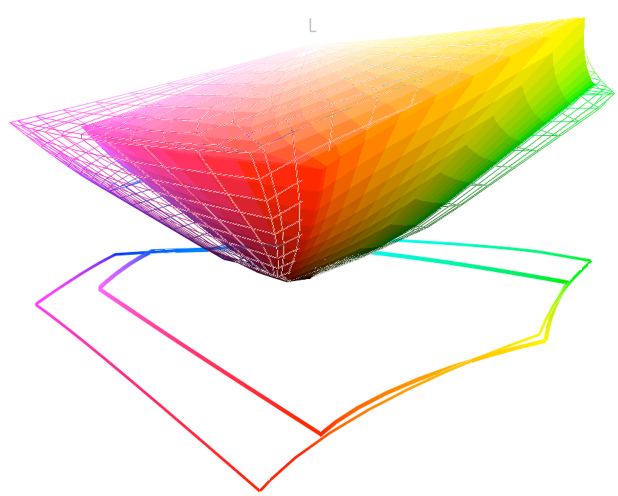

Figure 10: Comparison of monitor gamut, Mac (solid) and the Eizo ColorEdge (Wireframe)

4.) The participants for the study consisted entirely of individuals associated with RIT. The intent was to incorporate a large amount of volunteers with prior knowledge of imaging, equipment capabilities and output. Location factors of a small demographic were discovered later with regard to the familiarity of image content. Capturing images in the local area presents the possibility of skewing observer opinions if they had previously been exposed to selected contexts. A larger, varied sample of observers including industry professional may have provided different results. However, as a result of the sample size consisting of 38 observers, the data is not normal and therefore can only draw minimal statistical conclusions.

Analysis of the Data

Both quantitative and qualitative data were utilized to analyze the research objectives defined in *Chapter 3* of this document. A portion of the qualitative data were quantified and evaluated by statistical measurements of mean, median, variance, and frequency. The remaining qualitative data included optional observer response questions, which were recorded and categorized, to evaluate if common themes were present and lead to the indication of affiliations with other variables used in this study. The quantitative data was analyzed through the use of statistical approaches such as a crosstabulation and chi square test and an application of the Kendall tau-b test with the

objective of discovering significant correlations across variables of interest. A full data analysis can be located in the *Chapter 5- Data Analysis* section of this research.

Chapter 5

Results

Overview

With the goal of gaining further knowledge on media output preference and influential qualities of HDR imagery, 38 observers participated in the experiment, resulting in an 88% survey response completion rate. To ensure consistency in the responses, and to enhance the reliability of the methods, participants partaking in the experiment were given a brief verbal overview from the researcher regarding as to the tasks they would be asked to do during the experiment. The overview given did not contain specifics pertaining to the images being used in the study, but rather created awareness of respondent expectations. The participants were asked to evaluate 10 image pairs displayed through a dual media comparison setup. The respective HDR images, which were comprised of the same digital information, were presented simultaneously in two different output forms: a carefully reproduced ink jet print and an equally carefully reproduced monitor display. The participants were asked to evaluate each image in both display formats.

The data were obtained over a ten-day period with the average completion time of 35 minutes per subject. All observers stated that they felt they had the time they needed to understand and complete the study. To provide foundational information germane to the objectives of the study, a comparison of gamut behaviors of each image as compared to its respective media display was evaluated. In addition, foundational information is

provided for the respondent demographics. Further, each respondent participated in a color vision test; these results are also provided.

Foundational Information: Evaluation of Image Samples

Each image sample involved in the experiment was chosen and processed according to a consistent workflow established by the researcher based on the literature, common imaging practices, and recommendations by professionals in the field. A large variety of imaging techniques can be used when processing both HDR and photographic images, however the research focused on the results of the output methods as previously described in *Chapter 4: Methods.*

The preliminary evaluation of the images and respective gamuts were conducted by the researcher to confirm image compliance with the experiment prior to the involvement of participants. Using ColorThink Pro software, observations were made of each image sample color gamut and compared to given output media's display profile capabilities. This process allowed an opportunity for the researcher to better approximate the difference between the sets of HDR images and what was viewed on a display; reproductions of these gamut plot comparisons are represented in Figure 11.

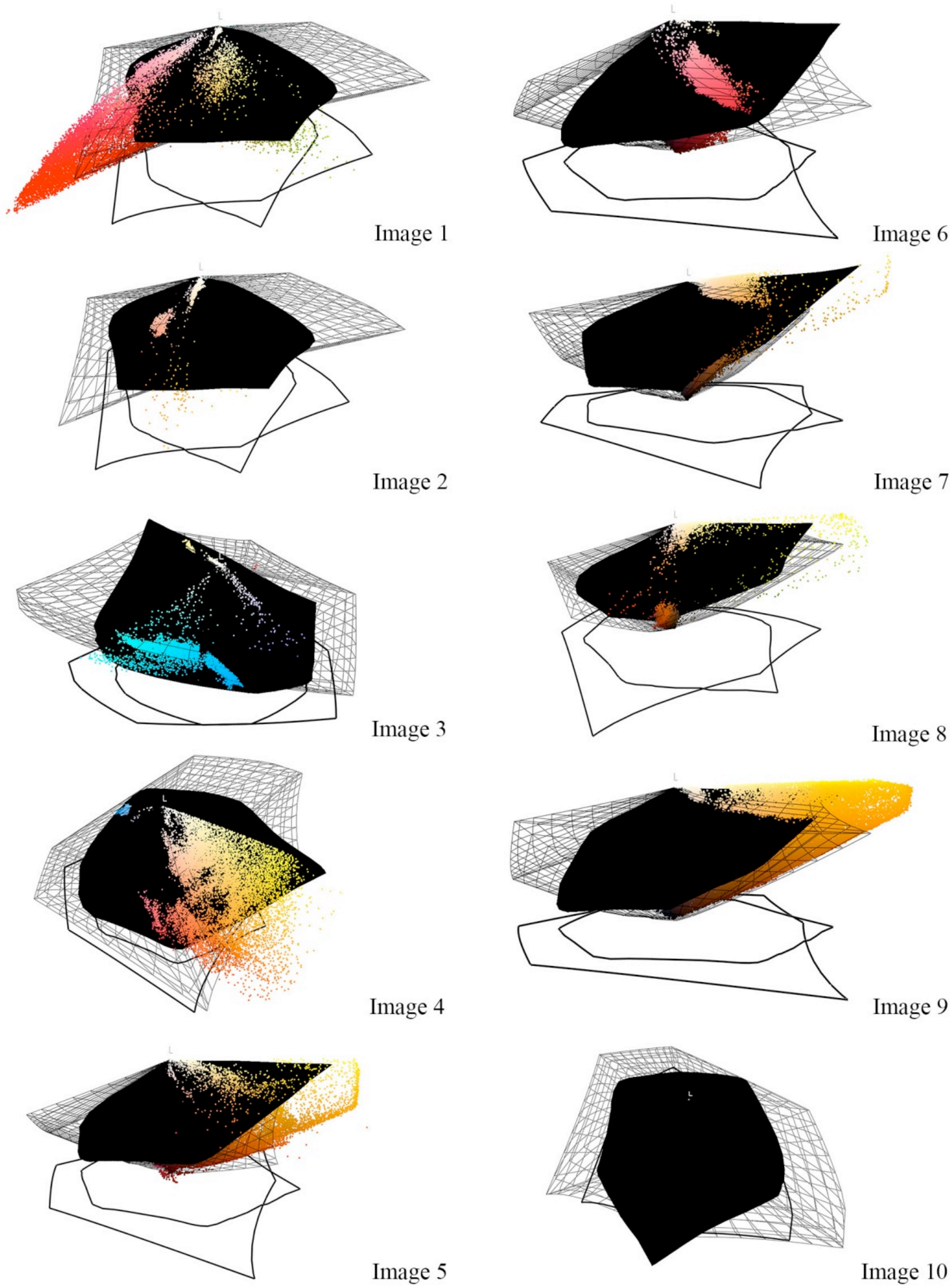

Figure 11: Gamut for each individual image shown with three different representations in the CIELAB space. Monitor and print (black wireframe and solid) compared to gamut of HDR image (color)

The graphical representations of the color gamut suggest that the HDR images contained characteristics outside of the monitor and printer gamut. Using the ProPhoto color space, allowing a large quantity of readable color data from an image, notable discrepancies in the gamut plots are recognized dominantly in Image 1 and Image 9, especially in the red and yellow portions of the color space.

Foundational Information: Survey Demographics

Observers that participated in the survey varied in age 18 to over 50 with the highest frequency of participants between 22-25; a common age of an upper-level undergraduate student as illustrated graphically in Figure 13. The majority of the participants were affiliated with the School of Media Sciences (63%); all research participants were affiliated with RIT Schools, particular affiliations are illustrated in Figure 12. Close to 82% of the subjects indicated that they had previous exposure to HDR imagery, with 58% of those subjects being exposed to HDR more than five times.

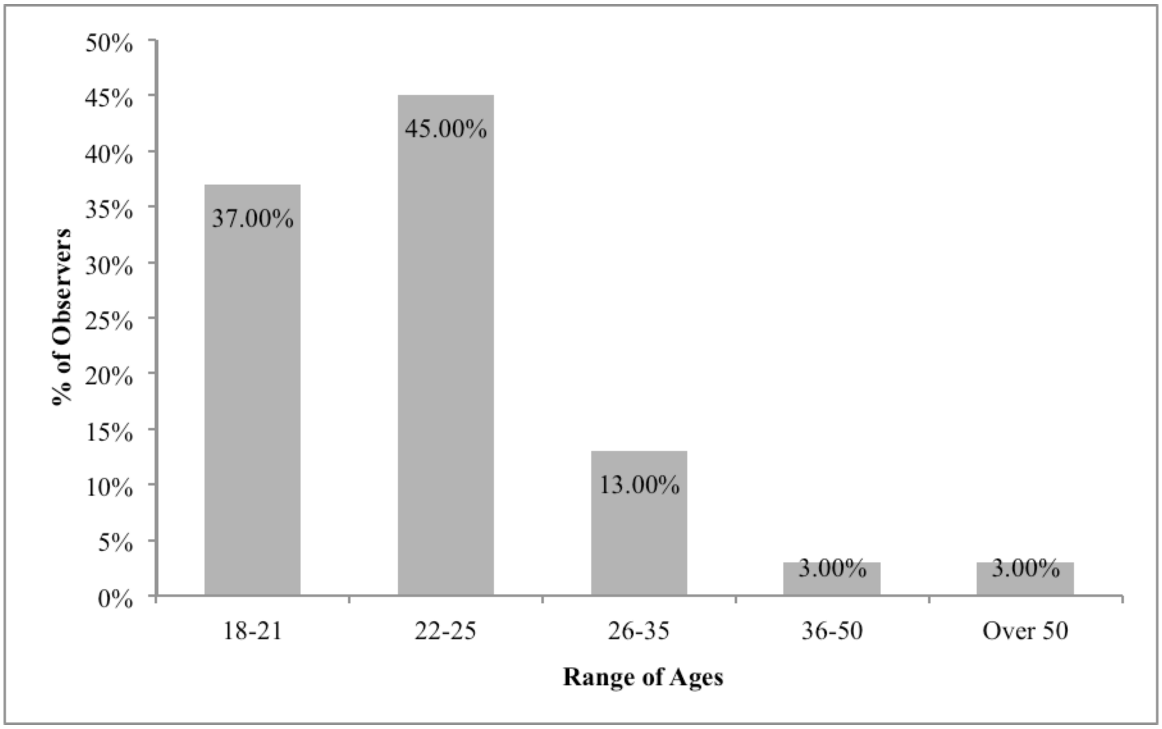

Figure 12: Percentage of Observers by Age

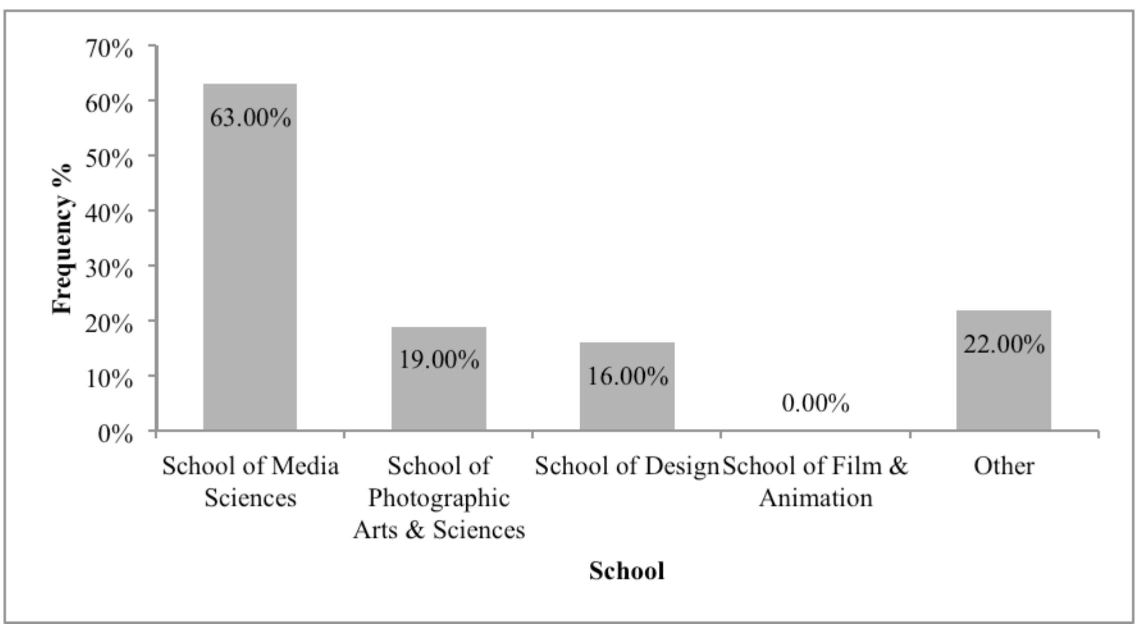

Figure 13: Percentage of observers by school affiliations

Due to the experiment parameters and location at RIT, observers were also asked to provide the year level they are considered according to their academic standing. The purpose of this particular inquiry is to verify that the research subjects were consistent with what can reasonable be expected of the imaging prosumer and enthusiast-level population. The year level of participants is show in Figure 14. Of the 38 responses, the majority of participants reported that they were in their third undergraduate year or higher, with only 8% in their first or second year of undergraduate study.

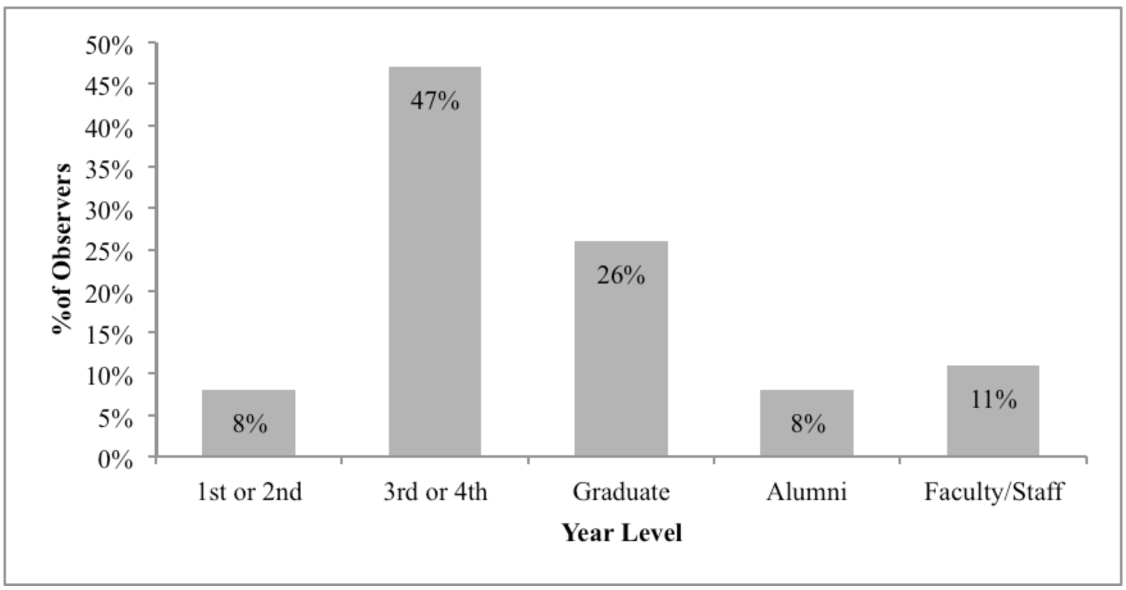

Figure 14: Percentage of Observers by year level

Foundational Information: Color Perception Test

Prior to viewing the image samples, each participants completed a digital version of the Ishihara Plate test administered via the iPad mini. All participants scored 70% or higher on this particular test; Most participants commented on the ease of use from the

test and felt their scores seemed accurate. A detailed summary of individual test scores can be found in *Appendix I: Summary of Color Perception Scores.*

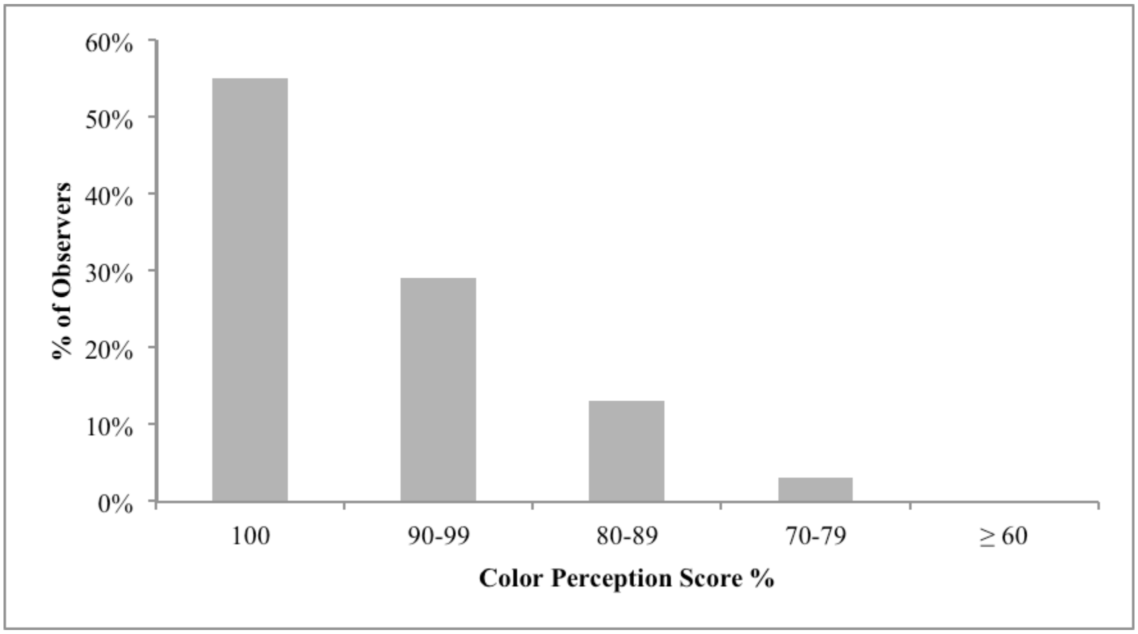

Figure 15: Observer Color Perception Test Score Percentages

Having provided the foundational information, the study now turns to the analysis of specific research objectives.

Analysis of Research Objectives

The present study collected quantitative and qualitative results to satisfy the established research objectives: the primary purpose of which is to analyze salient factors to determine optimal media display preference for HDR imagery which may influence media preference; specifically focusing on image content and image quality attributes.

Qualitative analyses were performed to address media display preference and to provide participants with the ability to express potentially relevant classifications for the respective images. This allows the researcher to examine potential commonalities among the responses. Further, quantitative analyses were utilized to examine respective quality attributes and to describe possible correlations in attribute relationships as applied to image quality of HDR imagery.

Research Objective: Media Preference

The first research objective is to examine respondent output media preference of HDR images between monitor display and inkjet print. This objective is articulated by the research question: "What is the preferred output media of HDR images between monitor display and inkjet prints?".

The present study addresses this objective in both a quantitative and qualitative manner. In the first part of the analysis, participants were asked to compare each printed reproduction to the respective monitor display and choose a level of pleasantness, which determined their preferred display. Subjects rated the print as being either significantly less pleasing, less pleasing, no change, more pleasing, or significantly more pleasing when compared to the monitor display. Results reported here in aggregate indicate that inkjet prints was preferred over the monitor display in 73% of the total responses, whereas in 15% of the cases the monitor display was preferred. Twelve percent indicated no preference. These results are represented graphically in Figure 16.

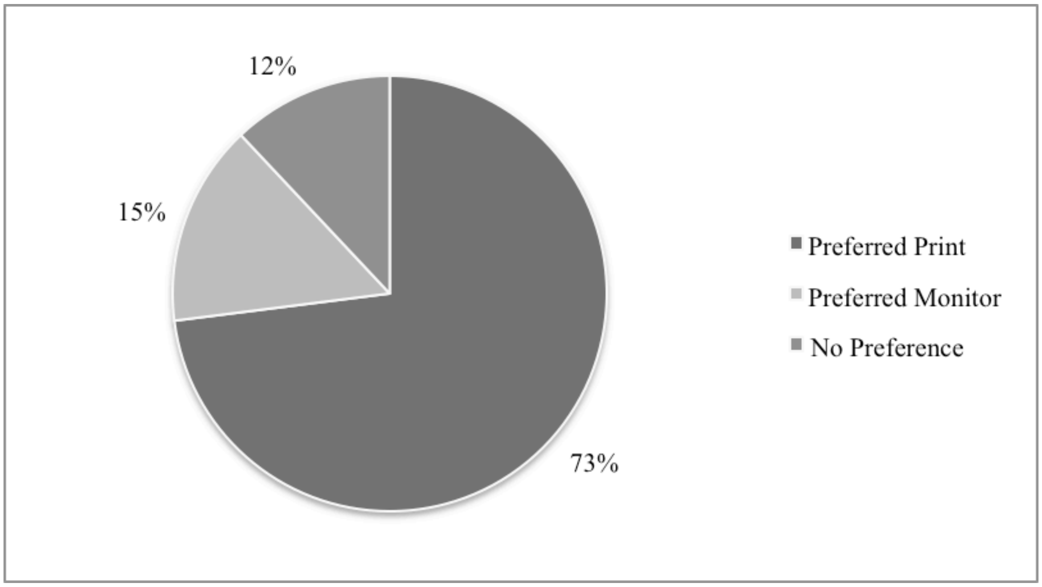

Figure 16: Overall Preferred Output Display for HDR Imagery

This examination of the relationships between the aforementioned variables relied on a subset of 376 of the 380 observed responses where the median display preference was 3.00, with a standard deviation of 0.691 and a variance of 0.478.

In addition to the preferences obtained via analysis of the individual images, each participant was asked, "which display media was most preferred when viewing the HDR images overall?" at the conclusion of the questionnaire. The purpose of this question was to gauge the overall impression of each research participant. The results of this question indicated that 78% stated that they preferred print overall while 22% stated both monitor and print. In comparison with the quantitative analysis of the aggregate of the individual display preferences discussed above, an interesting anomaly is observed. The data suggest that after evaluating all of the images, observers began to change their perception of personal preference, as there is no percentage of observers preferring neither and

finding no change between the display outputs. This observation is consistent with Engledrum's (2000) argument that "the assumption is that preference equal quality, which may not be true" (p. 254). After viewing a large set of stimuli and being exposed to the identifying variables, the literature suggest, and the present findings confirm, observers may shift the criteria by which they judge image quality.

In segmenting observer preference by respondent's gender, the analysis of the data implies that out of the 28 observers to prefer print, majority were men, while out of the 7 observers to have no preference, majority were women. These findings are illustrated in Figure 17. The data does show large variances between gender and media preference, however, due to the relatively small sample size, this particular finding should be viewed as informational rather than statistically significant.

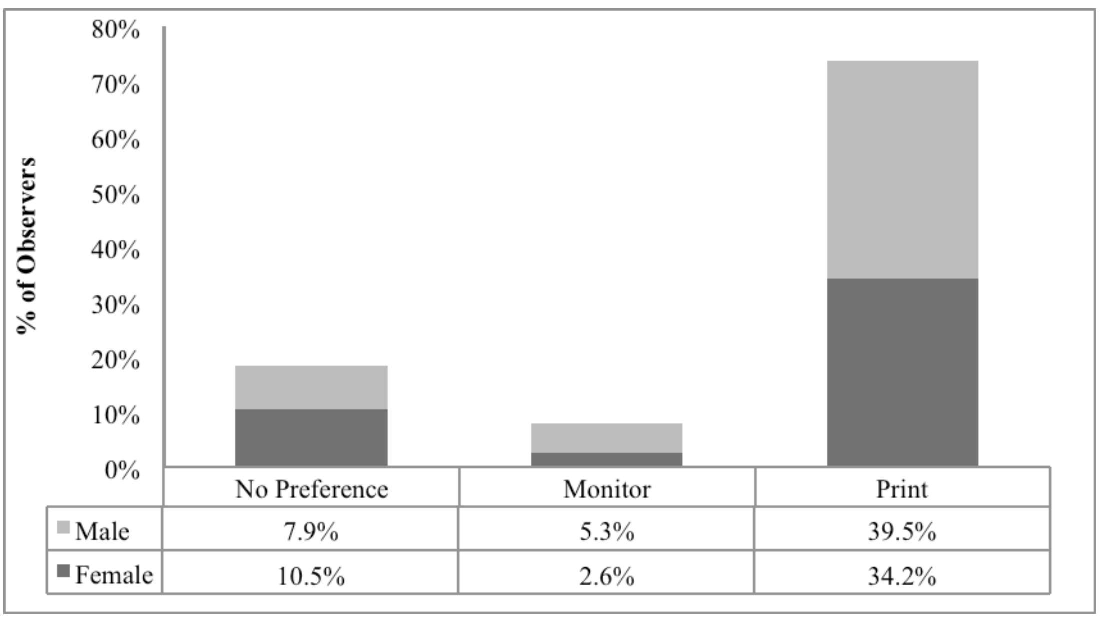

Figure 17: Investigation of observer preference and gender

In order to enhance the quantitative data collection, open-ended qualitative questions were asked of the respondents following their observations of each image pair. Common words used describing the print were: realistic, saturated, dark, warm, intense, clear, unnatural, reflective, grain, smooth, yellow, high-key, distracting, artifacts and distinct. Common words used when describing the monitor were: bright, distorted, tones, real, flaw, blue, cool, detailed, hue, neutral, boring, and typical. One observer argued that the monitor display appeared to him like a "regular image" with "nothing special", but after viewing the printed reproduction stated, "it was a whole different experience". This particular observation is especially interesting as it could suggest that the quality expectations for monitor display are not enhanced by HDR imaging, whereas the benefits of HDR imaging may be best realized when a print is the output.

Trends were discovered about viewing comfort level and feeling derived from image pairs; observers that felt a particular display was difficult or "harsh" to look at, they would simply "opt" for the alternate display. When observers debated between the two displays, more often the media that felt most "natural", and accurate to what they may view themselves, was the media the felt best exhibited the HDR photo. Another factor influencing preference involved prior exposure to the evaluated media. One particular observer stated, "I have a pre-established affiliation for physically printed photographs" and therefore was highly aware in perceived flaws within the monitor display, using them as justification to frequently prefer the printed HDR image. These observations suggest that preference can skew standard objective measures based on the past experiences and preconceived ideas on the part of the viewer. Evidence of preference

based on personal experience or rationale is harmonious with literature investigated in an earlier chapter of this research.

During the experiment, 68% of total observers claimed that the dual display comparison, which utilized both print and monitor, did not hinder their ability to objectively evaluate HDR imagery. Within the remaining 32%, a participant felt that comparing various media could make understanding the effects more complex if there is no drastic visual change.

Research Objective: Content Perception

The second research objective is to analyze the impact of factors within the content of an image on observer display preference for HDR images. This objective is satisfied by the subset question: "How does image content impact the visual perception of HDR imagery?"

The research supports this objective utilizing both quantitative and qualitative measures. Images were first assigned individual classifications based on qualifying criteria; these criteria were not disclosed to the research participants. Subjects were asked to use the preferential rating scale determining media preference, which in turn would signify the optimal media display for each HDR image. Evaluating qualitative data involving open-ended responses, participants used the content of images to describe motives for display preference decisions. Results reported here indicate that content within an image can directly impact display preference decisions. Further, image perception and participant's personal associations with individual images were found to

have strong influence in how the context of images was evaluated per display media. The results are consistent with Hoefflinger's (2007) argument, which states: "individuals perceive real world scenes primarily by content and less by actual changing light. Content can include variables such as objects, contours, texture, color and motion" (p. 8). Additionally, further investigation of qualitative analyses found trends within participants responses contained quality attribute descriptions to explain the content of images regarding preference. This result can signify a supplementary correlation between image content and quality attributes represented within a scene.

Quantitative analysis gives further insight in regard to the impact of image content through the evaluation of response variance and additional descriptive statistical analyses. The evaluation of a box plot, graphically represented in Figure 18, showed the range of preference based on each image used during throughout the study. Image 1, Image 4, Image 5 and Image 7 visually show a large variance between responses. The largest portion of responses can be found to have a print preference when considering the context of HDR images. Results indicate that those select images contained content with varying quality between the two media displays; therefore there was no concise decision among overall observer rating. An additional evaluation was performed upon the outliers present in the analysis, however it was found that there was no consistency between them, suggesting that outliers here cannot be attributed to individual participants.

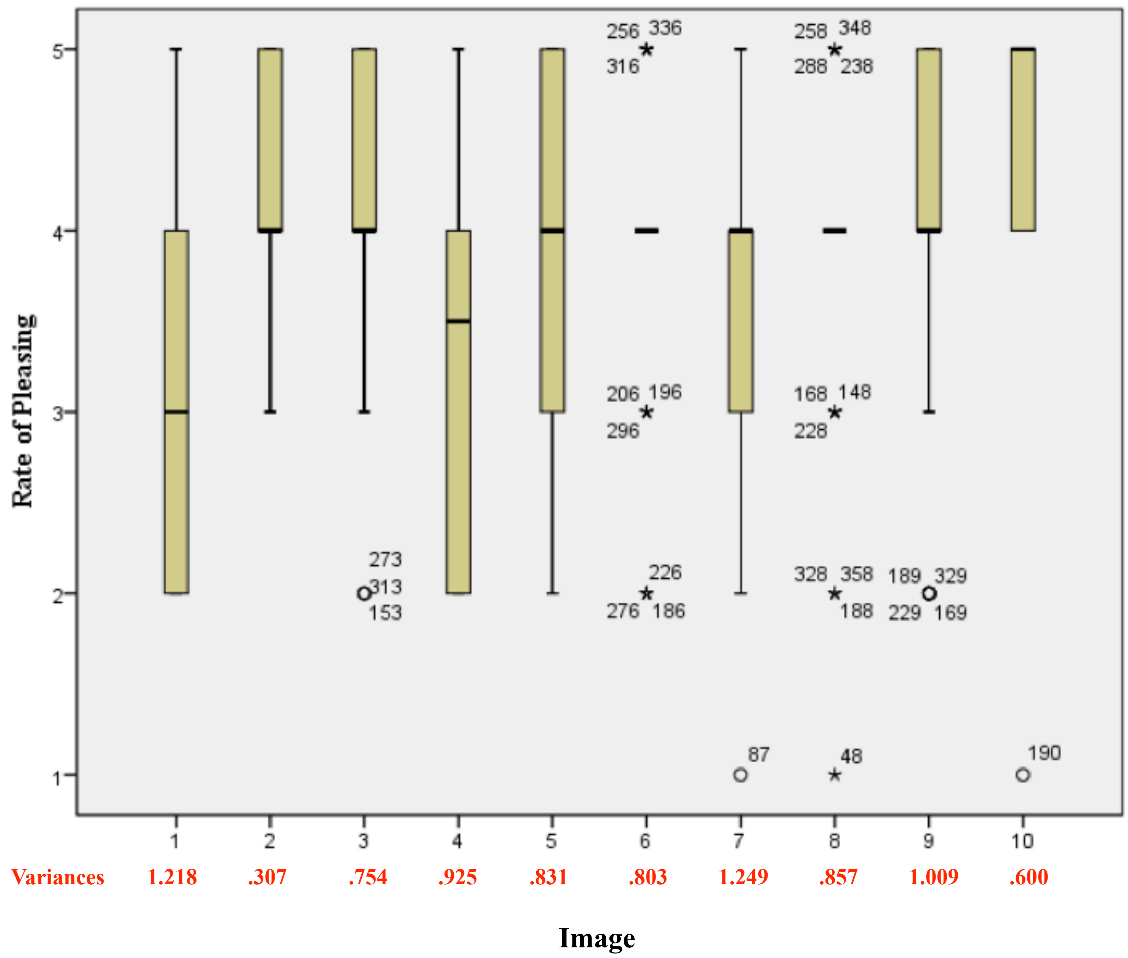

Figure 18: Box plot representing range and variance for image content and pleasing scale. Outliers are represented to show variance within the subjective nature of the variables.

Specific images contained notable characteristics based on the evaluation of variance, median values and qualitative evaluations. The ranked median values and variances for each image can be found in Table 7 and Table 8 respectively.

Image	Median	Variance	Minimum	Maximum	Range
1	3	1.218	2	5	3
2	4	0.307	3	5	2
3	4	0.754	2	5	3
4	3.5	0.925	2	5	3
5	4	0.831	2	5	3
6	4	0.803	2	5	3
7	4	1.249	1	5	4
8	4	0.857	1	5	4
9	4	1.009	2	5	3
10	5	0.600	1	5	4

Table 7: Variance and median evaluations of image content evaluation

Variance	Median	Image	Classification
0.307	4	2	Natural
0.600	5	10	Monotone
0.754	4	3	Variation of Lightness
0.803	4	6	Texture
0.831	4	5	Variation of Color Temperature
0.857	4	8	High Key
0.925	3.5	4	Color Transition
1.009	4	9	Saturation Variation
1.218	3	1	Emphasis
1.249	4	7	Fine Detail

Table 8: Rank order of images, including classifications, based on variance

Results indicated that Image 2 yielded the greater amount of homogeneity in responses: the reported variance here is 0.307. This image had the highest response, with 63.16% of observers selecting the HDR reproduction as more pleasing, with a median value of four. No responses for this sample given were within the lesser preference rating scale. Image two contained comments such as: “fantasy-like” and “vibrant realism”, indicating that if an individual’s perspective draws a parallel with assigned image classification, there is a higher probability of gathering concise results in regard to preference.

Additionally, Image 10 was the highest chosen sample to receive a preference rating of significantly more pleasing, with a median of five, however it was also one of only three times the significantly less pleasing rating was chosen. This image was the only one to rank highest most frequently, with a percentage response of 68.57%. Image ten is unique to the sample because it is the sole monotone image sample. As confirmed by literature, monotone images commonly have distinct tone variations, which was confirmed by participant responses as to the noticeable difference of the image when compared across the two display medias. This commonality can be seen by the low variance of Image 10, graphically represented by Figure 19.

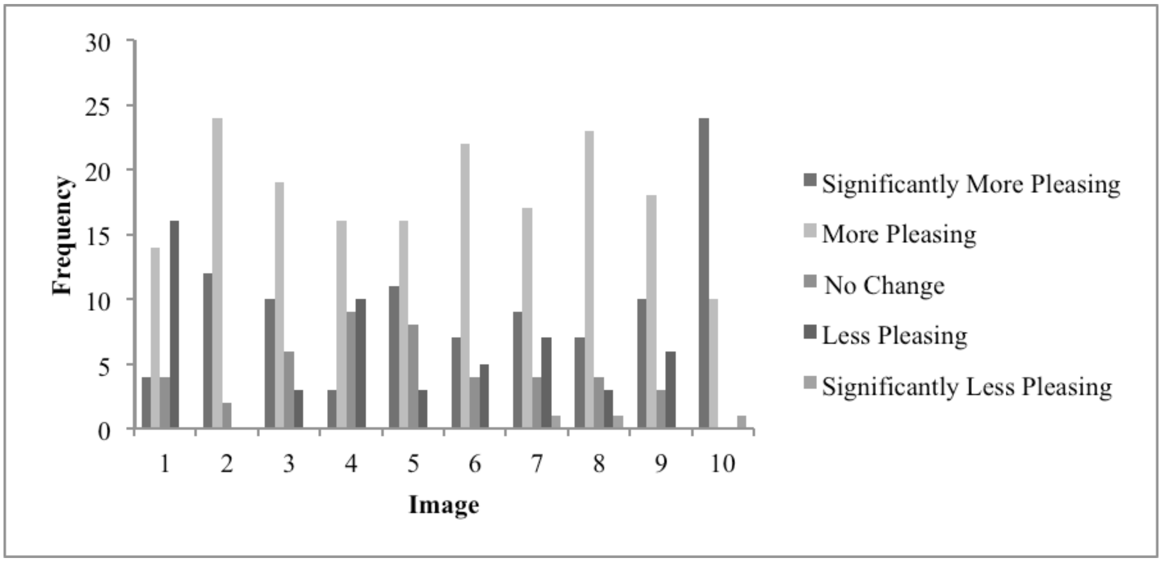

Figure 19: Frequency of Pleasantness by image content

Both Image 1 and Image 7 contained the largest variances based on the evaluation of image content in addition to having the lowest rate of pleasantness. Image 1 was lowest overall, with 42.11% of the observers rating the reproduction as less pleasing then the monitor display. The image yielded median of three with the second highest variance of 1.249. Participants had a variety of responses regarding the colors represented in the image, ranging from enjoyable to unbearable. Participants commonly found divergence within the media displays, which seemed to strongly influence their viewpoint of content. As Image 1 is a representation of primary colors, which are frequently described as "memory colors," the literature suggests there would be differentiating views on content displaying these elements. Image 7 produced the largest range of responses with a 1.249 variance and a median of four. Responses acknowledge subtle differences when comparing the image sample between display media based largely on perceived detail

and clarity. The results suggest that when observers evaluate images using content, tendencies show favoritism towards images that appear "real" and more natural.

Qualitative analyses of observations were congruent with the characteristics associated with the evaluation of images based on the sensitivity to content. Common responses invoked the respondent's experience with "memory colors", consisting of colors individuals are exposed to daily, and therefore invoking judgment regarding the representation of content within images.

> "The print appears more yellow in tone, which is noticeable by looking at the grass, which is not a normal "grass green". The clouds in the back of the image also appear to have better shadow detail in the monitor, and seemed more realistic"

> "The monitor presented a less distracting image. The content of the picture might suppose to be flashy and glitzy. Assuming that is the case, the printed piece accomplishes that feeling much better because of the attention-grabbing colors that draw you in"

> "I prefer the sky in the print because the perspective is very unique"

> "The detail really brought the print to life and created a texture in the image that looks like you could touch it"

In addition to preferences obtained via analysis of image content, each participant was asked, “were there any additional attributes that impacted your evaluation of the HDR images?” at the conclusion of the questionnaire. The purpose of this question was to offer an additional opportunity for participants to provide further insight on their personal viewing experience. Common responses were descriptors such as: “naturalness”, “perspective”, “hue”, “drama”, “perceived reality”, and “clarity”. It was found that images with a higher number of positive criticisms, such as statements about images being “lively and happy” and “vibrant and realistic” received a higher preferred level of pleasantness; while images with conflicting comments about the two displayed images, such as noticeability of the difference within the reproduction when compared to the monitor, received a larger amount of varied responses. Further, participants were asked if any image comparisons were especially challenging to evaluate. An observer said that “the themes of the images were influencing my decision because I prefer nature and landscapes scenes with a lot of color” while a different observer stated, “the black and white image because I always favor images that are black and white” therefore that observer felt that she “scrutinized” the image more. This indicates that personal preference of not only subject matter, but also previous exposure to output methods can be factors influencing viewer preference on media display of photographic images.

Figure 20: Visual display of the ten image samples used throughout the study

Research Objective: Influence of HDR Quality Attributes

The third research objective is to evaluate the influence of HDR quality attributes on display media preference. This objective is addressed by the research question: "Which image quality attributes are most influential when viewing HDR images across different media platforms?"

The study addresses this objective through quantitative analysis utilizing Crosstabs and Chi Square methods based on a 95% level of confidence. For this

particular statistical application, the null hypothesis (H_o) states that there is no relationship between quality attributes and the level of influence in media preference, and the alternative hypothesis (H_a) states that a relationship exists. Participants were asked to indicate the level of influence that nine specified quality attributes had on their media display preference. Subjects rated each attribute has have a strong, lesser or no influence based on their preferred media. Results show that attributes of sharpness, naturalness, contrast and highlights were found to be statistically significant, while color brightness, artifacts, shadows and physical qualities were not shown to be statistically significant.

A further evaluation of attributes to demonstrate the strength of the association using Cramer's V indicated that the attribute sharpness demonstrated the strongest association with media preference with 90.6% of responses indicating that particular attributes influenced their selection. In addition, the attribute next preferred with 90.5% of responses stating their selection was influenced by naturalness. It is important to note, although no statistical significance was found for the attribute of color, 91.5% of observer responses stated that color had an influence on their preferred media display. However, 25% of responses were found to consider color as having no factor on their overall perception of the image. The results suggest the consideration of the subjective evaluation of the paired image comparisons and difference in overall perception. Cramer's V measures for these attributes are graphically represented in descending rank order in Figure 22.

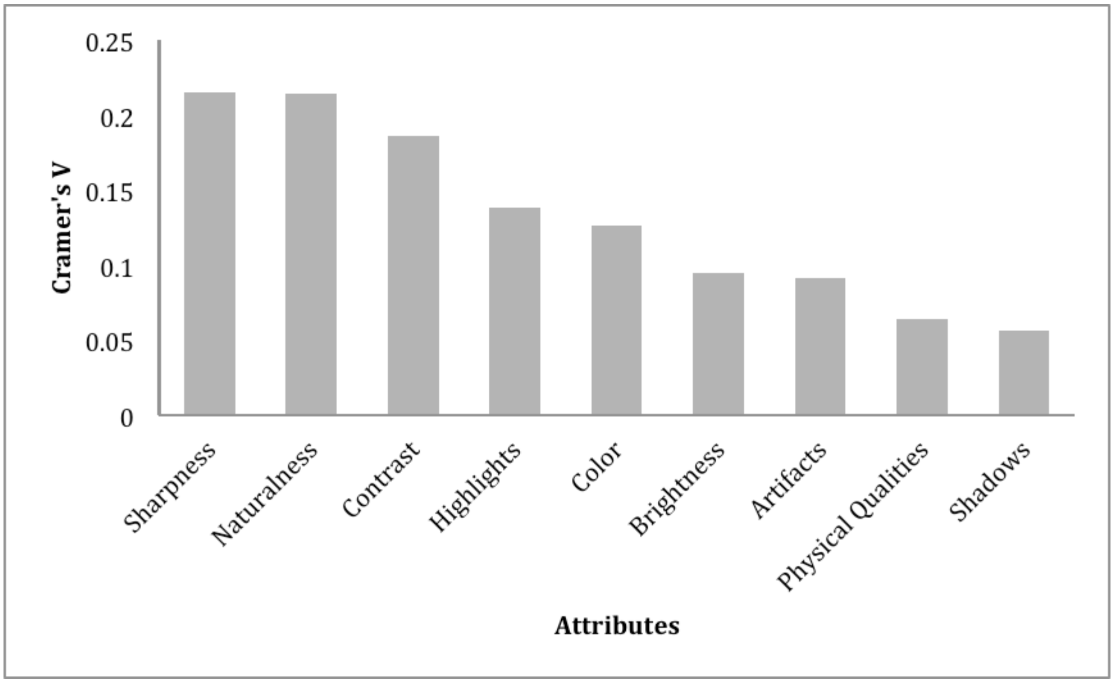

Figure 21: Strength of Association of Quality Attributes with Display Preference based on Cramer's V measure of Association

Rank	Attribute	Cramer's V Strength of Association
1	Sharpness	0.215
2	Naturalness	0.214
3	Contrast	0.186
4	Highlights	0.138
5	Color	0.126
6	Brightness	0.095
7	Artifacts	.091
8	Physical Qualities	.064
9	Shadows	.056

Table 9: Influential attributes ranked by highest association according to Cramer's V values

In addition to the quantitative results, a qualitative evaluation was performed based on responses comprised within each display media; observers preferring inkjet print, monitor and those having no preference. Figure 21 graphically represents these findings.

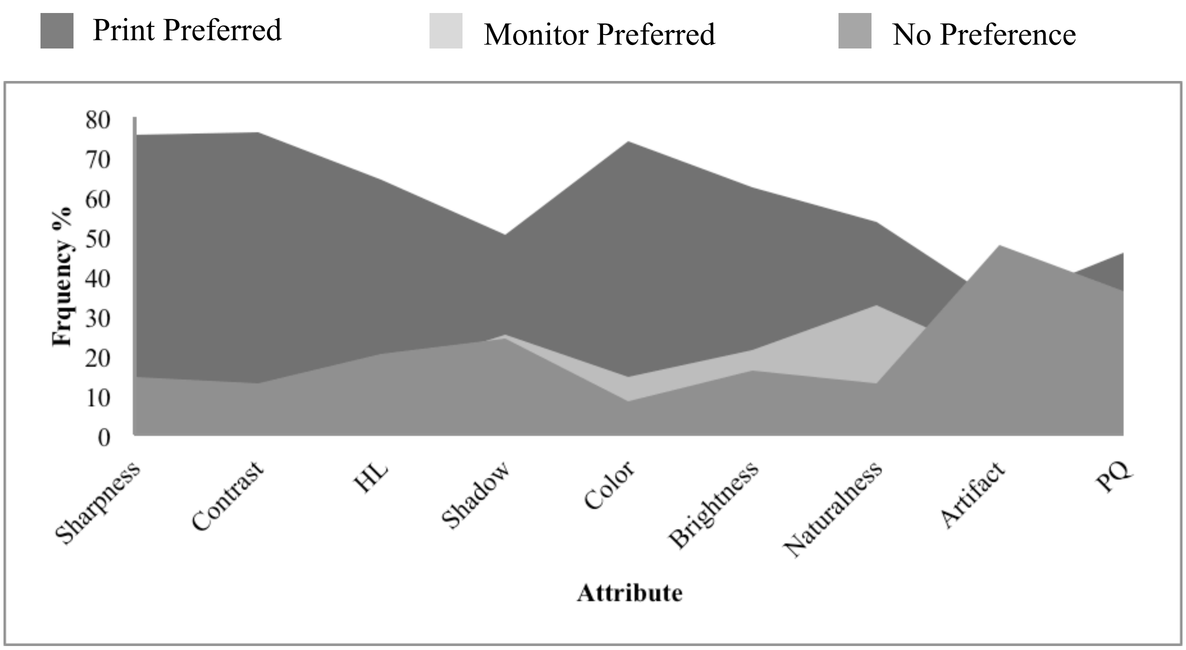

Figure 22:Overall Frequency of the Influence of Image Quality Attributes

This examination of the relationships between the aforementioned variables relied on a subset of 376 of the 380 observed responses, where 331 total responses had a chosen media preference of print or monitor. Results reveal that contrast, sharpness, color and highlights were the most influential attributes to those that preferred the inkjet print. In conjunction, those that preferred the monitor display indicate naturalness, shadows, brightness and artifacts were most influential. The results regarding monitor display preference suggest that the related attributes may have been affected during the necessary

image compression during the preparatory stages for a print output. Therefore, the given attributes were best represented through the display capabilities of the monitor display. Further, attributes commonly found to have no influence, and therefore causing no significant impact on image display preference, consisted of artifacts, physical qualities, shadows and highlights. These results are graphically represented across Figures 23, 24 and 25.

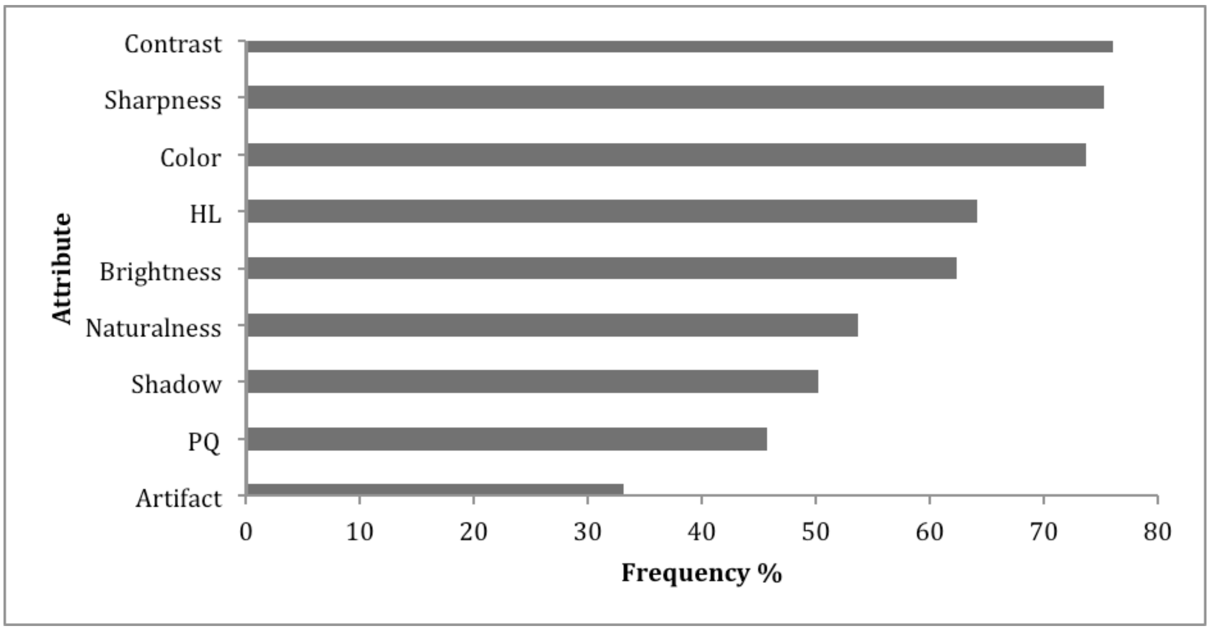

Figure 23: Attributes with a Strong Influence on the Printed Reproduction

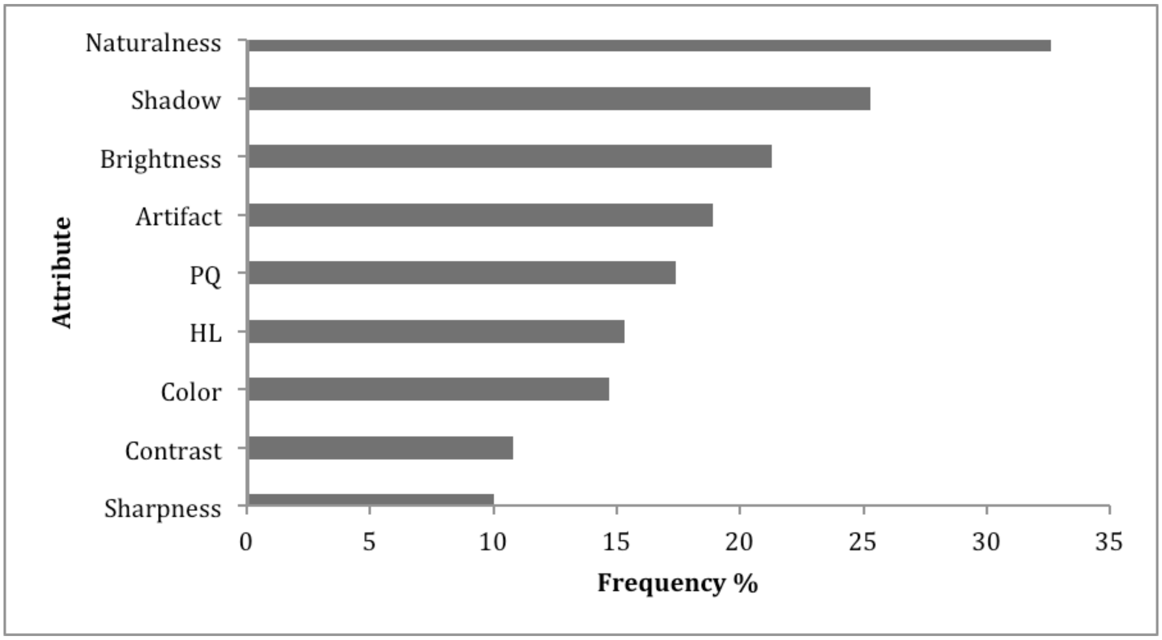

Figure 24: Attributes with Little Influence on the Printed reproduction

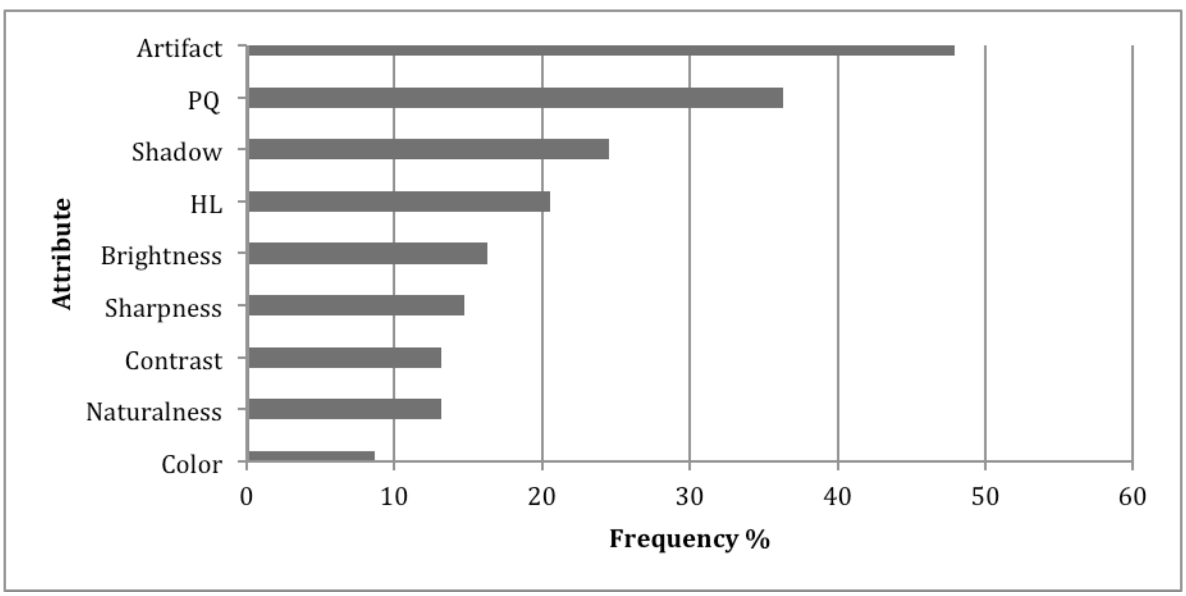

Figure 25: Attributes with No Influence on the Printed Reproduction

After completing all image comparison evaluations, participants were asked to "indicate which attribute(s) you feel had the strongest influence on your overall perception of image quality during the image comparisons" where multiple responses were encouraged. Visual representations of these findings are displayed graphically in Figure 26. Results of this question show color was indicated as having the greatest impact with 25.6% of responses. Observers often commented about a difference in hue, saturation and vibrancy between the two media displays with one observer claiming: "the warm and cool tones of the displays were so diverse that I almost felt I could not fairly compare them." Color was also a factor when observers were asked to if any comparisons were challenging to evaluate. Although preference was most often rewarded to the display that was most vibrant or saturated, the data finds that observers often questioned those characteristics and, in turn, found color to be questionable when basing a decision on reason. Contrast, sharpness and naturalness were also a frequent response by observers with overall frequency percentages greater than 50%. The data support the conclusion that physical qualities were not considered to have any influence on observer response, however investigation of observer response based quantitative analyses shows that physical qualities was acknowledged. These findings further suggest that image perception can be altered based on comparison methods and consistent exposure and awareness to specific image quality attributes.

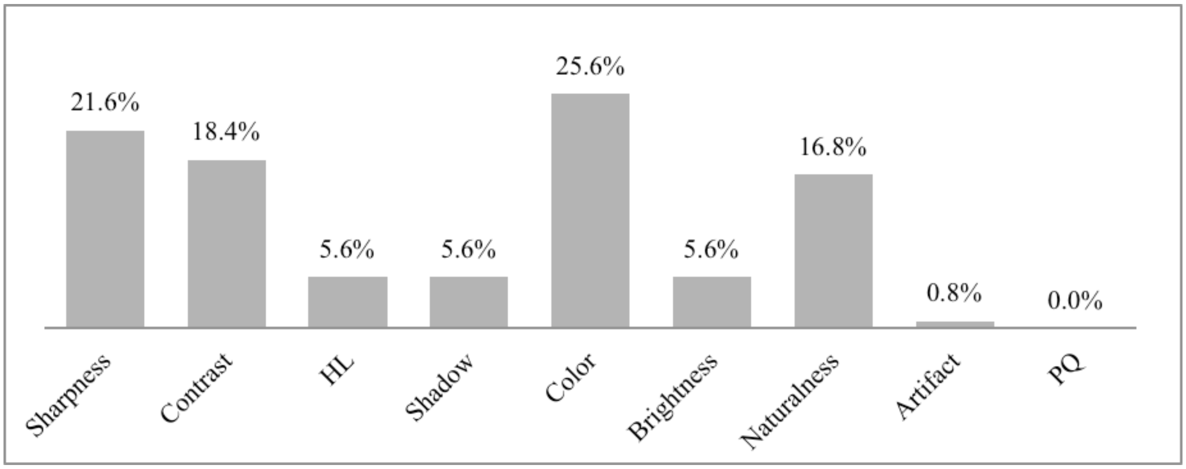

Figure 26: Summary of observer perception on the influence of image qualities

Research Objective: Relationships Among Quality Attributes of HDR Imagery

In order to explore possible correlations among the quality attributes of HDR images in their ability to predict display preference, a quantitative analysis using Kendall Tau-b[3] was conducted. For each attribute pair, the null hypothesis (H_o) is that the Kendall Tau-B value equals zero, and the alternate hypothesis (H_a) is that the Kendall Tau-B value does not equal zero, expressed as: H_o $T_B = 0$, H_a: $T_B \neq 0$. As displayed in the cross-tabulation table in Appendix G, statistically significant relationships are noted between the influences of several pairs of image attributes.

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[3] Kendall Tau-b was selected as process to express correlations for the given data. This process handles nonparametric measures of correlation for ordinal or ranked variables. Kendall Tau-b represents a probability that in the observed data the two variables are in the same order versus the probability that the two variables are in different orders. As a measure of correlation that is less sensitive to outliers than other methods, researchers indicate a preference for Kendall Tau-b versus Spearman rank correlations. For example, Conover (1980) states that the chief advantage of using Kendall's tau is that the distribution of this statistic has slightly better statistical properties other correlation methods.

The results indicate that there is the probability that visual comparisons could occur where the influence of one attribute could lead to a similar influence of other specific attributes present in an image. As a highlight of a specific example, the data suggest that when evaluating an image's quality, if an observer states that the image attribute "contrast" influenced that individuals' opinion of a image quality from a particular media display, there is a likelihood that both highlights ($T_B = 0.217$, $p < 0.001$) and shadows ($T_B = 0.211$, $p < 0.001$) will also influence that individuals' quality assessment. Further results pertaining to significant to relationships among attributes are shown in *Table 10*.

Attributes		Significant Correlation
Sharpness	Contrast	yes
Sharpness	Highlights	yes
Sharpness	Shadows	yes
Sharpness	Color	no
Sharpness	Brightness	yes
Sharpness	Naturalness	yes
Sharpness	Artifacts	no
Sharpness	Physical	no
Contrast	Highlights	yes
Contrast	Shadows	yes
Contrast	Color	yes
Contrast	Brightness	yes
Contrast	Naturalness	no
Contrast	Artifacts	no
Contrast	Physical	yes
Highlights	Shadows	yes
Highlights	Color	yes
Highlights	Brightness	yes
Highlights	Naturalness	yes
Highlights	Artifacts	yes
Highlights	Physical	yes
Shadows	Color	no
Shadows	Brightness	no
Shadows	Naturalness	yes
Shadows	Artifacts	yes
Shadows	Physical	yes
Color	Brightness	yes
Color	Naturalness	yes
Color	Artifacts	no
Color	Physical	yes
Brightness	Naturalness	yes
Brightness	Artifacts	no
Brightness	Physical	yes
Naturalness	Artifacts	yes
Naturalness	Physical	yes
Artifacts	Physical	yes

Table 10: Shaded pair indicate significant relationships among attributes

In judging the results, it was found that artifacts were not significantly related to other attributes. However, artifacts did demonstrate to be correlated with contrast and highlights. This could suggest that artifacts are drawing the attention of an observer only the light and dark areas of an image, further confirming Pedersen's (2010) work where he states: "the observers did not consider artifacts where it did not influence image quality, indicated that artifacts were only considered when they were perceivable or not present in

areas where observers expected to find artifacts" (Pedersen, 2010). Although the results present significant statistical evidence towards pairs of image attributes, additional research would be needed to further evaluate potential attribute multicollinearity in regard to predicting image quality perception.

Chapter 6

Summary and Conclusions

This study aimed to understand display media preferences and the influential characteristics considered for HDR imagery. The conclusions from this research have provided considerable information on various aspects of HDR imagery and subjective measures of image quality, including content and attributes commonly found in photography. Significant findings include:

1.) Inkjet prints were most preferred for the output of HDR images
2.) Based on observer perception, content can directly impact display preference when viewing photographic images
3.) Quality attributes have a strong influence on the evaluation and preference of HDR images across two media platforms; specifically sharpness, naturalness, contrast and highlights
4.) Attributes of HDR have significant associations in groups when evaluating images; however, additional research is needed to draw further conclusions

Preferred Media Display Output

When observers initially stated what media they normally prefer best when viewing photographic images, popularity was given to a monitor screen, with print as a close second. Additionally, observers also felt that monitor screen displays produce the highest quality images compared to other display medias. However, after evaluating

HDR image comparisons across two display medias, the overall preferred media output for displaying HDR imagery was found to be inkjet prints.

An analysis of observers' ratings indicated that the HDR print was found to be between more pleasing and significantly more pleasing for images where there was a noticeable difference between displays. When observers found it difficult to compare, more pleasing was chosen due factors of the viewing experience observers had when viewing a print, such as its apparent physical qualities and tangible nature. However, it was noted that when the monitor display was preferred, it was due to a discrepancy perceived by the inkjet print. During image evaluations, it was found that observers were inclined to first look for significant differences between the two images, rather than evaluate image quality objectively. If the monitor output displayed lesser quality then initial expected, observers would use their expectations as a determinant of preference and image quality. A considerable percentage of observers felt that comparing images across two different display medias hinder their ability to objectively evaluate HDR images.

The printed images were most preferred when observers felt they appeared realistic, saturated and contained warm tones. These subjective evaluations provoked the observer to form attachments with a specific display based and feeling and viewing experience. The monitor images were often described as bright, distorted, and flat. Evaluations for the monitor display have a stronger attachment to the device rather than the experience provided by the image.

The preference and subjectivity of HDR images can be directly affect the way they are perceived based on choice of display. This can be vital information for the graphic and fine arts industries where a value is placed on ability to communicate oneself through media. When preparing images for output, it is a necessity to have basic understanding on the behaviors of selected devices can assist in an accurate workflow in producing high quality images for any household device.

HDR Image Content

The research indicated that the content displayed by has a strong association with how HDR images are visually perceived. Results indicate that image classification (e.g., texture, high-key) were correlated with relevant image quality attributes (e.g.: detail, strong highlights) when considering the overall pleasantness of an image. When there was a noticeable difference involving qualities, such as tone variation, between the two media, the level in which an observer related to the content could be a determinant to how pleasing they found the reproduction to be. Viewers often mixed their analysis of image quality and image content, using one to describe the other inadvertently.

It was noted by the researcher that when an image appeared natural, it received a higher rating of pleasing; however, when an image become uncomfortable to look at or appeared distorted, the level of pleasing would decrease. This particular finding supports a longstanding critique of HDR imaging, namely, that HDR images often appear "unnatural" or "over processed". Observers used context of images to make evaluations, such as the color of grass or the sky or texture in the wood, concluding that an observer's

exposure to content of an image can directly relate to perception and viewing experience. Also, image classification subcategories were often used in additional remarks made about the overall image.

Influence of Image Quality Attributes

Quality attributes found in HDR images that influenced the perception of overall image quality for preferred media displays. An analysis of observer's evaluations indicate that images with noticeable areas of sharpness, naturalness, contrast and highlights were have a strong level of influence on the printed reproduction. Lesser influence was found based on qualities of color, brightness, artifacts, shadows and physical properties. However, the research shows that attributes having lesser influence on the printed reproduction have a strong influence on the monitor display. Viewers were most challenged when asked to evaluate images where there was little noticeable differences between the displays. Results gathered from this evaluation support the selected attributes used for evaluation of HDR photography.

Sharpness was found to have the largest influence on media display, with associations made on how accurate and realistic this particular attribute made the image appear. Color was the most popular influential attribute, however due to the nature of color consisting of a large amount of subjective evaluation; it was not proven to be statistically significant. It was noted by the researcher that attributes that required further explanation to observers, such as artifacts and physical properties, were considered largely to have no influence, however when they were considered it was frequently from

a specific issue noticed about the image. Attributes with the strongest relationship were contrast and highlight details, often influencing each other when evaluating an image. Shadows, artifacts and physical qualities had the least amount of relationships between attributes.

Relationships of note involve that of sharpness and color in addition to contrast and naturalness. Both pairs were found to not be influential to each other with the possibility of each attribute having the ability to deplete the other; however observers directly commented on the impact of color shift on their evaluation of sharpness. Additional data would need to be collected to evaluate accuracy of predicting image quality based on dependent quality attributes.

In conclusion, as indicated in the above summary, the present research adds to a significant body of literature that examines image and quality attributes as related to choice of media display. In limiting the evaluations to HDR imaging, the existing canon is potentially advanced, and a foundation for further research in this domain is provided. In addition to the relevant research community, the results here could also be useful for practitioners and vendors in the HDR imaging field.

Chapter 7

Suggestions for Future Research

With the results and summaries drawn from the research, a foundation was created for a deeper understanding of the evaluation of media displays and the impact on the perception of HDR images and quality attributes. With the fast-paced advancement of technologies and digital formats, a need for further exploration is evident. Suggested areas of research include:

1. An investigation into multicollinearity between image attributes related to the perception of image quality.
2. A similarly executed psychophysical experiment, involving prosumer equipment, using various commercially available fine art substrates for an evaluation of which is perceived to produce the highest quality HDR print.
3. Collaboration of current Image Quality Models to pursue exploratory models for specialized imagery with the intent of discovering alternative variables influencing perceive image quality and the use of attribute relationships to predict overall quality
4. Further investigation into HDR-specific formats, such as OpenEXR, and their practical use as a prosumer standard

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Appendix A

Experiment Survey

Demographics

1.) What is your gender?

2.) What is your age range?
- •18-21
- •22-25
- •26-35
- •36=50
- •>50

3.) What school are you affiliated with?
- •School of Media Sciences
- •School of Photographic Arts and Sciences
- •School of Design
- •School of Film and Animation
- •Other:______________________________

4.) What is your year level?
- •1st/2nd
- •3rd.4th
- •Graduate
- •Alumni
- •Faculty/Staff

5.) Have you ever seen, heard of, or experimented with HDR (High Dynamic Range) imagery in your lifetime?
- •No
- •Yes → (Branch Question) How many times would you say you have seen, heard of or experimented with HDR imagery?
  - •1-2 times
  - •3-5 times
  - •6-10 times
  - •11-15 times
  - •More than 15 times

6.) When viewing photographic images, which of the following medias do you PREFER BEST?

- •Monitor Screen
- •Printed Hard Copy
- •Tablet Device
- •Smart Phone/Mobile Device
- •None of the Above

7.) When viewing photographic images, which of the following medias do you feel displays the HIGHEST QUALITY images?

- •Monitor Screen
- •Printed Hard Copy
- •Tablet Device
- •Smart Phone/Mobile Device
- •None of the Above

Color Perception Test

8.) Please enter the score you receive out of 100%:

Image Comparisons

9.) Please view the two displayed images. Compared to the monitor display, the printed reproduction is:

5 : Significantly More Pleasing
4 : More Pleasing
3 : No Change
2 : Less Pleasing
1 : Significantly Less Pleasing

10.) Compare the print to the monitor. Please indicate the level of influence the following image attributes had on your opinion of the printed reproduction's quality:

Qualities Given	Influence Levels Provided
•Sharpness	• Strong (Favored the Print)
•Contrast	• Lesser/Weak (Favored the Monitor)
•Highlight Details	• No Influence
•Shadow Details	
•Color	
•Brightness	
•Naturalness	
•Artifacts	

•Physical Qualities

11.) Optional: Please list any further comments or observations for this image pairing

Note: the same set of three questions were used for each of the 10 image comparison pairs

Concluding Questions

12.) Please indicate which attribute(s) you feel had the strongest influence on your overall perception of image quality during the comparisons (more then one answer is acceptable)

•Sharpness
•Contrast
•Highlight Details
•Shadow Details
•Color
•Brightness
•Naturalness
•Artifacts
•Physical Qualities

13.) Were there any additional attributes that impacted your evaluation of the images?

14.) Did you feel that comparing images through two different medias (monitor screen and print) hindered your ability to objectively evaluate the images?

15.) Were any image comparisons especially challenge to evaluate?

Do you feel the length of this experiment was adequate to understand and complete all questions?

Appendix B

Accessible Definitions for Observers During the Experiment

WHAT IS..

SHARPNESS: Clarity of details & definition of edges within the image.

CONTRAST: The difference in brightness and/or color that can make objects appear more distinguishable or defined.

HIGHLIGHT DETAILS: Richness in details of the bright areas of an image.

SHADOW DETAILS: Richness in details of the dark areas of an image.

COLOR: Including all aspects of how you perceive color. This does **NOT** include brightness.
Example// Hue, Saturation, Color Rendition, etc.

BRIGHTNESS: Overall lightness of an image ranging from "light" to "dark".

NATURALNESS: How the image best represents the scene as you would commit it to memory.
Example// How accurate objects & colors appear (Blue Sky, Green Grass)

ARTIFACTS: Attributes that can degrade the quality of an image if they are detectable within the final displayed image. These can usually occuring during image processing and output.
Example// Noise, Contouring, Banding, etc.

PHYSICAL QUALITIES: All physical parameters that affect quality.
Example// Paper Properities, Gloss, etc.

Examples given may not include all possible options

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Appendix C

Image Samples and Metadata

Image 1
Metadata: Canon 5DmkII, 20mm lens, ISO 160, 1/20 sec., f/16, Scottsville, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Image 2
Metadata: Canon 5DmkII, 20mm lens, ISO 200, 1/160 sec., f/18, Scottsville, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Image 3

Metadata: Canon 5DmkII, 20mm lens, ISO 400, 0.8 sec., f/20, Rochester, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Image 4

Metadata: Canon 5DmkII, 20mm lens, ISO 600, 1/250 sec., f/8, Leicester, VT

Underexposed

Normal

Overexposed

Tone Mapped 16-Bit HDR

Final Image

Image 5
Metadata: Canon 5DmkII, 20mm lens, ISO 200, 1/20 sec., f/2.8, Rochester, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Image 6

Metadata: Canon 5DmkII, 20mm lens, ISO 100, 0.4 sec., f/16, Albion, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Image 7

Metadata: Canon 5DmkII, 20mm lens, ISO 100, 1/160 sec., f/8, Albion, NY

Underexposed

Normal

Overexposed

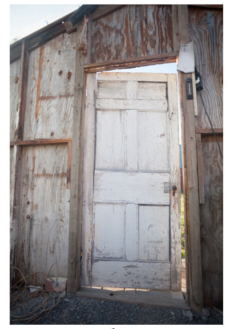
Tone Mapped 16-Bit HDR

Final Image

Image 8
Metadata: Canon 5DmkII, 20mm lens, ISO 100, 1/250 sec., f/4, Albion, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Image 9
Metadata: Canon 5DmkII, 20mm lens, ISO 400, 1/320 sec., f/4, Rochester, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Image 10
Metadata: Canon 5DmkII, 20mm lens, ISO 400, 1/10 sec., f/8, Buffalo, NY


Underexposed


Normal


Overexposed


Tone Mapped 16-Bit HDR


Final Image

Appendix D

Statistical Analysis of Media Preference Based on Pleasing Rating

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Media Preferred	376	1	3	2.61	.691	.478
Valid N (listwise)	376					

Statistics

Media Preferred

N	Valid	376
	Missing	4
Mean		2.61
Median		3.00
Mode		3
Std. Deviation		.691
Variance		.478

Media Preferred

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No Preference	45	11.8	12.0	12.0
	Monitor	56	14.7	14.9	26.9
	Print	275	72.4	73.1	100.0
	Total	376	98.9	100.0	
Missing	System	4	1.1		
Total		380	100.0		

Appendix E

Statistical Analysis of Image Content on Media Preference

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Media Preferred	376	1	3	2.61	.691
Sharpness	380	1	2	1.85	.355
Contrast	380	1	2	1.87	.338
Highlights	380	1	2	1.79	.404
Shadows	380	1	2	1.76	.430
Color	379	1	2	1.91	.282
Brightness	380	1	2	1.84	.370
Naturalness	378	1	2	1.87	.339
Artifacts	380	1	2	1.52	.500
Physical	378	1	2	1.63	.482
Valid N (listwise)	371				

Appendix F

Crosstabulation and Chi Square Analysis of the Influence of Quality Attributes on Media Preference

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Media Preferred	376	1	3	2.61	.691
Sharpness	380	1	2	1.85	.355
Contrast	380	1	2	1.87	.338
Highlights	380	1	2	1.79	.404
Shadows	380	1	2	1.76	.430
Color	379	1	2	1.91	.282
Brightness	380	1	2	1.84	.370
Naturalness	378	1	2	1.87	.339
Artifacts	380	1	2	1.52	.500
Physical	378	1	2	1.63	.482
Valid N (listwise)	371				

Sharpness

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Sharpness	No Influence	Count	15	11	29	55
		Expected Count	6.6	8.2	40.2	55.0
		% within Sharpness	27.3%	20.0%	52.7%	100.0%
		% within Media Preferred	33.3%	19.6%	10.5%	14.6%
		% of Total	4.0%	2.9%	7.7%	14.6%
	Media Influence	Count	30	45	246	321
		Expected Count	38.4	47.8	234.8	321.0
		% within Sharpness	9.3%	14.0%	76.6%	100.0%
		% within Media Preferred	66.7%	80.4%	89.5%	85.4%
		% of Total	8.0%	12.0%	65.4%	85.4%
Total		Count	45	56	275	376
		Expected Count	45.0	56.0	275.0	376.0
		% within Sharpness	12.0%	14.9%	73.1%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	14.9%	73.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	17.406[a]	2	.000
Likelihood Ratio	14.909	2	.001
Linear-by-Linear Association	17.187	1	.000
N of Valid Cases	376		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.58.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.215			.000
	Cramer's V	.215			.000
Interval by Interval	Pearson's R	.214	.061	4.238	.000[c]
Ordinal by Ordinal	Spearman Correlation	.204	.059	4.024	.000[c]
N of Valid Cases		376			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of sharpness and media preference. All expected cell frequencies were greater than five where the minimum expected count was 6.58. It was found that there was a statistically significant association between sharpness and media preference, x2(2)=17.406, P=.000, where a strong level of association existed, φc=.215, p=.000. Based on a 95% confidence level, the null hypothesis was rejected in favor of the alternative.

Contrast

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Contrast	No Influence	Count	13	9	27	49
		Expected Count	5.9	7.3	35.8	49.0
		% within Contrast	26.5%	18.4%	55.1%	100.0%
		% within Media Preferred	28.9%	16.1%	9.8%	13.0%
		% of Total	3.5%	2.4%	7.2%	13.0%
	Media Influence	Count	32	47	248	327
		Expected Count	39.1	48.7	239.2	327.0
		% within Contrast	9.8%	14.4%	75.8%	100.0%
		% within Media Preferred	71.1%	83.9%	90.2%	87.0%
		% of Total	8.5%	12.5%	66.0%	87.0%
Total		Count	45	56	275	376
		Expected Count	45.0	56.0	275.0	376.0
		% within Contrast	12.0%	14.9%	73.1%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	14.9%	73.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.946[a]	2	.002
Likelihood Ratio	10.951	2	.004
Linear-by-Linear Association	12.522	1	.000
N of Valid Cases	376		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.86.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.186			.002
	Cramer's V	.186			.002
Interval by Interval	Pearson's R	.183	.062	3.594	.000[c]
Ordinal by Ordinal	Spearman Correlation	.171	.059	3.352	.001[c]
N of Valid Cases		376			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of contrast and media preference. All expected cell frequencies were greater than five where the minimum expected count was 5.86. It was found that there was a statistically significant association between contrast and media preference, x2(2)=12.94, P=.002, where a strong level of association existed, φc=.186, p=.002. Based on a 95% confidence level, the null hypothesis was rejected in favor of the alternative

Highlights

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Highlights	No Influence	Count	16	12	50	78
		Expected Count	9.3	11.6	57.0	78.0
		% within Highlights	20.5%	15.4%	64.1%	100.0%
		% within Media Preferred	35.6%	21.4%	18.2%	20.7%
		% of Total	4.3%	3.2%	13.3%	20.7%
	Media Influence	Count	29	44	225	298
		Expected Count	35.7	44.4	218.0	298.0
		% within Highlights	9.7%	14.8%	75.5%	100.0%
		% within Media Preferred	64.4%	78.6%	81.8%	79.3%
		% of Total	7.7%	11.7%	59.8%	79.3%
Total		Count	45	56	275	376
		Expected Count	45.0	56.0	275.0	376.0
		% within Highlights	12.0%	14.9%	73.1%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	14.9%	73.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.119[a]	2	.028
Likelihood Ratio	6.394	2	.041
Linear-by-Linear Association	6.361	1	.012
N of Valid Cases	376		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.34.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.138			.028
	Cramer's V	.138			.028
Interval by Interval	Pearson's R	.130	.057	2.540	.011[c]
Ordinal by Ordinal	Spearman Correlation	.117	.056	2.276	.023[c]
N of Valid Cases		376			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of highlights and media preference. All expected cell frequencies were greater than five where the minimum expected count was 9.34.It was found that there was a statistically significant association between highlights and media preference, x2(2)=7.11, P=.028, where a moderate level of association existed, φc=.138, p=.028. Based on a 95% confidence level, the null hypothesis was rejected in favor of the alternative.

Shadows

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Shadows	No Influence	Count	14	14	65	93
		Expected Count	11.1	13.9	68.0	93.0
		% within Shadows	15.1%	15.1%	69.9%	100.0%
		% within Media Preferred	31.1%	25.0%	23.6%	24.7%
		% of Total	3.7%	3.7%	17.3%	24.7%
	Media Influence	Count	31	42	210	283
		Expected Count	33.9	42.1	207.0	283.0
		% within Shadows	11.0%	14.8%	74.2%	100.0%
		% within Media Preferred	68.9%	75.0%	76.4%	75.3%
		% of Total	8.2%	11.2%	55.9%	75.3%
Total		Count	45	56	275	376
		Expected Count	45.0	56.0	275.0	376.0
		% within Shadows	12.0%	14.9%	73.1%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	14.9%	73.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.163[a]	2	.559
Likelihood Ratio	1.116	2	.572
Linear-by-Linear Association	1.036	1	.309
N of Valid Cases	376		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.13.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.056			.559
	Cramer's V	.056			.559
Interval by Interval	Pearson's R	.053	.054	1.018	.309[c]
Ordinal by Ordinal	Spearman Correlation	.047	.053	.912	.362[c]
N of Valid Cases		376			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of shadows and media preference. All expected cell frequencies were greater than five where the minimum expected count was 11.13.It was found that there was not a statistically significant association between shadows and media preference, x2(2)=1.16, P=.559.. Based on a 95% confidence level, there was failure to reject the null hypothesis.

Color

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Color	No Influence	Count	8	3	21	32
		Expected Count	3.8	4.8	23.4	32.0
		% within Color	25.0%	9.4%	65.6%	100.0%
		% within Media Preferred	17.8%	5.4%	7.7%	8.5%
		% of Total	2.1%	0.8%	5.6%	8.5%
	Media Influence	Count	37	53	253	343
		Expected Count	41.2	51.2	250.6	343.0
		% within Color	10.8%	15.5%	73.8%	100.0%
		% within Media Preferred	82.2%	94.6%	92.3%	91.5%
		% of Total	9.9%	14.1%	67.5%	91.5%
Total		Count	45	56	274	375
		Expected Count	45.0	56.0	274.0	375.0
		% within Color	12.0%	14.9%	73.1%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	14.9%	73.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.916[a]	2	.052
Likelihood Ratio	4.958	2	.084
Linear-by-Linear Association	3.052	1	.081
N of Valid Cases	375		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 3.84.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.126			.052
	Cramer's V	.126			.052
Interval by Interval	Pearson's R	.090	.063	1.752	.081[c]
Ordinal by Ordinal	Spearman Correlation	.068	.059	1.323	.187[c]
N of Valid Cases		375			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of color and media preference. Two cell frequencies had an expected count less than five where the minimum expected count was 3.84. It was found that there was not a statistically significant association between color and media preference, x2(2)=5.916, P=.052. Based on a 95% confidence level, there was failure to reject the null hypothesis.

Brightness

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Brightness	No Influence	Count	11	6	45	62
		Expected Count	7.4	9.2	45.3	62.0
		% within Brightness	17.7%	9.7%	72.6%	100.0%
		% within Media Preferred	24.4%	10.7%	16.4%	16.5%
		% of Total	2.9%	1.6%	12.0%	16.5%
	Media Influence	Count	34	50	230	314
		Expected Count	37.6	46.8	229.7	314.0
		% within Brightness	10.8%	15.9%	73.2%	100.0%
		% within Media Preferred	75.6%	89.3%	83.6%	83.5%
		% of Total	9.0%	13.3%	61.2%	83.5%
Total		Count	45	56	275	376
		Expected Count	45.0	56.0	275.0	376.0
		% within Brightness	12.0%	14.9%	73.1%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	14.9%	73.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.427[a]	2	.180
Likelihood Ratio	3.370	2	.185
Linear-by-Linear Association	.622	1	.430
N of Valid Cases	376		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.42.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.095			.180
	Cramer's V	.095			.180
Interval by Interval	Pearson's R	.041	.057	.789	.431[c]
Ordinal by Ordinal	Spearman Correlation	.020	.054	.391	.696[c]
N of Valid Cases		376			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of brightness and media preference. All expected cell frequencies were greater than five where the minimum expected count was 7.42. It was found that there was not a statistically significant association between brightness and media preference, x2(2)=3.427, P=.180. Based on a 95% confidence level, there was failure to reject the null hypothesis.

Naturalness

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Naturalness	No Influence	Count	14	2	34	50
		Expected Count	6.0	7.5	36.5	50.0
		% within Naturalness	28.0%	4.0%	68.0%	100.0%
		% within Media Preferred	31.1%	3.6%	12.5%	13.4%
		% of Total	3.7%	0.5%	9.1%	13.4%
	Media Influence	Count	31	54	239	324
		Expected Count	39.0	48.5	236.5	324.0
		% within Naturalness	9.6%	16.7%	73.8%	100.0%
		% within Media Preferred	68.9%	96.4%	87.5%	86.6%
		% of Total	8.3%	14.4%	63.9%	86.6%
Total		Count	45	56	273	374
		Expected Count	45.0	56.0	273.0	374.0
		% within Naturalness	12.0%	15.0%	73.0%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	15.0%	73.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	17.069[a]	2	.000
Likelihood Ratio	15.934	2	.000
Linear-by-Linear Association	5.285	1	.022
N of Valid Cases	374		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.02.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.214			.000
	Cramer's V	.214			.000
Interval by Interval	Pearson's R	.119	.064	2.312	.021[c]
Ordinal by Ordinal	Spearman Correlation	.076	.059	1.472	.142[c]
N of Valid Cases		374			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of naturalness and media preference. All expected cell frequencies were greater than five where the minimum expected count was 6.02. It was found that there was a statistically significant association between naturalness and media preference, x2(2)=17.06, P=.000, where a strong level of association existed, φc=.214, p=.000. Based on a 95% confidence level, the null hypothesis was rejected in favor of the alternative.

Artifacts

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Artifacts	No Influence	Count	26	30	125	181
		Expected Count	21.7	27.0	132.4	181.0
		% within Artifacts	14.4%	16.6%	69.1%	100.0%
		% within Media Preferred	57.8%	53.6%	45.5%	48.1%
		% of Total	6.9%	8.0%	33.2%	48.1%
	Media Influence	Count	19	26	150	195
		Expected Count	23.3	29.0	142.6	195.0
		% within Artifacts	9.7%	13.3%	76.9%	100.0%
		% within Media Preferred	42.2%	46.4%	54.5%	51.9%
		% of Total	5.1%	6.9%	39.9%	51.9%
Total		Count	45	56	275	376
		Expected Count	45.0	56.0	275.0	376.0
		% within Artifacts	12.0%	14.9%	73.1%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	14.9%	73.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.130[a]	2	.209
Likelihood Ratio	3.134	2	.209
Linear-by-Linear Association	3.059	1	.080
N of Valid Cases	376		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 21.66.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.091			.209
	Cramer's V	.091			.209
Interval by Interval	Pearson's R	.090	.051	1.754	.080[c]
Ordinal by Ordinal	Spearman Correlation	.091	.051	1.766	.078[c]
N of Valid Cases		376			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of artifacts and media preference. All expected cell frequencies were greater than five where the minimum expected count was 21.66. It was found that there was not a statistically significant association between artifacts and media preference, x2(2)=3.13, P=.209, where a strong level of association existed, φc=.215, p=.000. Based on a 95% confidence level, there was failure to reject the null hypothesis.

Physical Qualities

Crosstab

			Media Preferred			Total
			No Preference	Monitor	Print	
Physical	No Influence	Count	18	24	95	137
		Expected Count	16.5	20.5	100.0	137.0
		% within Physical	13.1%	17.5%	69.3%	100.0%
		% within Media Preferred	40.0%	42.9%	34.8%	36.6%
		% of Total	4.8%	6.4%	25.4%	36.6%
	Media Influence	Count	27	32	178	237
		Expected Count	28.5	35.5	173.0	237.0
		% within Physical	11.4%	13.5%	75.1%	100.0%
		% within Media Preferred	60.0%	57.1%	65.2%	63.4%
		% of Total	7.2%	8.6%	47.6%	63.4%
Total		Count	45	56	273	374
		Expected Count	45.0	56.0	273.0	374.0
		% within Physical	12.0%	15.0%	73.0%	100.0%
		% within Media Preferred	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	15.0%	73.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.550[a]	2	.461
Likelihood Ratio	1.531	2	.465
Linear-by-Linear Association	1.020	1	.313
N of Valid Cases	374		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 16.48.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Nominal by Nominal	Phi	.064			.461
	Cramer's V	.064			.461
Interval by Interval	Pearson's R	.052	.052	1.010	.313[c]
Ordinal by Ordinal	Spearman Correlation	.059	.052	1.148	.252[c]
N of Valid Cases		374			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Ho: No influence of attribute

Ha: Influence of attribute

A Chi-square test for association was conduct between influence of physical qualities and media preference. All expected cell frequencies were greater than five where the minimum expected count was 16.48. It was found that there was not a statistically significant association between physical qualities and media preference, x2(2)=1.55, P=.461.. Based on a 95% confidence level, there was failure to reject the null hypothesis.

Appendix G

Kendall Tau B Analysis of Relationships Among Quality Attributes

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Sharpness	380	1	2	1.85	.355
Contrast	380	1	2	1.87	.338
Highlights	380	1	2	1.79	.404
Shadows	380	1	2	1.76	.430
Color	379	1	2	1.91	.282
Brightness	380	1	2	1.84	.370
Naturalness	378	1	2	1.87	.339
Artifacts	380	1	2	1.52	.500
Physical	378	1	2	1.63	.482
Valid N (listwise)	375				

Kendall's tau_b	Sharpness	Correlation Coefficient	1.000								
		Sig. (2-tailed)	.								
		N	380								
	Contrast	Correlation Coefficient	.321**	1.000							
		Sig. (2-tailed)	.000	.							
		N	380	380							
	Highlights	Correlation Coefficient	.211**	.265**	1.000						
		Sig. (2-tailed)	.000	.000	.						
		N	380	380	380						
	Shadows	Correlation Coefficient	.212**	.249**	.408**	1.000					
		Sig. (2-tailed)	.000	.000	.000	.					
		N	380	380	380	380					
	Color	Correlation Coefficient	.003	.101*	.144**	.041	1.000				
		Sig. (2-tailed)	.949	.050	.005	.421	.				
		N	379	379	379	379	379				
	Brightness	Correlation Coefficient	.178**	.102*	.199**	.146**	.167**	1.000			
		Sig. (2-tailed)	.001	.047	.000	.004	.001	.			
		N	380	380	380	380	379	380			
	Naturalness	Correlation Coefficient	.233**	.170**	.264**	.270**	.294**	.291**	1.000		
		Sig. (2-tailed)	.000	.001	.000	.000	.000	.000	.		
		N	378	378	378	378	377	378	378		
	Artifacts	Correlation Coefficient	.107*	.079	.139**	.177**	.022	.190**	.077	1.000	
		Sig. (2-tailed)	.038	.125	.007	.001	.675	.000	.135	.	
		N	380	380	380	380	379	380	378	380	
	Physical	Correlation Coefficient	.148**	.126*	.211**	.210**	.174**	.124*	.197**	.267**	1.000
		Sig. (2-tailed)	.004	.015	.000	.000	.001	.016	.000	.000	.
		N	378	378	378	378	377	378	376	378	378

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix H

Summary of Substrate Characteristics and Recommendations

Product and Recommendations provided by Red River Paper	
Supplier	Red River Paper
Label	Polar Pearl Metallic
Weight	66 lb. (255gsm)
Thickness	10.4mil (.014”)
Media Type	Photobase RC
Coating	Microporous
Surface	Pearlescent Reflective
Printable	Glossy Side
OBA	Low OBA paper
Back	Not printable
Available Sizes	4x6, 5x7, 8x10, 8.5x11, 11x14, 12x12, 11x17, 13x19, 16x20, 17x22, 17x25, Rolls
Recommended Print Driver Settings	For Epson Printer: Premium Glossy Photo Paper or Ultra-Premium Photo Paper Gloss
Print Quality Setting Recommendations	For Epson Printer: Best Photo or 1440dpi Quality
High Speed Printing Recommendations	Leave High Speed Turned OFF for Best Possible Print Quality

Appendix I

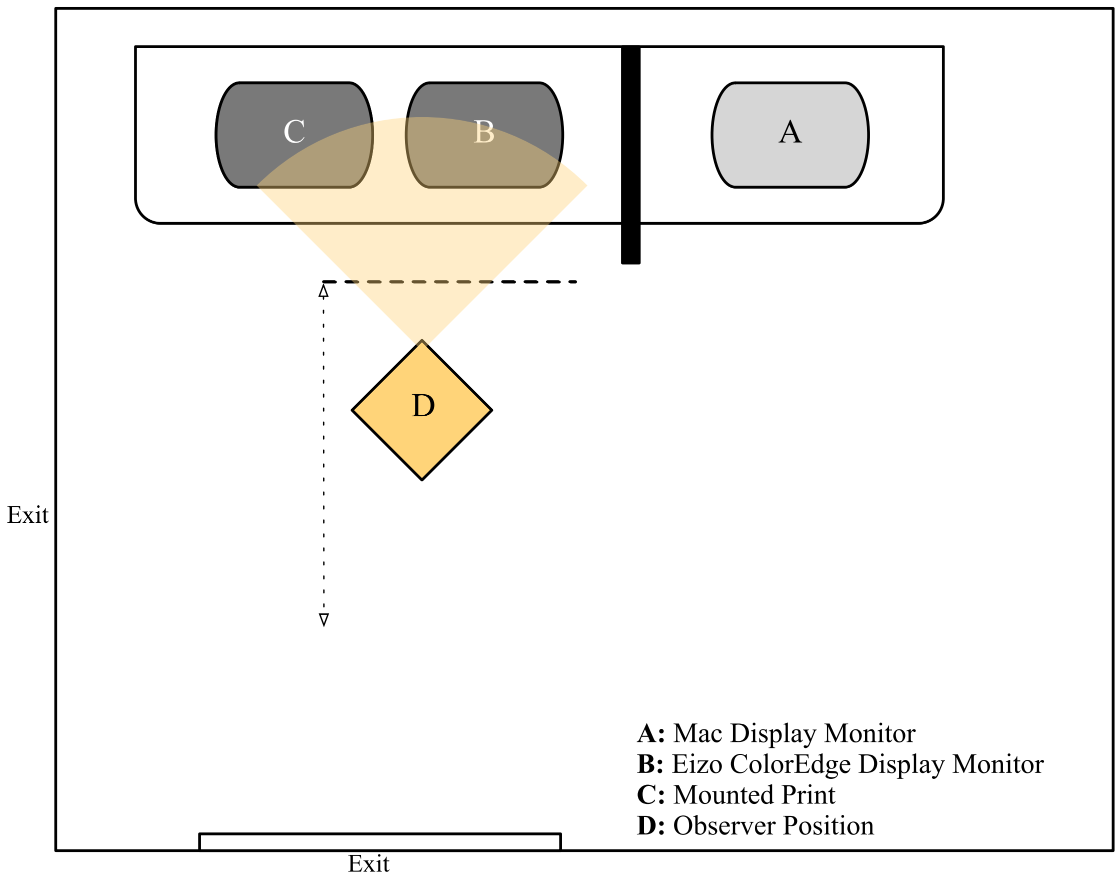
Summary of Color Perception Scores

Observer ID	Score Percent	Evaluation
1	100	Good
2	100	Good
3	92	Good
4	100	Good
5	100	Good
6	80	Okay
7	100	Good
8	88	Good
9	88	Good
10	100	Good
11	96	Good
12	100	Good
13	96	Good
14	96	Good
15	100	Good
16	100	Good
17	100	Good
18	100	Good
19	100	Good
20	96	Good
21	100	Good
22	100	Good
23	92	Good
24	84	Okay
25	100	Good
26	96	Good
27	96	Good
28	96	Good
29	100	Good
30	92	Good
31	96	Good
32	100	Good
33	100	Good
34	72	Okay
35	96	Good
36	100	Good
37	100	Good

38	100	Good

Appendix J

Overview of Experiment Location



Appendix K

Image Capture: Breakdown and Organization

ID	Sample#	Orientation	ToneMapped File ID	Noticeable Strengths	Descriptors	Considerations
1	sample1_HDR	Landscape	0264_5_6	Detail	Hallway, Artisans	
2	sample2_HDR	Portrait	7860_1_2	Color	Tree, Mt.Hope, Leaves, Blue Sky	
3	sample3_HDR	Landscape	7931_2_3		Bridg, Sky, Rochester	
4	sample4_HDR	Landscape			Eastman Building	Focus, Color
5	sample5_HDR	Landscape			Barn, Blue Sky, Fence	Focus
6	sample6_HDR	Landscape	0243_4_5	Detail	Barstool, Artisans	Color
7	sample7_HDR	Landscape	7960_1_2	Brightness	Eastman Building, Evenly Exposed	
8	sample8_HDR	Landscape	0382_4_5	Texture	Cactus, Macro	Focus, Framing
9	sample9_HDR	Portrait			Cactus	Framing, Color
10	sample10_HDR	Landscape			Leaves	Boring
11	sample11_HDR	Landscape	0514_5_6		Church, Perspective	Focus
12	sample12_HDR	Landscape			Rochester, Waterfall	Gross
13	sample13_HDR	Landscape	0593_4_5	Color, Tone	Red, Farms, Perspective	
14	sample14_HDR	Landscape			" "	Cropped Sky
15	sample15_HDR	Landscape			Train Tracks	Warped, Color
16	sample16_HDR	Landscape			Night time, Long Exposure	Color?
17	sample17_HDR	Landscape	0744_5_6	High Key	Night time, Architecture	use sample 17_HDR, rotate
18	sample18_HDR	Landscape		Texture	Bricks	Color
19	sample19_HDR	Landscape			Bricks, Garage, Abandoned	Apparent Sky Halo
20	sample20	Landscape			Blue Railing,	Raindrop in

	_HDR				High Falls	Center, Halo
21	sample21 _HDR	Landscape			Parking Garage	Color, Lighting Conditions
22	sample22 _HDR	Portrait	1482_3_4		Galleria Mall, Buffalo	
23	sample23 _HDR	Landscape	1370_1_2	Detail	Windows, Abandoned Building	
24	sample24 _HDR	Portrait	1452_3_4	Perspective	Buffalo Terminal, Abandoned	
25	sample25 _HDR	Portrait		Detail	Abandoned Boats, Buffalo, Ceiling	
26	sample26 _HDR	Landscape			Abandoned BMW, Buffalo	Lighting
27	sample27 _HDR	Portrait	1319_20_21	Detail	Abandoned Building, Grunge	
28	sample28 _HDR	Landscape		Tone	Parking Lot, Rain	Sky Detail, Halo
29	sample29 _HDR	Landscape	1262_3_4		Truck Tires, Landscape	Water Edit
30	sample30 _HDR					
31	sample31 _HDR	Portrait	1024_5_7		Yellow Tractor Wheel	Sky
32	sample32 _HDR	Landscape	1163_4_5	Perspective, Neutral Tones	Abandoned Structure, LeRoy	
33	sample33 _HDR	Landscape	1229_30_31		Buffalo Museum, Pillars	Color
34	sample34 _HDR	Landscape			Abandoned Boats, Buffalo	Boring
35	sample35 _HDR	Landscape			Graffiti, Macro	
36	sample36 _HDR	Landscape			Graffiti, Macro	
37	sample37 _HDR					
38	sample38 _HDR	Landscape	1310_1_2		Abandoned Boats, Two Boats, Plastic	too much
39	sample39 _HDR	Landscape			Abandoned Boats, Buffalo, Tarp	
40	sample40 _HDR	Landscape	6012_2_3		Sunset	
41	sample41 _HDR	Portrait			Building, High Falls	Halo
42	sample42	Portrait		Detail	Ladder, Barn	Color

	_HDR					
43	sample43_HDR	Portrait	1802_3_4	Brightness, Detail	Green House Door	
44	sample44_HDR	Landscape	1706_7_8	Solid Color	Red Barn, Reflection Window	
45	sample45_HDR	Portrait	1673_4_5		Barn with Barrell	Lens Distortion
46	sample46_HDR	Portrait	1749_50_51	Contrast	Barn with Lightbulb	Contrast
47	sample47_HDR	Portrait	1814_5_6		Green House, Detail, Boxes	
48	sample48_HDR	Landscape	1826_7_8		Green House Ceiling, Water Strip	Tone
49	sample49_HDR	Portrait			Green House Table	Boring
50	sample50_HDR	Portrait			Barn Stairwell	
51	sample51_HDR	Landscape	1792_3_4		Barn, Deer	Dead Deer, Blown out Windows
52	sample52_HDR	Landscape	1586_7_8		Barn, Sun, Blue Sky	
53	sample53_HDR	Portrait			Barn Inside	Lens Flare
54	sample54_HDR	Portrait			Little Theatre, Night	Color
55	Extra	Portrait				