Evaluating the Effect of Varnishes on the Color and Spatial Image Quality of Paintings

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Abstract

It was hypothesized that the molecular weight of the resin used to form painting varnishes is the dominant parameter in affecting the color and spatial image quality of varnished paintings. As an exploratory experiment, a cleaned painting was simulated by a "sandwich" of a photographic transparency and double-thickness window glass sandblasted on one of its surfaces. Two varnishes, one with low molecular weight and one with extremely high molecular weight, were applied to the ground-glass surface at two thicknesses. The photographic transparency consisted of three types of targets to facilitate spatial analyses (via a modulation transfer function), colorimetric analyses, and visualization using a reproduction of an Old Master painting. Digital images of the photographic transparency projected through the varnished ground glass revealed that a varnish's image quality was highly correlated with the resin's molecular weight.

Introduction

In painting conservation, varnishes are regularly employed. Most commonly, the existing varnish has deteriorated; following its removal and other treatments, a new varnish is applied. One of the functions of a varnish is to unify the gloss across a painting's surface. A varnish has a great effect on the appearance of a painting in that colors become darker and more chromatic. Sometimes, when the paint medium has become depleted, due to deterioration or leaching as a result of various cleaning procedures, the function of the varnish may be in part to replenish the paint medium. Paintings from which the varnish has been removed and those that were never varnished have a relatively rough surface. A varnish reduces the surface roughness.

The conservator controls the optical properties of the varnish by the choice of resin, the choice of solvent, the concentration of solution, the amount of solution applied, and the method of application. There is a complex interaction between physical properties of the varnish (i.e., viscosity, rate of evaporation, and refractive index),[1,2] the paint medium (i.e., roughness and porosity), and how the conservator applies the varnish to the painting (i.e., brushing and spraying). The net effect of these interactions is that two physical parameters that are being manipulated during conservation, film thickness and surface roughness.

Of particular interest is the capability of a varnish to level a topographically nonuniform paint surface. Reducing the surface roughness is desirable: simply, first surface reflectance increases in occurrence along the specular direction. When the painting is viewed under typical gallery conditions, this leads to improved color rendition and image quality.

The determinant of a varnish's leveling properties is molecular weight and by extension, viscosity.[1,2] In general, varnishes preferred by conservators have low molecular weight, whether natural or synthetic. Thus, a long-term research goal is to fully understand how physical parameters of a varnish affect its optical properties when applied to paintings. The first step in this research was to develop an analytical method to quantify leveling, particularly as it affects appearance. This is the subject of this paper.

Experimental Paradigm

It is useful to conceptualize a varnished painting as an imaging system. The paint layers represent a scene and the varnish represents the image optics. A number of factors affect image quality including tone reproduction, color reproduction accuracy, image noise, and sharpness.[3,4] For this research, color and sharpness were evaluated. Color is evaluated by spectral and colorimetric analyses.[5] Sharpness is evaluated by a modulation transfer function (MTF).[3,4,6] Recently, a Photoshop plugin filter was developed which estimates MTF based on analyzing a slanted edge.[7,8] Because this method does not consider the MTF of the test target edge, it is referred to as SFR, spatial frequency response.

Ideally, varnishes would be evaluated on actual paintings. However, direct analyses are problematic. One problem is obtaining a painting with a depleted medium that has consistent roughness across the test area. The second is developing a method of varnish application that is repeatable. The third is minimizing the possible detrimental effects caused by repeated cleaning and varnishing of the painted surface. The fourth is obtaining a painting with the necessary spectral and spatial features for quantitative and qualitative analyses. For all of these reasons as well as an interest in using image analyses, the following experimental paradigm was developed. A photographic positive transparency was used to simulate the painted image. Double thickness window glass sandblasted on one side simulated a depleted paint medium. By rear illuminating the ground glass and photographic transparency "sandwich," a painting with a very rough depleted surface was simulated. Varnishes applied to the ground glass would have different abilities to level the surface thereby affecting image quality. Digital images of the simulated painting could be readily evaluated qualitatively and quantitatively.

Experimental

Transparency

The transparency target is shown in Figure 1. The top left is a slant-edge target, used to measure SFR. The top right is a 6x6x6 factorial sampling of red, green, and blue digital counts, used to measure colorimetric values. Below it is an 18 step gray scale, also uniformly sampled digitally. The bottom is a portion of Rembrandt van Rijn's *Self Portrait* [oil on canvas, 0.845 x 0.660 m (33 1/4 x 26 in.)

Andrew W. Mellon Collection, National Gallery of Art, Washington] digitized at 600 pixels per inch from an 8" x 10" positive transparency. A 4" x 5" Ektachrome photographic positive transparency of the test target was created using a CRT-based film recorder.

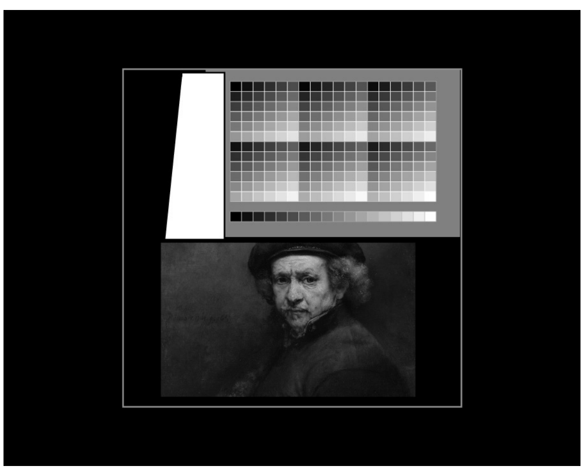

Figure 1. Experimental target

Varnish and Varnish Application

As an exploratory study, two resins were selected, each applied at two thicknesses. The first resin was Union Carbide AYAT polyvinyl acetate having an extremely high molecular weight (weight average molecular weight = 343,829). The second was Hercules Regalrez 1094, a low molecular weight hydrogenated hydrocarbon resin (weight average molecular weight = 1091) that has recently come into use as a varnishing material.[9,10] It has similar molecular weight to common natural resins used for painting varnishes. Toluene was used as the solvent for both resins in forming varnish solutions.

Paint drawdown applicator bars were used to produce uniform film layers. Each varnish was applied at two thicknesses. The AYAT varnish resulted in films of 21.8 and 43.5 microns while the Regalrez varnish resulted in films of 16.9 and 33.9 microns.

Imaging and Image Analyses

An IBM Pro/3000 imaging system was used for the experiment. This is a scanning system with a spatial resolution of 3000 x 4000 pixels and three filters optimized such that the overall system spectral sensitivities are nearly colorimetric.[11] This camera captures at 12-bit color resolution. An exponential function was used to reduce the bit depth from 12 to 8 resulting in 24-bit TIFF files. (The 24-bit images were required in order to use the SFR plug-in filter.)

A Kodak ANSI IT8.7/2[12,13] Ektachrome target was first imaged. Batch colorimetric data for this target along with the average digital counts of each color patch were used to develop a transformation from digital to colorimetric data for the 1931 standard observer and illuminant D50.[5]

The photographic target was positioned on rear-illuminated opal glass and imaged successively with clear glass, ground glass, and ground glass with each varnish positioned between the target and detector. The average digital counts of each patch of the color target were transformed to estimated CIELAB coordinates. A 300 x 400 pixel area of the slanted edge was used to estimate SFR. Only the green channel was used.

Results and Discussion

Spatial Analysis

The slant-edge SFR spectra of each image were converted to MTF spectra by dividing by the SFR spectrum of the clear glass, plotted in Figure 2. The data are only plotted between 0 and 0.3 cycles per pixel; above 0.3, there is considerable noise. There are clear trends in the data. Varnish improved MTF. The ground glass had a very low spatial response, quickly dropping off in its modulation at very low spatial frequencies. With a varnish coating, the curve begins to change shape and increases in modulation. However, the 21.8-micron AYAT produced only marginal improvement compared with ground glass. At 43.5 microns, MTF is certainly higher than ground glass without a varnish coating. The Regalrez was much more effective than AYAT in improving MTF. For both varnishes, increasing the film thickness improved MTF.

Sharpness is a visual perception whereas MTF (or SFR) is a physical parameter. Many metrics have been proposed to relate MTF to perceived sharpness, summarized by Higgins.[4] Common to these calculations is the convolution of the human visual system's MTF with the optical system's MTF and integration over spatial frequency. Because the ground glass is only a simulation of a painting surface and viewing distance for any arbitrary painting has not been defined, performing this convolution seems specious. Therefore, the MTF spectra plotted in Figure 2 were integrated as a function of spatial frequency between 0 and 0.3 cycles per pixel and used as a first-order correlate of sharpness. These integrated MTF are listed in Table 1. Clearly, Regalrez 1094 is much more effective than AYAT in improving the spatial image quality of the ground glass. Regalrez at less than half the thickness of AYAT (16.9 vs. 43.5 microns) resulted in more than twice the integrated modulation (42.27 vs. 15.96).

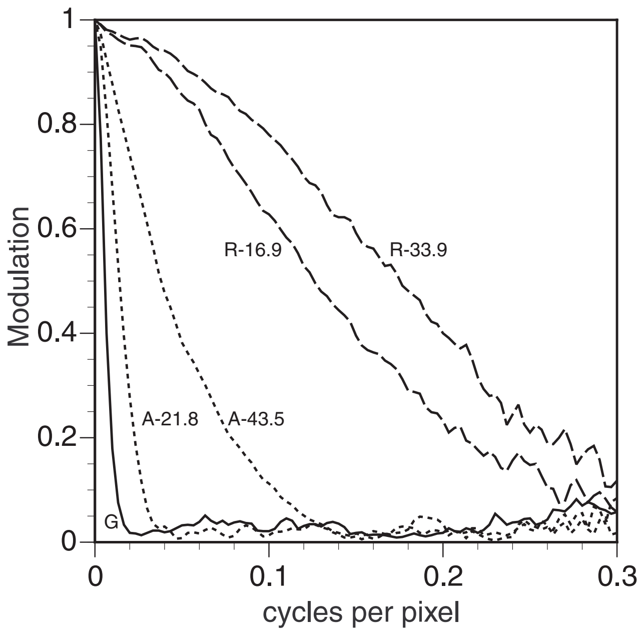

Figure 2. Modulation transfer function results: 43.5 and 21.8 micron AYAT films (dotted lines), 33.9 and 16.9 micron Regalrez films (dashed lines), and ground glass (solid line).

Table 1 Integrated area of the MTF spectra plotted in Figure 2.

Sample	Integrated modulation
Regalrez 33.9 microns	52.67
Regalrez 16.9 microns	42.27
AYAT 43.5 microns	15.96
AYAT 21.8 microns	7.08
Ground glass	5.25

Colorimetric Analysis

The surface roughness of the ground glass causes light transmitting through the glass to be scattered. This is equivalent to adding optical flare through an imaging system. The visual effect is that dark colors are rendered lighter and lower in chroma.

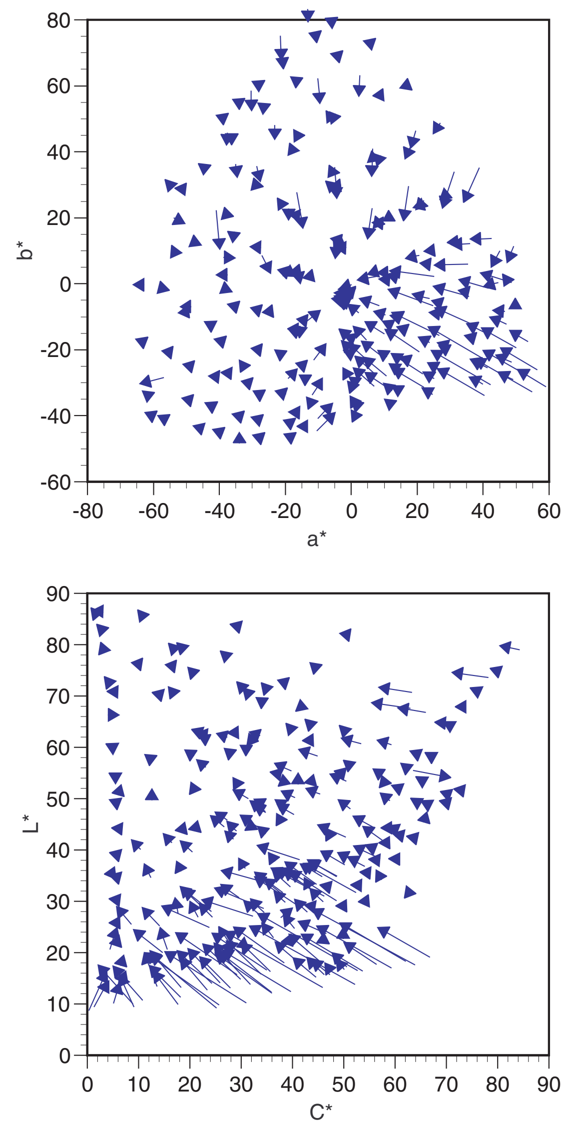

Figure 3. Vector plots for the 21.8 micron AYAT film applied to ground glass compared with clear glass

The change in color was quantified by calculating colorimetric differences using CIELAB as an approximately uniform color-difference space[14] for the 6 x 6 x 6 color target and gray scale. Vector plots, in which the tail of each arrow represents the coordinates of a color patch imaged through the clear glass and the arrow head represents the coordinates through the ground glass, are shown in Figure 3 for the 21.8 micron AYAT film. There are large changes in chroma and lightness for the darker colors. The upward left arrows indicate a decrease in chroma and an increase in lightness. The effects for lighter colors are much smaller. The systematic trend where the chromatic changes are greatest for the red-blue quadrant (+a*, -b*) is more a function of these colors' L* values than their specific hue.

CIE94 color differences[15] were calculated for all four films, summarized in Table 2. The trends are similar to the spatial analyses. Regalrez was more effective in improving the quality of the ground glass, in this case, the color quality. Increasing the film thickness for the Regalrez had a very small effect whereas the increase in film thickness for the AYAT had a dramatic effect.

Table 2. CIE94 color differences for each varnish compared with clear glass.

Sample	Average	Maximum
Regalrez 33.9 microns	1.0	5.2
Regalrez 16.9 microns	1.0	5.4
AYAT 43.5 microns	1.8	8.8
AYAT 21.8 microns	3.3	13.0

Conclusions

Image analysis using measurements of modulation transfer function and colorimetry allows for the quantification of the optical effects provided by a varnish when it levels a rough paint surface. This was possible by defining a painting as an imaging system in which paint layers are equivalent to a scene and the varnish is equivalent to an optical system. As an exploratory experiment, a cleaned painting was simulated by a "sandwich" of a photographic transparency and double-thickness window glass sandblasted on one of its surfaces. Two varnishes at two thicknesses were applied to the ground-glass surface.

It was hypothesized that the molecular weight of the resin used to form the varnish was the dominant parameter in affecting a varnish's image quality. This was verified by testing Hercules Regalrez 1094, a low molecular-weight hydrogenated hydrocarbon resin, and Union Carbide AYAT, an extremely high molecular-weight polyvinyl acetate. The color and spatial image quality of the ground glass varnished with Regalrez were much higher than the quality achieved using AYAT.

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Biography

Roy S. Berns is the Richard S. Hunter Professor in Color Science, Appearance, and Technology at the Munsell Color Science Laboratory and Graduate Coordinator of the Color Science master's degree program within the Center for Imaging Science at Rochester Institute of Technology. He received B.S. and M.S. degrees in textile science from the University of California at Davis and a Ph.D. degree in chemistry with an emphasis in color science from Rensselaer Polytechnic Institute. His research includes colorimetry, colorimetric device characterizations of imaging peripherals using spectral models, color tolerance psychophysics, and spectral-based color reproduction.

E. René de la Rie received M.S. and Ph.D. degrees in chemistry from the University of Amsterdam, The Netherlands. He has been Head of Scientific Research at the National Gallery of Art in Washington, DC since 1989, where he directs a staff of researchers who study artists' methods and materials, and test and develop conservation materials. Before coming to the National Gallery of Art, he held positions at the Metropolitan Museum of Art, New York, and the Training Program for Conservators and the Central Research Laboratory for Objects of Art and Science, both in Amsterdam.