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Friday, May 31, 2013

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The Research and Conservation Treatment of *Jar of Apricots/Le Bocal d’abricots*, 1758 by Jean-Siméon Chardin

**ABSTRACT**

A great masterpiece in the collection of the Art Gallery of Ontario, *Jar of Apricots*, is a rare oval and one of a pair presented by Chardin at the Salon of 1761. The painting presented extensive over-painting and a deteriorated varnish. Analyses were carried out at the Canadian Conservation Institute to document the materials. Examination of comparable works assisted in the understanding of Chardin’s materials and techniques and provided important reference material in the cleaning and reconstruction of damaged areas. Unexpected subtlety of color and texture is revealed throughout and the quiet beauty characteristic of Chardin’s work is revealed.

1. **INTRODUCTION**

Jean-Siméon Chardin was born in Paris in 1699 to the family of a master carpenter who specialized in billiard tables. He lived his entire life in the district of Saint-Germain-des-Prés. Chardin achieved early success in the 1720s with his still lifes but turned to genre painting in the 1730s.

When he returned to still-life painting in 1748, it was with a particular interest in the play of light, transparency, and reflection. His application of paint is now more fluid with none of the impasto characteristic of his earlier still lifes.

Chardin painted *Jar of Apricots* (57 × 51 cm) in 1758, a period in which he had a royal pension and an apartment in the Louvre. It is one of a pair of rare ovals and one of the most celebrated paintings from the period (fig. 1). Jacques Roettiers, silversmith to the king, first purchased the paintings. Several sales followed, but *Jar of Apricots* was sold by James de Rothschild in 1951 and purchased by the Art Gallery of Ontario (AGO) in 1962.

![Figure 1. (a) Jean-Siméon Chardin, *Jar of Apricots*, oil on canvas, Art Gallery of Ontario collection (b) Jean-Siméon Chardin, *The Cut Melon*, oil on canvas, private collection](image-url)
It is one of the most loved paintings in the collection. The pendant painting, *The Cut Melon* (57 × 52 cm), remains in a private collection. Figure 1 shows both paintings on exhibition at the Museo del Prado, Madrid, 2011.

2. EXAMINATION OF THE PAINTING

*Jar of Apricots*, as seen in Figure 2, has an old glue lining and has experienced several harsh restorations. There was extensive overpaint, and the changes interfered with the appreciation of this remarkable painting. Most immediately disturbing was the lack of transparency in the varnish. It was identified as an EVA copolymer, a resin patented by DuPont in 1956, placing the most recent restoration(s) after this date. Many groups were involved in the development of vinylacetate copolymers with DuPont filing a patent in 1956 and introducing the Elvax range of materials in 1960. This is based on the copolymerization products of ethylene with vinylacetate.

The surface of the painting was severely abraded in the upper left background, there was old damage on the middle left side, and the extensive drying cracks had been overfilled and broadly retouched. The area under the marble table was completely overpainted in a red-brown color. The cracks on the central fruit were broadly overpainted with orange colors confusing its identity as an orange or a lemon. The highlights were obscured and the painting generally lacked depth.

The UV fluorescence photograph as seen in Figure 3 clearly shows the most recent retouching in the background, in the central and middle left side and the area under the table. Much of the retouching follows the pattern of the drying cracks.

The x-ray radiograph (fig. 4) shows the extensive drying cracks, an oblique damage in the upper right, and a pentimento in the repositioning of the tie around the cover on the jar of apricots.

The infrared reflectography (fig. 5) did not reveal any underdrawing but shows greater subtlety in the reflections and shadows now heavily overpainted.
3. TECHNICAL ANALYSES

For a better understanding of the materials, the painting was taken to the Canadian Conservation Institute (CCI) where it was analyzed noninvasively with x-ray fluorescence (XRF) and Raman spectroscopy. In addition, microscopic samples were taken from the edge of several losses or damages in a few selected areas and other samples were removed during the course of the treatment to provide more detailed compositional information. The samples were analyzed by FTIR, polarized light microscopy, Raman spectroscopy, and scanning electron microscopy/energy dispersive spectrometry.2

3.1 Cross Sections

A cross section (figs. 6, 7) taken from a damage at the bottom edge revealed a preparation characteristic of Chardin: a red ochre ground followed by gray priming. The red ground contains red iron oxide (with associated kaolin and quartz)
mixed with lead white. The gray ground is composed of lead white, chalk, charcoal black, and small amounts of Prussian blue and red iron oxide. Figure 8 is a backscattered electron micrograph showing a fragment of charcoal with remaining cellular structure of the wood. Both the red ground and gray priming have a drying oil-binding medium and contain lead fatty acid salts produced by a reaction of the lead white with the oil medium. The mixture of chalk and lead white is often observed in Chardin paintings. The chalk absorbs a lot of oil and increases the transparency while also thickening the paint. It also gives the whites a softer appearance.

### 3.2 The Reds
The following indicators on Figures 9 and 10 show the different areas examined on the wine glasses and teacups before treatment:

- **yellow circles**: the location of noninvasive XRF analysis
- **green diamonds**: the location of noninvasive Raman analysis in areas of original paint

Figure 8. Cross section, detail of charcoal black, backscattered electron image

Figure 9. Before-treatment areas examined
3.4 The Blues

Areas examined on the box and wrapped sugar cone before treatment are illustrated in Figure 12. The yellow circles show the location of noninvasive Raman analysis in areas of overpaint attended in a highlight on the bread. Cadmium-based pigments were identified in overpaints.

3.3 The Yellows

Analyses of the lemon revealed orpiment on the highlights and vermilion in the darker shadows. Lead tin yellow (type I) was identified in a highlight on the bread. Cadmium-based pigments were identified in overpaints.
Table 1. Jean-Siméon Chardin’s Palette 1730–1766 as Identified in Museum Collections

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<td>Vegetable Carbon Black</td>
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<td>Organic Brown Earth</td>
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<td>Umber</td>
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<td>Red Lakes</td>
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<td>Prussian blue</td>
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<td>Ultramarine blue</td>
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<td>Ultramarine blue mixed with Prussian blue</td>
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The blue paint from the wrapped sugar cone is composed of lead white, chalk, ultramarine blue, and Prussian blue with small amounts of Naples yellow, charcoal black, and red lake. A mixture of Prussian blue and ultramarine blue has been observed in other Chardin paintings (Merrill 1981).

3.5 Chardin’s Palette 1730–1766

Table 1 shows the AGO’s findings added to a chart published by Ross Merrill in 1981 on the basis of technical investigations conducted by several institutions in preparation for the large Chardin exhibition held in 1979 (Merrill 1981, 125). The palette of the AGO’s Chardin is consistent with that observed in other Chardin paintings from the period 1730–1766.
4. QUESTIONS AND COMPARISON TO RELATED PAINTINGS

The analyses provided many insights, but many questions remained unanswered. The central fruit, for example, was the shape of a lemon, but it had not yet been determined if some 18th-century oranges looked like this. The reds on the teacup decoration were smudged and abraded, but it was not known how they originally appeared. There was an obvious need to better understand the artist’s working method.

The loan of the AGO painting to the Chardin exhibitions in Ferrara and Madrid allowed a study of the pendant painting and other comparable paintings that included some of the same objects depicted in Jar of Apricots. A consultation with Pierre Rosenberg, noted Chardin scholar and director emeritus of the Louvre, at the Ferrara venue provided helpful insights.

The Cut Melon was particularly useful as a reference, because it has never been restored. In the same marble table, there was a direct point of comparison. The heightened color of the reflections on the pear was reminiscent of the heightened color of the reflections between the apricots, the lemon, and the bread. On the ewer were observed the familiar drying cracks and the smudged decoration very similar to the teacup decoration. It is clear that Chardin sometimes applied color and wiped it with solvent; others have reported drip lines and runs (Merrill, 1981). Drip line and runs were observed by Ross Merrill on Chardin’s Rabbit with Red Partridge and Seville Orange at Musée de la Chasse et de la Nature, Paris. Girl with a Shuttlecock, painted in 1737 in a private collection, has a red and blue decoration treated in a similar manner. In the painting from the collection of the Louvre, The Butler’s Table, 1763, there are several objects that also appear in Jar of Apricots: the sugar cone wrapped in blue paper, the round confectionary box and fruits with dramatic reflective color, a jar of fruit (if not apricots), and painted porcelain. Chardin’s treatment of reflections in the wine and the glass of Grapes and Pomegranates, 1763, is similar to Jar of Apricots.

5. TREATMENT AND FURTHER ANALYSES

In the course of the treatment, as earlier underlying layers were exposed, further samples were analyzed by CCI.

5.1 Central Wine Glass

The discolored retouching on the drying cracks of the bottom central wine glass is visible in Figure 13. Photomacrographs (figs. 14, 15) reveal greater detail.

5.2 Left-Side Wine Glass

The bright green modern paint as observed in the glass on the left side appeared in cracks all over the surface. This modern paint was determined to contain barium sulfate, barium yellow,
Prussian blue, and phthalocyanine green (patented in 1936), and as part of a 20th-century restoration, possibly from paint on the lining canvas. Old fills were calcium carbonate, natural resin, and/or a drying oil.

5.3 Empty Wine Glass
In the small empty wine glass, there are broad discolored overpaints covering pink wax fills and much original surface (fig. 17). Figure 18 shows more of the original surface and some of the pink fills in the process of being removed mechanically.

The most superficial retouchings were easily removed along with the EVA varnish in xylenes. The chalk and resin fills were reduced mechanically under the microscope to reintegrate the surface texture. The cleaned surface was saturated with a stabilized natural resin damar varnish, isolating it from further conservation treatment (fig. 19). Retouching was completed with B-72 and dry pigments (fig. 20). The transparency and reflection that Chardin so loved is recovered.
Following careful research, the foreground teacup was understood to be very close to how it was originally painted (fig. 21). The decoration is thought to be inspired by the Japanese Kakiemon pattern produced in Chantilly, and made popular in France at the time by the Prince of Condé who founded the factory there in 1730.4

Red overpaint on the recessed teacup decoration is clearly visible in the photomicrographs (figs. 22, 23).

5.4 The Teacups

Following careful research, the foreground teacup was understood to be very close to how it was originally painted (fig. 21). The decoration is thought to be inspired by the Japanese Kakiemon pattern produced in Chantilly, and made popular in France at the time by the Prince of Condé who founded the factory there in 1730.4

Red overpaint on the recessed teacup decoration is clearly visible in the photomicrographs (figs. 22, 23).
Figure 24 shows the areas after the overpaint removal and the overfilled drying cracks become exposed. Figure 25 shows the surface after removal of the fills. These shallow recesses were not refilled but accepted as part of the original surface since they were not considered disfiguring and were not visible from normal viewing distance.

**Spoon handle:** The large drying cracks in the spoon handle and the inside reflection were broadly overpainted and discolored (fig. 26). The overpaint removal restored a more 3-dimensional shape and another reflective surface.

The image of the recessed cup after treatment seen in Figure 27 shows the subtle gradation of tone in the painted decoration which was recovered and the lovely blue shadows were revealed (fig. 28).
5.5 The Orange Lemon

In Figure 29 and Figures 30–32 details of the orange-colored overpainting on the dark mechanical crack lines and some open drying cracks are evident.

As seen in Figures 33 and 34 the fruit is now more convincing as a lemon with the lighter colored reflections on the top and the darker orange-red reflections in the shadows as Chardin imagined them.
Figure 30. Photomacrograph: Upper edge detail

Figure 31. Photomacrograph of lemon: Lower right shadow
5.6 Jar Of Apricots

The upper right reflection on the jar (figs. 35, 36) reveal the large disfiguring drying cracks of the area, the very green retouching on the cooler blue/gray background and spots of phthalocyanine green paint.

Figure 37 shows this area after removal of retouching and reduction of the old fills. Figure 38 shows the jar after treatment; there is much greater clarity and depth and the original colors.
The repositioned tie is the only pentimento observed in this painting and it remains slightly visible.

5.7 The Wrapped Package
This curiously simple object (a wrapped package) was very disfigured by dark mechanical cracks and light colored overpaints. After removal of the varnish, accretions and overpaint, a lovely violet emerged and the texture of the paper is palpable (figs. 39, 40).

5.8 Under The Table
The space under the table was very flattened by the broadly applied red/brown overpaint. The UV fluorescence demonstrates clearly the extent of damage in this area: note the
The Research and Conservation Treatment of Jar of Apricots/Le Bocal d’abricots

The photomacrographs (figs. 41–43) reveal how much original surface was recovered.

Figure 43 shows the blue-green phthalocyanine green paint emerging at the periphery. Very meticulous work under the microscope was required to reduce the fills and recover much of the original dark brown surface. Figure 44 shows the extent of damage after the removal of the extended fills but reveals the gradation of tones in the blacks and browns. A more convincing marble table surface has emerged. The shadows are also more natural and the sense of space has been recovered.

**The Signature and Date**

Almost all of the original signature and date survive (figs. 45, 46). Only part of the digit “8” has been lost in an old restoration (fig. 47).

**5.9 Upper Left Quadrant**

Because of the extensive abrasion of the priming in an early restoration (see damaged background, upper left fig. 48) the decision was made to soften the transition to the less damaged central background at the in-painting stage (figs. 49, 50). We accepted some of the old retouching where no underlying original paint remained.
Figure 42. Photomacrograph: After overpaint removal

Figure 43. Photomacrograph: After removal of excess fill
The Research and Conservation Treatment of Jar of Apricots/Le Bocal d’abricots

Figure 44. Area after removal of overpaint and excess fill

Figure 45. Photomacrograph: Signature left side

Figure 46. Photomacrograph: Signature right side

Figure 47. Photomacrograph: Date ‘1758’

Figure 48. Damaged upper left quadrant
6. CONCLUSIONS

Much original color has been recovered, and the relationship between the various objects has been clarified and transformed (fig. 51). The play of light in and around these objects of everyday life is captivating, and the painting’s quiet beauty has been recovered. This treatment clearly demonstrates the critical nature of research and the need for dialogue in the cleaning of paintings.

ACKNOWLEDGMENTS

Thank you to Kenza Kahrim and Jane Sirois at the Canadian Conservation Institute for their work on the scientific analysis.

Special thanks are extended to M. Pierre Rosenberg, director emeritus, Musée du Louvre, for his larger perspective on Chardin’s style and technique.

Thank-you to Maria Pacelli, curator at the Palazzo dei Diamanti, Ferrara, Italy, for her thoughtful discussion of Chardin’s pendant paintings.
Thank-you to Maria Alberola, exhibitions coordinator, and Karina Marotta Peramos, head of exhibitions of the Museo del Prado, for their support of my research at the closing of their exhibition.

Thank-you to Prof. Ron Spronk, Queen’s University, Kingston, Ontario, and Alexander Gabon, conservator, Kingston, for carrying out the infrared reflectography at the AGO with the Osiris infrared camera (InGaAs sensor).

Thank-you to all our colleagues in the conservation department at the AGO for their enthusiastic interest in the project.

The Art Gallery of Ontario is grateful to the BNP Paribas Foundation for their support of the project.

NOTES

1. Plastics Historical Society, 297 Euston Road, London, NW1 3AQ, UK. Plastiquarian.com website, 2011


3. CHARDIN, Il pittore del silenzio, Palazzo dei Diamanti, Ferrara, Italy October 2010–January 2011; Museo del Prado, Madrid, Spain, February–May 2011, Curator Pierre Rosenberg; organized by Ferrara Arte and Museo Nacional del Prado. The other painted pair in the exhibition (Basket of Wild Strawberries and Glass of Water and Coffee Pot ca.1760) was of particular interest to the discussion.

4. De Rochebrune, M.-L., Galeries nationales du Grand Palais (France); Metropolitan Museum of Art (New York, N.Y.); Kunstmuseum Duesseldorf and Staedtische Kunsthalle Duesseldorf; Royal Academy of Arts (Great Britain), London, 1999, Chardin, 37–53.

REFERENCE


FURTHER READING


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1. INTRODUCTION

The treatment of St. Nicholas Croatian Catholic Church (St. Nicholas) aimed to install preventive conservation measures, introduce no further elements of deterioration into the work, and achieve good and long-lasting results. Previous treatment on one of the murals was carried out in the 1990s using synthetic resins to stabilize areas of efflorescence. Few treatments would have been able to fend off damage from hurricane-force winds and record-breaking water levels. The span of time since previous treatment and the new damage was less than one decade, and the necessity to re-treat was an opportunity to assess the success of previous measures. At the time these materials were selected for their inert properties and reversibility. Development of this new conservation program took into consideration shortcomings of previous materials used and the effects of previous interventions in the church as well as measures that offer a more positive outlook on long-term stability of the murals.

St. Nicholas is situated in Millvale, Pennsylvania, a former industrial suburb north-easterly adjacent to the city of Pittsburgh along the Allegheny River. Many Croatian immigrants found jobs in steel mills and coal mines in the Pittsburgh area and settled in communities within the industrial neighborhoods along the Allegheny River. Escape from economic hardships, political oppression, and infringement of personal freedoms led many Croatians to flee their homeland in the late 19th and early 20th centuries. An estimated 10 percent of Croatians in American lived in Pittsburgh in 1937. (Bulletin Index 1937) St. Nicholas was established in 1894 to preserve language, customs, and community unique to the Croatians.

Frederick C. Sauer, a German-born architect, and contractors, the Murphy Brothers, were hired to build the Romanesque-style building. The Croatians insisted on using materials of the highest quality for their church design, which included electric lights and central heating. The first mass was held 25 November 1900. A fire destroyed the church on 26 March 1921 and church members again contracted Sauer to draw new plans for the church. This new building was dedicated 30 May 1922.

Father Albert Zagar of St. Nicholas commissioned Maximilian (Maxo) Vanka in 1937 to paint a series of murals on the church’s white walls. The Croatian artist ended up calling the work his “contribution to America,” and painted half of the 22 murals in the course of eight weeks in 1937 (Leopold 2001). He painted another 11 over five months in 1941 and finished details in 1950. Vanka admired Zagar for breaking with tradition and allowing him to decorate walls of the church with images of “modern social significance” (Nayler 1941). The murals’ expansive imagery covers 11,000 sq. ft. (1,022 m²) and reflects values of the Croatian immigrants in their new country combined with their Roman Catholic faith. Traditional religious images are mixed with messages of a central mother figure, industry, social injustice, horrors of war, and experiences of the immigrants. Vanka’s murals are recognized for portraying imagery timeless in their social and religious meaning. St. Nicholas was added to the National Register of Historic Places in 1980.

1.1 Murals

Maxo Vanka worked on sketches in his New York studio while contractors prepared the walls of the church according to his specific instructions (Adamic 1938). Unfortunately, Vanka’s
guidelines for these preparations were not documented. The
murals were not executed in *buon fresco* and significant contro-
versy exists regarding identification of the medium used by the
artist. The medium has been previously identified as “dry
fresco,” (TIME 1937) casein made from cheese (*Bulletin Index*
1937; Nayler 1941), dry powdered casein (Demarest 1981)
distemper (McDevitt 1999) and egg tempera on plaster
(Leopold 2001). In numerous early accounts, the artist stated
that he ground his pigments and mixed enough to work for a
day, working in wet plaster, a technique consistent with *buon
fresco*. It is evident that the mural consists of a paint layer
applied over dry plaster. Photographs confirm that the artist
carried out an underdrawing over the plaster in a wet medium
and followed his preparatory drawings in paint. Vanka worked
quickly, and, in the heat of summer months, his brushes
became so sticky with the medium he had difficulty working
(Breig 1941).

A sample of the artist’s original medium from an area of brown
paint, from the mural *Mati 1941*, was analyzed. Results from
FTIR revealed a spectrum with N-H stretching and amide
stretching is consistent with no oil, resin, wax, or synthetic is
present in the original medium (Martin 2009).

1.2 Wall Treatment
Square-shaped folk-patterned stencils were once painted on
the wall adjacent to *Mati 1941*. Early photographs of the
interior church walls depict decorative borders. Chevron
patterns, some of which are still present around the murals,
covered additional square footage.

2. CAUSES OF DETERIORATION

Observers in 1972 confirmed that the murals were in excellent
condition (Miller 1972); however, subjected to a wide variety
of pollutants from industry and auto emission, they eventually
began to exhibit a heavy accumulation of these pollutants,
which made them increasingly difficult to see. Pollutants from
industry also contributed to the degradation of the materials.
Subject to water infiltration in the past from roof damage,
“water spots” and “evidence of deterioration” was noted as
early as 1981 (Demarest 1981), and, in the next decade, a
conservator documented that some of the murals exhibited
efflorescence (McDevitt 1999). Significant damage resulted
after remnants of hurricanes Frances and Ivan came through
Pittsburgh in 2004. The damage induced by the hurricanes was
not noticed, however, until a considerable amount of efflorescence
appeared on interior walls around 2006. A building inspection
revealed that the strong winds blew off part of the metal roof
covering the sanctuary, fractured brick and mortar in the two
bell towers, and caused significant damage to the north bell
tower. Windows constructed with wood frames on the second
and third floors were also discovered to be failing. Record-
breaking rainfalls of 2004 were granted easy migration through
damages to the interior of the church.

Another contribution to alterations in the condition of the
murals is the undocumented measure to paint over the
decorative folk motifs covering nonmural walls with white
oil-based commercial paint. The congregation concurred,
however, that after these decorations were no longer visible,
the bright white contrasted with the dark murals making them
difficult to see. The parish hired a contractor in the 1990s to
tax the walls in medium gray and pale green, using synthetic
interior paints and glazes, resulting in a very glossy impermeable
surface.

2.1 Water Damage
Water, entering through cracks, migrated through the walls and
efflorescence is found primarily in areas of the murals *Pietà* and
*Mati 1941*. *Pietà* is located in the corner of the interior of the
building to the right of the high altar. Efflorescence is concen-
trated along the right edge of the mural. *Mati 1941* is located
to the right of the large stained-glass window, in the adjacent
corner. Damage to *Mati 1941* from efflorescence is concen-
trated along the right edge and is characterized by a dry, fluffy
white powder on the surface. Crystallization of infiltrates
occurred at the interface of the plaster wall and paint layer.
Increased volume of this new formation forced areas of
original paint from the surface. Numerous losses resulted from
small pockets filled with salts, and, having lost all inherent
binding, fell from the wall. The ceiling in the choir loft and the
stairwell leading to the north bell tower also exhibit extensive
water damage and efflorescence, but these walls do not contain
Vanka’s paintings.

2.2 Previous Interventions
Contributing to a further weakened condition is the previous
conservation treatment carried out in the late 1990s on the
*Pietà*, which was to address efflorescence and removal of
surface dirt. Water damage from the 2004 hurricanes has
appeared in areas of the *Pietà* previously treated (fig. 1).
Efflorescence was handled by brushing away the salts, and
fragile areas were re-adhered with synthetic polymers in the
earlier treatment. Fills were made with modern materials, and
retouching was executed in acrylic. The undamaged, original
surface of the *Pietà* was matte while areas with synthetic
adhesives appeared dark and saturated, particularly where these
polymers had been heavily applied. These materials were
chosen, no doubt, in the belief that they were easily reversed.
Areas of modern fill were as saturated with salts as original
plaster. Passages with modern retouch responded to new water damage by trapping salts beneath the relatively elastic layer and billowing from the surface due to volume of its contents. Earlier attempts to re-adhere weakened areas with polymers failed and delamination of paint from the wall re-occurred.

Further inspection of the glossy walls painted in gray revealed that salts were widely present beneath this synthetic layer. The modern coatings retained water, which was trapped beneath the paint as it migrated through the building. Moisture then either followed the path of least resistance by migrating to a surface more porous than itself (the mural) or remained behind the impermeable coating, slowly converting plaster into sulfates. Light hand pressure confirmed that pockets of delamination existed throughout the walls treated with the modern coating.
3. ANALYSIS

3.1 Salts Analysis
The efflorescence that was analyzed indicated that compounds of calcium and sulfur constituted 50 percent of the efflorescence. Magnesium, silicon, and carbon account for the bulk of the remainder. Additional trace elements are found in smaller percentages.

3.2 Sem-eds Analysis
A sample of the efflorescence was examined with an AMRAY 1830 scanning electron microscope. Energy dispersive spectroscopy (EDS) performed on the sample exhibits a strong presence of sulfur, 66 percent weight, and calcium in nearly 20 percent of weight, followed by magnesium and trace elements. Identification of sulfates supports the degradation of the healthy calcium hydroxide Ca(OH)$_2$ into calcium sulfate CaSO$_4$ by environmental conditions.

4. TREATMENT

4.1 Preventive Conservation Measures
Removal of elements that contribute to deterioration, mainly pollutants and water, is paramount to a successful conservation treatment. Pittsburgh, having once earned the status as the steel-making capital, underwent a dramatic transformation in the 1980s to clean up the city. The previously sooty black skies are blue again. The departure of industry and this “green” renaissance removed many sources of pollutants. Structural repairs made to the church in 2008 included repairs to the roof, replacement of fractured mortar and brick, and replacing weakened wood window frames with metal ones. Inspections carried out on completion concluded that structures were sound and more recent inspections confirmed that structural repairs were successful. Since repairs were made, no additional efflorescence or worsening of the condition has been noticed. Maintaining dry conditions in the building prevents the formation of new efflorescence on the walls.

<table>
<thead>
<tr>
<th>Material</th>
<th>Salts from Church Walls</th>
<th>SCL#: 10002766-01</th>
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<tr>
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<td>Sample 1</td>
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<tr>
<td><strong>Test</strong></td>
<td><strong>Result</strong></td>
<td><strong>Units</strong></td>
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<tr>
<td>Al$_2$O$_3$</td>
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<tr>
<td>CaO</td>
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</tr>
<tr>
<td>Cl</td>
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</tr>
<tr>
<td>Cr$_2$O$_3$</td>
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<tr>
<td>CuO</td>
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<tr>
<td>F</td>
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</tr>
<tr>
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<tr>
<td>CO$_2$</td>
<td>19.17</td>
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A planned future removal of the modern coating on the walls adjacent to murals would reduce the risk of the formation of future efflorescence on the walls of historic significance. Although it may not be feasible to selectively remove the top layers of paint and reveal original folk decorations, it may be possible to selectively remove the layers in an area adjacent to the walls with murals. These passages would allow any moisture in the future to be released through these “sacrificial” bands, mitigating damage to the murals. New fills in these areas should consist of a material more porous than the mural, such as lime and sand.

4.2 Ferroni-Dini Method
Before consolidating damaged murals, sulfates that threatened physical stability had to be removed. The previous attempts to consolidate the mural with synthetic polymers were unsatisfactory. Prior adhesives darkened the original surface and were not sympathetic to the porosity of the wall and contributed to further degradation processes. *Buon fresco* is not a common medium in the United States, and routine treatments for fresco are not in common practice. Although the murals were not carried out in true fresco, the traditional training of the artist and his preparation of the wall inspired the exploration for alternative options for stabilizing efflorescence. Minute tests were carried out on the murals using the inorganic Ferroni-Dini (barium) method to remove salts and consolidate murals with flaking caused by efflorescence. The technique, developed in the late 1960s by Enzo Ferroni and improved upon by Dino Dini, is in wide use in Europe, but has not been incorporated into common American practice. The process involves multiple steps of applying poultices to remove sulfates and consolidate flaking wall material with inorganic materials. Earlier publications on this method should be consulted for a complete description of the chemical process (Matteini 1999; Giorgi 2006; Baglioni 2010).

The first step of the Ferroni-Dini method uses poultices of ammonium carbonate \((\text{NH}_4 \text{CO}_3)\) to de-sulfate calcium sulfate by turning it into ammonium sulfate. The formed product is a soluble salt and is absorbed by the cellulose fibers of the poultice. Removal of sulfates reduces the volume of material. Once stable, the dry poultice material is exchanged for a new poultice of cellulose wet with distilled water. This step rinds the treated surface to help remove most of the soluble ammonium sulfate salts \((\text{NH}_4 \text{SO}_4)\), which, if left on the surface, may lead to the formation of additional efflorescence.

The second step of the Ferroni-Dini method, barium hydroxide \((\text{Ba(OH)}_2)\), is applied in a super saturated solution in water to a fresh cellulose poultice. This step removes soluble ammonium sulfate \((\text{NH}_4 \text{SO}_4)\) and provides inorganic consolidation of damaged mural by forming the insoluble salt of barium sulfate \((\text{BaSO}_4)\). Products of water and ammonia have a cleaning effect on the wall then evaporate while barium sulfate partly fills small losses in the plaster. The materials continue a gradual consolidation process by conversion of barium sulfate \((\text{BaSO}_4)\) into barium carbonate \((\text{BaCO}_3)\) and reformation of calcium hydroxide \((\text{Ca(OH)}_2)\). These two steps are the primary action of consolidation in the Ferroni-Dini method. By this method, efflorescence on wall murals were de-sulfated and consolidation took place without the use of synthetic polymers.

Samples of a treated area of the wall were collected and examined again with SEM-EDS. Elemental analysis performed on a sample after treatment with the Ferroni-Dini method shows dominance of the presence of calcium at 43 percent of the composition. Barium is present in nearly 52 percent of composition. Sulfur, which constituted 66 percent of the material prior to treatment, was reduced to almost 2 percent. Reduction of sulfur and the reaction of the barium support the effectiveness of de-sulfating process and consolidation of the wall through the inorganic treatment method.

4.3 Nanoparticles
Experimenting with the Ferroni-Dini method was a preliminary measure to determine the feasibility of the use of nanoparticles for treatment on the painted murals. This treatment may not be effective on all types of efflorescence; it is most applicable on walls contaminated by sulfates. This was a very successful means of removing salts and strengthening the mechanical attachment of the original preparation and paint layers to the wall, but delivery of a nanoparticle consolidation material offers several advantages. Instead of delivery of material in an aqueous system, nanoparticles of barium hydroxide measuring micrometers in size are dispersed in isopropanol. Delivery in alcohol reduces surface tension, increases capillary action, and allows more thorough penetration of the barium hydroxide into interstices. These properties of the nanoparticles are considerably advantageous when the plaster has been painted. Nanoparticles are more effective in penetrating the paint layer to reach the layer in need of consolidation, but they are less easily absorbed in areas treated previously with polymers and acrylic. Nanoparticles were preferred because consolidation could take place in a nonaqueous delivery method, avoiding high pH levels, which are harmful to secco, and reduced the risk of migration of the water-sensitive binding medium.

A combination of methods was used in practical treatment of efflorescence on the painted murals. All areas of previous retouching in acrylic were removed. Because of salt buildup beneath the acrylic, this nonoriginal layer was easily lifted. In areas of heavy loss of original paint and in areas previously covered with acrylic retouch, the Ferroni-Dini method was
used to treat salts. Because original paint was no longer present, the aqueous component did not present a risk of additional damage. Areas of original paint affected by salts were treated with nanoparticles. Treatment in isopropanol assured less damage to the original medium and better penetration of the inorganic consolidation materials.

Unless a wall painting exhibits flaking without any salts present, any treatment begins with the poultices of ammonium carbonate in an aqueous solution to remove harmful efflorescence. Treated areas must be allowed to dry completely before introducing the nanoparticle dispersion of barium hydroxide alcohol. Like the aqueous application of barium hydroxide, complete consolidation is a gradual process. Areas too far damaged by efflorescence may lack the necessary calcium binder for barium hydroxide nanoparticles to convert for consolidation. In these instances, treatment should be preceded by introduction of nanoparticles of calcium carbonate.
hydroxide in alcohol to wall or paint flakes. Direct application of calcium hydroxide is hindered by its low solubility in water. Dispersions of nanoparticles in isopropanol, however, have low surface tension and increase penetrability of the inorganic binding medium in the wall where needed.

5. CONCLUSIONS

It is difficult to predict the effects of natural disasters and safeguard a work of art against unforeseeable misfortunes. Some contributions to deterioration of the St. Nicholas murals were the effects of modern interventions. Local pollutants were reduced and controlled by means larger than the scope of the conservation campaign of the church. Their successful removal fortunately contributes to the long-term preservation of Maxo Vanka’s murals (fig. 2). Previous measures to update the church interior with modern paints and the prior conservation treatment were made with the most earnest of intentions, but the passing of time revealed shortcomings in these decisions. It remains the goal to rectify these deficiencies, introduce treatment materials designed for durability, and achieve long-lasting results to ensure appropriate stewardship of the murals. The decades-long track record of the inorganic Ferroni-Dini treatment method in Europe assures long-lasting results and does not introduce materials that could contribute to further degradation of the walls in St. Nicholas. Adjustment of the Ferroni-Dini method with nanoparticles was an appropriate selection to adjust for the painted layer in the traditional medium and improves efficacy in the inorganic treatment system.

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THIS ARTICLE HAS NOT UNDERGONE A FORMAL PROCESS OF PEER REVIEW
VIVIANA DOMINGUEZ

Assembly-Line Conservation for the Recovery of Haitian Paintings

ABSTRACT

The Haiti Cultural Recovery Project was the Smithsonian Institution's first international disaster-recovery initiative. The project's goal was to rescue, recover, safeguard, and help restore Haitian artwork, artifacts, and documents that had been damaged and endangered by the 2010 earthquake. Professional conservators from AIC and AIC–CERT volunteers hand in hand with international and Haitian staff members contributed to the recovery of 30,000 pieces of Haitian material culture.

The three case studies presented in this paper illustrates how the paintings conservation studio implemented traditional treatments and innovative methods, overcoming challenges such as budget and time constrains, and limited material resources.

1. INTRODUCTION

The Smithsonian Institution (SI) Haiti Cultural Recovery Project, under the direction of Richard Kurin, Undersecretary of History, Art and Culture, was the institution’s first international disaster-recovery initiative. The project’s goal was to rescue, recover, safeguard, and help restore Haitian artwork, artifacts, documents, media, and architectural features that had been damaged and endangered by the 2010 earthquake as well as to train Haitians in conservation skills.

The Haiti Cultural Recovery Center (HCRC) was established in a three-story structurally safe building in Port-au-Prince. The Center housed the offices of staff members including a registrarial area, storage spaces, and conservation studios. During 18 months between 2010 and 2011, professional conservators from the American Institute for Conservation of Artistic and Historic Works (AIC) and the American Institute for Conservation–Collections Emergency Response Team (AIC–CERT) worked hand in hand with international and Haitian staff members on the recovery of approximately 30,000 pieces of Haitian material cultural.

2. HAITIAN ART AND CULTURE

Haitian culture is a narration of the beauty of the country. Within that narrative emerges the identity of the people and the expression of pride in a deep and lasting tradition. Art in Haiti has a long history of academic trained artists as well as a popular pictorial tradition since the country’s independence in 1804. Influenced by native and European esthetics and religion, Haitian art brings the country’s African roots to the surface.

Many times referred to as the Haitian Renaissance, the opening of the Centre D’Art in 1944 by American artist Dewitt Peters greatly contributed to the development of Haitian painting. Artists and artisans from all over the country were invited to paint and exchange ideas and were provided with materials to work. In addition, art and literature personalities such as André Breton, Wifredo Lam, Alejo Carpentier, and others were captivated by the academy. As Gerald Alexis wrote: “Artists were able to express the singularity of Haiti through the popular religions, which are the most important elements of national culture, blending modern styles with popular traditions…”

Haitian painters, inside and outside Haiti, such as Hector Hyppolite, Philome Obin, Preferet Duffaut, Bourmond Byron, and Jean–Michelle Basquiat, just to mention a few, have achieved international recognition. In addition, local contemporary artists were welcomed at the 54th Venice Biennial in 2011, the first time the country was represented at the Italian biennial.
3. THE SMITHSONIAN HAITIAN CULTURAL RECOVERY CENTER

The 7.0 magnitude earthquake leveled most of Port-au-Prince museums and galleries such as the Centre D’Art and the Nader Museum, completely burying their entire collections. The Holy Trinity Episcopal Cathedral and its 14 murals was among the many Haitian landmarks destroyed. Three of the murals in the cathedral, however, managed to survive the devastating tremors (fig. 1).

Six months after the earthquake, the HCRC was established. Led by Chief Conservator Stephanie Hornbeck and Haitian Manager Olsen Jean-Julian, AIC professional conservators, AIC–CERT members, and Haitian workers recovered from the rubbles, surveyed, assessed the condition and documented the damaged Haitian Cultural Heritage. Materials and tools, brought to Haiti in staff’s and volunteers’ luggage, helped to transform the building’s office spaces into painting, sculpture, paper, and media conservation studios (fig. 2).

Training Haitians to participate in the recovery of their own cultural heritage for that moment and for the future was conceived as a central and integral component of the project. Foreign experts working together with local colleagues organized and adapted workshops and seminars for the different collections’ needs. The scale of the catastrophe and its aftermath demanded the immediate stabilization of the large volume of injured cultural material. Training artists on laborious conservation treatments in addition to the technical, theoretical, and ethical matters that

Figure 1. The walls of Holy Trinity Episcopal Cathedral after the 2010 earthquake
accompanied each process presented one of the most difficult challenges.

4. ONE-YEAR ANNIVERSARY OF THE JANUARY 12, 2010, EARTHQUAKE

On the one-year anniversary of the earthquake, the author and Rosa Lowinger started the stabilization and removal of the Holy Trinity Episcopal Cathedral murals. The intricate and long process took six months, at the end of which the author was hired to oversee activities at the paintings conservation atelier. She worked with AIC professionals who volunteered on-site for no longer than two weeks at a time. In addition, because of budget constraints, the paintings conservator position only allowed for the conservator to be on site no more than two to three weeks each month. At the time, the author had already established a strong personal relationship with the HCRC staff and the Haitian assistants and had gained extended experience in dealing with the Haitian disaster-recovery scenario. The combination helped her successfully implement an “assembly-line” conservation program. Eric Pourchot, institutional advancement director of the Foundation of the American Institute for Conservation Historic and Artistic Works (FAIC), and Stephanie Hornbeck were efficiently able to puzzle together everybody’s complex traveling and work schedule. During first week of the two-week-on-site period, the author would work with the Haitian assistants on a selected group of paintings. The following week, she and one of the AIC volunteers would overlap for a week. During that time, the professionals would discuss the projects, review methodologies, and agree upon the treatment protocols. At the end of her two weeks, the author would hand the baton to the AIC volunteer, who in turn would continue with the work in progress for another week; then two weeks later, the author would be back to take the lead again. Frequent discussions over a specific project continued via e-mail.

Even though the studios were very well equipped, time and resources were very limited. In addition, the paintings’ severe condition of disrepair and the amount of work required was overwhelming, but that never intimidated the professionals—whose creativity rose to the occasion.

The three case studies presented subsequently illustrate how traditional treatments and innovative methods were implemented at the paintings conservation studio, overcoming challenges such as budget and time constrains and limited material resources.
5. MARIO BENJAMIN’S PORTRAIT OF AN ELDERLY WOMAN

*Portrait of an Elderly Woman* (1980s) by contemporary artist Mario Benjamin was rescued from the destroyed National Palace by Patrick Vilaire (Haitian engineer and artist) and his team. The painting (128 × 180 cm) was extracted from the rubbles in five pieces and brought to the studio rolled on a PVC pipe. Kristín Gisladóttir, conservator from Iceland, was in charge of assembling the pieces together by mending them with threads. The debris on the surface was mechanically cleaned and then manually lined with BEVA film on a white polyester fabric. Kristín effectively trained Jean Menard Derencourt and Frank Louissiant, two teachers from the *École Nationale des Artes*, to assist her on the treatment process as well as on the in-painting of the multiple losses (fig. 3).

By the time the author arrived, Jean Menard and Frank were almost at the final stage of in-painting and they had successfully brought the image back together; however, there were still two very large lacunae: 18 × 24 inches of the woman’s forehead and 14 × 8 inches on the lower left corner (part of neck and shirt), disfiguring the oversized portrait. Apart from the lacunae dimensions, the fact that the woman was looking upwards increased the viewers’ attention to the loss (fig. 4).

The author Viviana joined Stephanie and Olsen’s debate regarding the in-painting of the large losses. They were trying to find a balance between saving the artist intent and the historical integrity of the piece. The piece had been hanging on the Presidential Palace for many years and was almost lost during the earthquake. The catastrophe had such a strong impact on the Haitian people that the paintings’ scars could now be regarded as part of the history of the piece. On the other hand, stabilization of the affected artwork was the main priority at the HCRC as opposed to spending too much time or resource on cosmetic work.

They first in-painted the area with an even neutral color to tone down the bright white of the Modostuc fill. Once applied, the neutral tone helped set back the losses, but these were still too predominant on the painting and stood out over the rest of the image. The second attempt to integrate

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**Figure 3.** Marion Benjamin, *Portrait of an Elderly Woman*, ca. 1980s. 71 × 51 in. After the pieces of canvas were mended and lined

**Figure 4.** Frank Louissiant and Jean Menard Derencourt inpainting *Portrait of an Elderly Woman*
6. MAX PINCHINAT’S PORTRAIT OF A WOMAN (1956)

Max Pinchinat’s Portrait of a Woman (1956), 36 × 23½ inches, oil on canvas was also dug out from the National Palace. During the many months the painting was buried, it was exposed to the harsh tropical weather. The strainer was broken, and the top bar was missing. The canvas was very rigid, and it was not only rippled and torn but also exhibited a considerable amount of loss of linen canvas, primer, and paint layer. Most of the painted surface was either detached or flaking, and covered with white debris (fig. 8).

The team started by consolidating the paint layer with Paraloid B-72 while cleaning the debris with soft brushes. To remove the canvas from the stretcher, a simple humidity chamber was built. The painting was placed inside a box made with a thick piece of plastic and two pieces of wood from another extra broken stretcher, which was tall enough for the plastic not to touch its surface. Then a slightly damp blotting paper was placed under the canvas (fig. 9).

the losses was to add a suggestive drawing: a line drawing rendered on top of the neutral color based on an amateur photograph of the painting before the earthquake. The goal was to bridge the large lacunae to the original parts. For this purpose, the drawing of the original design was traced on a thick Mylar sheet with a permanent marker. The drawing was then transferred onto a large (the size of the woman’s head) tracing paper. Cotton strings were placed vertically and horizontally, along key areas of the image that were used as points of reference, conforming a grid like pattern. This pattern was then transferred onto to the tracing paper as well as to a photocopy of the painting’s photograph. This helped complete the drawing on the large tracing paper and then to transfer the finished product to the lacunae. Even though the drawing was now complete, it didn’t bridge the areas as expected. To reduce the visual disruption, the design was completed with pointillism (painting small color dots). The dots were more densely applied in areas close to the original and more dispersed toward the edges and upper right corner (figs. 5–7).

Figure 5. Transferring the drawing to the lacunae on the forehead of Portrait of an Elderly Woman
Figure 6. Marion Benjamin, *Portrait of an Elderly Woman*, c. 1980s. During inpainting.

Figure 7. Marion Benjamin, *Portrait of an Elderly Woman*, c. 1980s. After treatment.


Figure 9. Max Pinchinat, *Portrait of a Woman*, 1956. During treatment, dry surface cleaning.
Assembly-Line Conservation for the Recovery of Haitian Paintings

boards glued together was shaped to fit the painting. The canvas was lined to a piece of Tyvek, which was then adhered to the Coroplast board. BEVA Gel was used to adhere the tacking edge, and the extra Tyvek was wrapped around the board.

Even though the original surface had a medium textured impasto, this texture was not copied on the new fills. This decision was the result of the ethical discussion about respecting the damages produced by the earthquake as part of the history of the piece. As a result, the fills were toned with a neutral color and the missing design was copied in from an old exhibition catalog and in-painted on a lighter shade with Gamblin colors (figs. 12, 13).

7. STIVENSON MAGLOIRE’S UNTITLED

Stivenson Magloire’s Untitled (1988), the acrylic on board (48 × 48 inches) painting, was rescued in 22 pieces by María Isabel Moreno, owner of Gallery Flamboyant. Three weeks
after she had been almost buried alive under the rubbles of her gallery building along with the artwork, she went back to rescue her favorite piece (fig. 14).

Magloire’s abstract painting, full of political and religious symbolism, made an impact among his peers; he has been compared to Jean-Michel Basquiat. He started his career as a painter at a very early age and was a well-respected painter. He was stoned to death the week Father Aristide returned to Port-au-Prince as president in 1994. Magloire’s damaged painting represented Aristide as an activist Catholic priest.

The painting’s fragments, from tiny to very large, had the edges beveled or delaminated. The Masonite board was very acid.
rigid, and brittle with punctures that were accompanied by planar distortions. Because of the distortions and delamination, the fragments’ edges overlapped when the pieces were assembled (fig. 15).

At the HCRC, the pieces were first puzzled together, and each piece was identified with a number. Next, each fragment was treated one by one either by shaving or cutting its edges or by shaving the inner core of the piece to help diminish the planar distortions when placed under weights. The slow and laborious process took a month until all 22 pieces were adhered together with a sheet of Hollytex to unify the back of the piece and reinforce the support. The next steps were geared to fill a large lacunae on the lower left corner and to add structural support to the Masonite. A sheet of Tyvek was first adhered to two pieces of Coroplast (glued with BEVA Gel). Afterward, the painting was adhered to the covered board but only to five inches around the perimeter to simplify its reversibility in the future. The small losses were mended with Japanese paper and a large lacunae on the lower left corner was completed with layers of thick blotting paper. The gaps were filled with black pigmented Flugger (filler) including the corner lacunae (figs. 16–19).

The large loss presented a challenge in terms of the in-painting because of the lack of photo documentation of the original piece before the earthquake. The large loss was color-reintegrated with fine hatched lines in the style of the Italian “trattegio,” which proved to work with the rest of the painting (figs. 20, 21).
Figure 19. Stivenson Magloire, *Untitled*, 1988. Detail of corner with fill composed of black pigment and plaster.


The project had a great impact on the Haitian community, and the assistants proudly did PowerPoint presentations of their accomplishments to the press and their peers. A great storage facility, incorporating cargo containers, was built on the grounds of the Centre D’Art, where the collection is presently well-guarded.

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Lisa Mehlin, AIC volunteer
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Richard Caton Woodville: In Palette and Process

ABSTRACT

Richard Caton Woodville created what became some of the most iconic images of antebellum America while working abroad. His early education in Baltimore coupled with his studies at the Düsseldorf Academy instilled in him a fairly traditional, conservative painting methodology. By identifying his painting materials and the process involved in creating his compositions, we can appreciate how he transformed his vision of American life onto canvas. His sixteen known paintings were examined and analyzed with a variety of techniques and compared to available drawings and sketches.

1. INTRODUCTION

The Walters Art Museum (WAM) owns eight of the 16 known1 paintings by the mysterious artist Richard Caton Woodville. Images of his paintings are found not only in anthologies of American art but in American history textbooks, illustrating 19th-century uses of the telegraph, the prevalence of the newspaper, and issues of war, antebellum norms, or intergenerational conflict. War News from Mexico (fig. 1) perfectly encapsulates these themes and represents Woodville's tendency to rework his compositions. Woodville's images are useful not only for illustrative purposes, but they were so well regarded in his lifetime that they were widely reproduced in print by the American Art-Union and Goupil.

The saga of Woodville’s professional career is enriched by his dramatic personal life. Woodville was born on April 30, 1825, to an affluent Baltimore family and raised in the distinguished Mount Vernon neighborhood (fig. 2). His earliest education was at St. Mary’s College in nearby Seton Hill, where he took drawing classes. He attended the University of Maryland’s Medical College for only a year. By 1845, Woodville made serious changes to his life: he announced that he had secretly married the 17-year-old daughter of a close family friend, Mary Buckler, and that he was going to be an artist.

Besides his earliest known watercolor, completed when he was in his early teenage years, Woodville’s artistic training in America appears to be self-directed. As a young adult, he often sketched in his personal time, during university courses or while accompanying his close friend, Stedman Tilghman,2 to local almshouses. He visited the home of a local Baltimore collector, Robert Gilmor, Jr., and is believed to have made studies of some of Gilmor’s paintings. Woodville attained some professional success in America, including the commission for a portrait of Baltimore collector Thomas Edmondson and the New York sale of a genre painting, Scene in a Bar-Room, to American Art-Union president Abraham M. Cozzens.
As the artist’s oeuvre is small, a comprehensive examination allowed researchers to make general observations about his materials and his precise, miniaturist-like technique. Scientific analysis identified the artist’s materials and deciphered the methods and techniques Woodville used in making his complex paintings. The findings suggested that Woodville’s traditional working methods and materials were enhanced with new and sometimes expensive pigments very recently introduced into the marketplace. Microscopic examination, x-ray radiographs, infrared reflectography, cross-sectional and elemental analysis identified Woodville’s painting materials and revealed the artist’s skillful working practice. Collaboration with Dr. John Delaney of the National Gallery of Art allowed researchers at the Walters Art Museum to image the paintings using a Santa Barbara Focalplane infrared camera with an InSb detector, identifying changes that remained hidden despite examination with other analytical techniques.

Woodville’s paintings were very carefully composed to project the artist’s keen perception of American life. The genesis of his finished compositions can be understood by examining a small number of seminal drawings and watercolors that were made as preparations for his major compositions. By comparing these preparatory sketches, underdrawings (as revealed in infrared reflectography images), pentimenti (changes in the paint layers as detected in x-ray radiographs) and cross-sections with the final painting, we are able to see the step-by-step transformation in Woodville’s images. By sensitively rearranging figures, objects, and compositions, the artist subtly changed the meaning in his paintings, including the celebrated War News from Mexico recently acquired by the Crystal Bridges Museum.

2. STUDY PROCESS

In preparation for the WAM 2013 exhibition New Eyes on America: The Genius of Richard Caton Woodville, scholars investigating the artist could only guess at his life story from fragments of information, most of which are derived from institutional records. Other pieces exist in a handful of letters surviving outside the Woodville family or in anecdotes. All personal notes within the family—his letters, sketches, and notes on his work—are lost. Despite these losses, the paintings and sketches that survive allowed for an in-depth study into Woodville’s working process.

Initially, only the eight works in the WAM collection were to be studied, both with the analytical equipment available at the WAM and with the assistance of Dr. Jennifer Mass and Catherine Matsen of the Scientific Research and Analytical Laboratory (SRAL) at the Winterthur Museum, Garden and Library. With the support of the lenders for the exhibit, the study grew to include all of the known paintings by the artist.
Each painting was visually examined with the use of stereobinocular magnification, UV, and IRR and was x-ray radiographed using the WAM’s x-ray radiography unit and digital scanner. Initial pigment characterization and ground composition analysis were carried out with the WAM’s ArTAX XRF unit or with Winterthur’s handheld XRF unit.

To clarify compositional changes or singular elemental responses using the XRF unit, cross-sectional samples were taken from paintings. Fragments from the sampling process were saved for FTIR, gas chromatography–mass spectroscopy (GC–MS), or for dispersion and analysis using polarized light microscopy (PLM). After the cross-sectional samples were embedded in acrylic and stained for binder characterization, they were reground for analysis with Raman or scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM–EDX) at Winterthur’s SRAL. The Card Players could not be lent for study before the exhibition, but on-site examination and pigment characterization using the Detroit Institute of Art’s (DIA) ArTAX XRF unit was made possible. In addition, the DIA provided copies of the painting’s x-ray radiograph and infrared reflectographs for interpretation. Each lender was provided with a full report of the technical examination of its painting and the characterization of any materials found.

3. MATERIALS

Woodville was fortunate to paint at a fruitful time of supply for artists. He could buy canvases prestretched and preprimed, even double-primed, in colors varying from white to gray to buff, depending on his purpose. New pigments were also arriving as new methods of refining minerals were developed.

4. SUPPORTS

The earliest paintings attributed to Woodville include his portrait of Thomas Edmondson and Scene in a Bar-Room, both completed in America and painted on commercially prepared pasteboard supports. On the reverse of Thomas Edmondson is an original G. Rowney paper label applied over the multiple-ground preparation (fig. 3).
There was no evidence of a paper label on the reverse of *Scene in a Bar-Room* (fig. 4), but this pasteboard support had also been prepared on both sides by the supplier. Woodville took advantage of this opportunity: on the verso, he sketched a man’s head in graphite, nearly in reverse-profile, and a quick oil study of a solemn female bust (fig. 5).

The awkward composition of the figures in *Scene in a Bar-Room* had previously suggested that this painting had been cut down; however, examination of the edges revealed ground and paint dripping over the edges, showing the size to be original. The awkward placement of the figures results from Woodville’s addition of the right figure late in the painting process, over the previously painted (and dried) door.

The only other solid support Woodville used was a high-quality mahogany panel on which he painted a self-portrait. This panel, prepared by London artists’ colormen Winsor & Newton,4 would have cost as much as two shillings at the time Woodville is believed to have painted this self-portrait. In contrast, the pasteboard supports for *Thomas Edmondson* and *Scene in a Bar-Room* were nine and eight pence, respectively5 (Templeton, 1849). The mahogany panel was also commercially prepared; its ground was composed of lead white in oil bulked with quartz filler.

Other than the previously noted works, rest and majority of Woodville’s oeuvre was painted on canvas. All but three have been lined, their original stretchers have been replaced;6 any information on the stretchers or stamps on the canvas have been covered or lost. In one case, during the relining of *The Sailor’s Wedding*, an original canvas stamp was discovered and photographed (fig. 6). On the remaining unlined paintings, no distinguishing information pertaining to a supplier could be found; however, the variation in weave and in the coarseness of the canvas, as well as the various suppliers indicated by the surviving stamps and labels, suggest that Woodville was not dedicated to any one particular supplier. Rather, it seems he purchased artists’ materials on an ad hoc basis, with some attention paid to materials indeterminate.

Woodville’s preferences seemed to include finely woven canvases, particularly twill-weave canvases, which he used for four of his paintings. Three of these are his finest and most recognizable genre
paintings: The Card Players, War News from Mexico (fig. 7), and Old ’76 and Young ’48. Twill-weave cloth, occasionally known as “ticken,” was preferred by some artists because it was thought that the diagonal pattern had the capacity to retain more paint. Twill-weave fabric was more costly to produce, resulting in a slight markup for commercially prepared twill canvases. The 1849 catalog of materials by G. Rowney lists various sizes of “Prepared Canvass and Ticken” [sic] (Templeton, 1849). For a prepared canvas the approximate size of Old ’76 and Young ’48, Woodville could have purchased a “24 [inch] by 20 [inch] canvas . . . on plain frame,” for three shillings if the fabric was prepared plain-weave canvas, four shillings if it was prepared ticken. If Woodville desired a “stretching frame,” the price rose to four shillings for canvas, and five shillings for ticken. The twill canvases used for the four paintings were not made from the same fabric; the patterns of the twills were either 2/1 or 3/1 fractions of warp and weft, and the thread counts varied between 16/25 and 41/48 threads per inch. Woodville’s plain-weave canvases were fine and often closely woven, with thread counts measuring 30/30 to 44/48 threads per inch.

5. GROUNDS

In many cases, primary and secondary cusping could be seen in the x-ray radiographs. The pasteboard supports have multiple grounds. For Thomas Edmondson, the board was first prepared with chalk in glue, then lead white in oil, and the final ground was a medium-value gray of mixed pigments in oil. All three of these grounds were applied on both sides of the pasteboard, in contrast to the grounds applied to the board for Scene in a Bar-Room. For this pasteboard, a layer of lead white in oil was applied to both sides of the board, and then a layer of mixed gray in oil was applied to one side, over which Woodville painted his primary composition. Grounds in Woodville’s other works were either one or two layers of lead white bound in a drying oil, characterized first through XRF analysis and cross-sectional staining, and confirmed with FTIR, Raman, or SEM. Many of the grounds also had bulking agents, including barium sulfate, chalk, quartz, and silicates.

6. UNDERDRAWING

Initial infrared reflectography (IRR) with a Vidicon did not reveal underdrawing that was not already visible with magnification, but the NGA’s advanced Focalplane infrared camera revealed striking underdrawings that had been previously hidden. Several paintings had underdrawings, executed in both dry and wet media (see chart in appendix). One was executed in dry media only (graphite); three in both dry and wet media; and four in wet media only. For the wet media, the artist typically used a thinned paint, often applied with a narrow brush, in long, fluid strokes (fig. 8).
A grid system was found in two of his oil paintings, *War News from Mexico* (fig. 9) and *The Cavalier’s Return* (figs. 10, 11). The use of the grid suggests the transfer of a finished composition from a smaller sketch onto the prepared canvas. The sketches for these paintings unfortunately have been lost over time. Only a few preparatory sketches for his existing oil paintings survive, and none shows evidence of gridlines.

7. PAINT APPLICATION

Woodville painted methodically. After creating his underdrawing, the artist often applied a layer of *imprimatura* to block in the shadows of his composition, generally scraping it down to reveal the texture of the ground beneath. Ten paintings exhibited an *imprimatura*; seven are red-brown in tone (fig. 12).

The most vivid example of the red-brown *imprimatura* is found in the quick oil sketch of the woman’s head on the reverse of *Scene in a Bar-Room*, unfinished over the brusquely applied background strokes (fig. 5). The *imprimatura* served as Woodville’s midtone, and is visible in many of the negative spaces between passages.

Figure 8. Detail of *The Sailor’s Wedding*, 1852. Thin wet lines of the underdrawing used to define the space are visible (marked by arrows) underneath glazes of paint.

Figure 9. Detail, IRR, 2100–2500 nm, of architecture in *War News from Mexico* (fig. 1); a sampling of gridlines indicated by arrows. An additional gridline, offset from the regular interval, is also present (blue arrow).

Figure 11. Detail, IRR, 2100–2500 nm, of central figures in *The Cavalier’s Return*, gridlines are visible (a sampling noted by arrows), and over the cavalier’s proper right shoulder, the window was originally painted shut.

Figure 12. Sample A from *Politics in an Oysterhouse*. The red-brown imprimatura is visible between the ground layers and multiple green layers used to depict a green umbrella.
preferred by artists for their properties of hue, tinting strength, and, to some degree, availability. Present in all of his paintings are lead white, carbon black, vermilion, ocher and other earth colors, and Prussian blue. From the beginning of his career in Baltimore, Woodville used bone black (confirmed by the presence of phosphorus), emerald green, and verdigris.

Woodville’s palette expanded considerably with training in Europe. Pigments not used in Baltimore found their way into his palette, including Naples yellow, cobalt blue, and chrome-based yellows and reds. Rather than relying on green pigments alone, he typically blended his green passages from Prussian blue and chrome yellow. A commercial blend of this green was marketed as “green cinnabar” or “chrome green,” and Woodville may have purchased this blend or mixed it on his palette. A variant of chrome-based yellow, generically known as lemon yellow, was widely available as early as 1847, and Woodville used it as soon as he began studying in Düsseldorf. Lemon yellow could be made with barium chromate, strontium chromate, or a blend of the two. The characteristic energies for barium, strontium, and chromium were detected in light green hues in *The Cavalier’s Return* (fig. 10) and in light yellow flowers in *War News from Mexico*, indicating some use of this pigment.

The most significant finding regarding Woodville’s palette was the introduction of cadmium-based pigments. Cadmium is present in the finely painted orange highlights in the peacock feather at the foreground of *War News from Mexico*, and in the bright yellow highlights in the china in *Old ’76* and *Young ’48*. Cadmium was detected only in minute areas such as highlights applied near the end of each painting’s completion, suggesting a parsimonious application. While suggested for use as a pigment in the first quarter of the 19th century, cadmium availability was limited by difficulties in production until thirty years later (Feller 1986, 67). Even when commercial production increased, cadmium pigments were costly. Available as early as 1846 from Winsor & Newton, by 1863—eight years after Woodville’s death—they were still one of the most expensive pigments to purchase, either in watercolor or in oil. Vermilion, lead white, and chrome oil paints could be purchased for four pence per tube, but a tube of cadmium orange, yellow pale, or yellow deep oil paint was priced at one shilling, six pence (more than four times as much). If the cost of the pigment did not deter Woodville from use, perhaps it was the relative scarcity of the pigment. In 1850, when Woodville was actively painting, George Field wrote the following on the difficulty of acquiring cadmium-based paints: “The metal from which it is prepared being hitherto scarce, it has been as yet little employed as a pigment” (Field 1850, 34–35).

No caches of supplies or palettes are known and it was necessary to create the artist’s theoretical palette by characterizing the pigments in the paintings by analyzing approved samples. Throughout his career, Woodville’s palette centered around traditional mineral pigments consistently
9. CHANGES IN COMPOSITION

Infrared reflectography confirmed a number of compositional changes, some of which could be initially inferred through visual examination, *pentimenti*, and x-ray radiography. Despite Woodville’s use of sketches and underdrawings and his practice of transferring compositions onto his canvases with a grid system, he struggled with his paintings. Some of the changes were simple, such as reworking a profile or repainting the background. Other changes had dramatic effects on the narrative.

*Old ’76 and Young ’48* depicts a wounded soldier returning from the Mexican–American War. He sits at the dining-room table to tell his stories of war, surrounded by his concerned family, as the family servants hover at the threshold. The soldier’s grandfather, a Revolutionary War veteran, stares into the fire, a troubled expression on his face. A number of changes helped Woodville create a focused, layered setting. The framed print over the fireplace, John Trumbull’s *Declaration of Independence*, was initially on the back wall. In its place was an oval portrait, which might have depicted the grandfather or another Revolutionary War hero, George Washington. The marble bust on the cabinet in the back corner also pays homage to George Washington. The cabinet on which it rests was originally a wider, shorter hutch with its door open, which blocked part of the print when it hung on the back wall. In addition, the door to the room originally opened from the opposite hinge; changing it removes the physical barrier between the servants and the family group. Most dramatically, the soldier’s uniform was changed from that of the Second Seminole War to that of the Mexican–American War.7

Woodville also took *War News from Mexico* through a number of changes, giving its viewers the opportunity to form their own opinions. In this painting, a crowd of onlookers gathers on the steps of the American Hotel to hear the newspaper read aloud. Originally, the hotel was a tavern, as revealed by a sign (originally “TAVERN”) uncovered by IRR. The pensive man at the back left, perhaps knocking his knuckles for luck, was originally a hat-swinging celebrant (figs. 14, 15). Woodville changed this figure entirely, dropping his head, shifting his expression, moving his hand, making the soft cap a wide-brimmed straw hat, and then eliminating the hat entirely. Woodville removed the passion from the picture by painting this figure as contemplative rather than expressive, which would engage the viewer. This transformation removed the figure’s powerful response to the news, leaving the viewer to form his own reaction.

10. INTERLAYER VARNISHES

One unfinished Woodville painting revealed the presence of a working varnish. The *Portrait of a Woman* had a layer of opaque, white, almost crystalline material across most of its surface, except in one upper corner, which had been partially repainted. Examination revealed this layer to be underneath the repainted corner, indicating its use as a working varnish. This working varnish was only soluble in a solution tailored for proteins. (It was necessary to reduce the varnish to make the painting ready for exhibition; treatment was performed in 1990 by Eric Gordon.) The use of egg white as a temporary varnish has been documented previously.
change was distinguished by the auto-fluorescing varnish above it. These interlayer varnishes coalesced into a single, thick layer in the cross section taken from an area in the hurdy gurdy (figs. 18, 19). The red paint of the hurdy gurdy over the interlayer varnishes, and the repainted left hand, confirm the addition of the instrument and the olive green lap blanket in the final stages of the painting process. This portrait may not have been originally intended to be a musical street performer, but it became one in the end. The interlayer varnish in this painting could only be characterized as a natural resin using FTIR, but there was indication that it could be shellac.

From the extensive, scholarly research conducted by Lance Mayer and Gay Myers (1998, 2011) and Leslie Carlyle (2001), we know that oleo-resinous varnishes and fossil resins were commonly used as picture varnishes, as was bleached shellac. As Dr. Kenneth Sutherland has noted, the use of bleached shellac as a picture varnish during the 19th century is much more prevalent than was previously thought (2010, 129–149). In his 1841 edition of Chromatography, George Field wrote of “white lac” (bleached shellac) to be “more perfect as [a] varnish” than mastic or copal (Field 1841, 380–381).

At least three other paintings showed some indication of interlayer varnishes in their cross-sections when viewed in UV light. One of these, Italian Boy with a Hurdy Gurdy (fig. 16), had several layers of interlayer varnish between numerous changes. The boy was initially painted without an instrument, and his pose was adjusted at least twice (fig. 17). At one point during this process, he looked out at the viewer with a desultory expression, the brim of his hat just above his eyes. After lifting the boy’s head over his left shoulder and exposing his neck, Woodville was finally satisfied with his composition. Each change was marked with an application of varnish over the entire painting. In a sample taken adjacent to an existing loss in the face, each layer of paint depicting a change was distinguished by the auto-fluorescing varnish above it. These interlayer varnishes coalesced into a single, thick layer in the cross section taken from an area in the hurdy gurdy (figs. 18, 19). The red paint of the hurdy gurdy over the interlayer varnishes, and the repainted left hand, confirm the addition of the instrument and the olive green lap blanket in the final stages of the painting process. This portrait may not have been originally intended to be a musical street performer, but it became one in the end. The interlayer varnish in this painting could only be characterized as a natural resin using FTIR, but there was indication that it could be shellac.

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Figures 16 and 17. Richard Caton Woodville, Italian Boy with a Hurdy Gurdy, 1853, oil on canvas, 36⅞ × 28 in; Walters Art Museum, Baltimore (Courtesy of Susan Tobin, Walters Art Museum) X-ray radiograph of the changes over the face, with changes highlighted; the final version is depicted in green.
Figures 18 and 19. Sample taken from the hurdy gurdy, adjacent to the boy’s hand. The layers of paint depicting the brown coat and the red of the hurdy gurdy are separated by a fluorescing layer of natural resin, visible when viewed through a UV filter cube.
Shellac is bleached by exposure to chlorine gas, which destroys its naturally orange autofluorescence in ultraviolet irradiation. It must therefore be identified by other means. Because GC–MS would have required samples that were too large to obtain, Catherine Matsen of Winterthur's SRAL pursued characterization of the interlayer varnish through another analytical technique. In the interlayer varnish portion of the sample taken from *Italian Boy with the Hurdy Gurdy*, SEM–EDS detected trace amounts of chlorine, which is possibly an artifact of the shellac-bleaching process.

11. OTHER FINDINGS

Other interesting findings hint at Woodville's studio practices. His smallest finished oil portrait, *Maria Johnston*, was completed on canvas, and at one point it was cut into a circle and glued onto a green card. The card has an indecipherable ink drawing on one side, hinting at its original life as a drawing card, but it has been cut down and repurposed as a secondary support. The marouflaged support of this painting looks as though it were made by Woodville himself, as faint incised lines relating to the painting's new size were made directly into the background of the painting when it was still quite soft and malleable.

When *Portrait of a Woman* was discovered in 1990 by Eric Gordon, it had been tacked underneath Woodville's *Self-Portrait on Canvas*. The painting was abandoned but not painted over; rather, it was likely covered up by the artist when he may have tacked his own portrait to the stretcher at all four corners. The self-portrait itself was painted over an earlier portrait of an older man, which was covered with a thick layer of lead white before Woodville painted his own image. The portrait was then cut down and the canvas tacked over the *Portrait of a Woman*.

12. SUMMARY

This technical study revealed broad changes in Woodville's technique and materials over his brief 10-year professional career. After beginning his training in Europe, Woodville's working practices shifted from using solid supports with gray grounds to canvas supports with white grounds. His use of twill-weave canvases for his more complex-genre paintings may have been a deliberate choice based on the way the texture of the weave picked up the paint from the brush. Woodville's palette also expanded to include chrome-based pigments, emerald green, Naples yellow, and cadmium-based pigments. While he struggled with his compositions from the outset of his career, he began to use temporary varnishes between his campaigns of reworking beginning in the late 1840s. No singular material stands out as his medium of choice for temporary varnish, but he experimented with both egg white and probably bleached shellac, and may have adjusted his media to suit his working practices.

Woodville was not a bravura painter; his brushstrokes, even when sure, are short, staccato, and multilayered, countered with wandering brushstrokes reinforcing silhouettes. By the late 1840s, his technique evolved to include the hatching and stippling brushstrokes used by miniaturists, particularly when he painted faces. Although Woodville was a successful artist of his time, and could afford expensive twill-weave canvases and cadmium pigments, there is still a sense of economy about his materials. He reworked his paintings extensively, especially those on twill, and went as far as transferring a compositional sketch for *War News from Mexico* onto the canvas before beginning the painting.

Although this study adds only a small part to the growing body of published information in the field of technical art history, it provides a basis of material characterization of Woodville's paintings that may assist in future attributions.

ACKNOWLEDGMENTS

This technical study was supported financially by the Wyeth Foundation for American Art. The breadth of scientific research accomplished in such a short time was made possible in large part through the assistance of Dr. Jennifer Mass and Catherine Matsen of the Winterthur Museum, Garden and Library’s Scientific Research and Analytical Laboratory, who devoted countless hours to analysis and interpretation, and Dr. Chris Petersen, who performed GC–MS analysis. We are truly grateful for their help. Dr. Glenn Gates of the Walters Art Museum aided in on-site analysis and interpretation. We would also like to thank Dr. John Delaney (National Gallery of Art), Kristin de Ghetaldi (Ph.D. candidate, University of Delaware), Dr. Paula Ricciardi (The Fitzwilliam Museum), Dr. Joyce Hill Stoner (University of Delaware), Carol Aiken (conservator in private practice, Baltimore), Alfred Ackerman and Dr. Cathy Selvius de Roo (Detroit Institute of Art), Dare Hartwell (Corcoran Gallery of Art), and Dr. Joy Heyrman (Walters Art Museum). We are indebted to our colleagues for their support and encouragement of the study. All uncredited images are by the authors.
### APPENDIX 1. FRAMES, STRETCHERS, AND SUPPORTS

#### TABLE 1. FRAMES, STRETCHERS, SUPPORTS

<table>
<thead>
<tr>
<th>Title</th>
<th>Date</th>
<th>Frame</th>
<th>Stretcher</th>
<th>Lined</th>
<th>Original Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Thomas Edmondson</td>
<td>ca. 1844</td>
<td>Post-1850s</td>
<td>none</td>
<td>—</td>
<td>pasteboard</td>
</tr>
<tr>
<td>Scene in a Bar-Room</td>
<td>1845</td>
<td>not original</td>
<td>none</td>
<td>—</td>
<td>pasteboard</td>
</tr>
<tr>
<td>The Card Players</td>
<td>1846</td>
<td>possibly original</td>
<td>replacement</td>
<td>yes</td>
<td>twill (n/a)1</td>
</tr>
<tr>
<td>Portrait of a Woman</td>
<td>1846–1849</td>
<td>not original</td>
<td>original</td>
<td>no</td>
<td>twill (44/48)1</td>
</tr>
<tr>
<td>The Soldier’s Experience&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1847</td>
<td>not original</td>
<td>—</td>
<td>—</td>
<td>paper</td>
</tr>
<tr>
<td>Head of a Soldier</td>
<td>1847</td>
<td>not original</td>
<td>original</td>
<td>no</td>
<td>twill (41/48)1</td>
</tr>
<tr>
<td>The Cavalier’s Return</td>
<td>1847</td>
<td>—</td>
<td>replacement</td>
<td>yes</td>
<td>plain (46/36)1</td>
</tr>
<tr>
<td>Portrait of Maria Johnston</td>
<td>1847</td>
<td>original</td>
<td>none</td>
<td>glued to board</td>
<td>plain (n/a)1</td>
</tr>
<tr>
<td>War News from Mexico</td>
<td>1848</td>
<td>not original</td>
<td>possibly original</td>
<td>yes</td>
<td>twill (n/a)1</td>
</tr>
<tr>
<td>Politics in an Oyster House</td>
<td>1848</td>
<td>not original</td>
<td>replacement</td>
<td>yes</td>
<td>plain (42/36)1</td>
</tr>
<tr>
<td>Self-Portrait in a Black Coat</td>
<td>1848–1850?</td>
<td>not original</td>
<td>replacement</td>
<td>yes</td>
<td>plain (30/30)1</td>
</tr>
<tr>
<td>Self-Portrait with Flowered Wallpaper</td>
<td>1848–1850?</td>
<td>not original</td>
<td>none</td>
<td>—</td>
<td>mahogany panel</td>
</tr>
<tr>
<td>Old ’76 and Young ’48</td>
<td>1849</td>
<td>original</td>
<td>replacement</td>
<td>yes</td>
<td>twill (16/25)1</td>
</tr>
<tr>
<td>Old Woman and Child Reading a Book</td>
<td>1840’s</td>
<td>possibly original</td>
<td>possibly original</td>
<td>yes</td>
<td>plain (30/32)1</td>
</tr>
<tr>
<td>Waiting for the Stage</td>
<td>1851</td>
<td>—</td>
<td>replacement</td>
<td>yes</td>
<td>plain (31/29)1</td>
</tr>
<tr>
<td>The Sailor’s Wedding</td>
<td>1852</td>
<td>not original</td>
<td>replacement</td>
<td>yes</td>
<td>plain (36/36)1</td>
</tr>
<tr>
<td>The Italian Boy with the Hurdy Gurdy</td>
<td>1853</td>
<td>not original</td>
<td>replacement</td>
<td>yes</td>
<td>plain (40/44)</td>
</tr>
</tbody>
</table>

1. (thread/in)  
2. This gouache is an early version of the narrative found in *Old ’76 and Young ’48*, but there are dramatic compositional changes between the two works.
### APPENDIX 2. GROUNDS, UNDERDRAWINGS, IMPRIMATURA, AND PALETTE

**TABLE 2. GROUNDS, UNDERDRAWINGS, IMPRIMATURA, AND PALETTE**

<table>
<thead>
<tr>
<th>Title</th>
<th>Ground Underdrawing</th>
<th>Imprimatura</th>
<th>White</th>
<th>Black</th>
<th>Red</th>
<th>Orange</th>
<th>Yellow</th>
<th>Blue</th>
<th>Green</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Dr. Thomas Edmondson</em></td>
<td>Chalk¹ in glue, lead white¹, in oil, mixed gray in oil</td>
<td>no</td>
<td>—</td>
<td>lead white¹,²</td>
<td>carbon¹,²</td>
<td>vermilion²</td>
<td>—</td>
<td>iron oxide²</td>
<td>Prussian¹</td>
<td>verdigris¹,³, chalk¹</td>
</tr>
<tr>
<td><em>Scene in a Bar-Room</em></td>
<td>lead white¹ in oil, mixed gray in oil</td>
<td>no</td>
<td>—</td>
<td>lead white¹,²</td>
<td>carbon¹,², bone²</td>
<td>vermilion mixture</td>
<td>iron oxide²</td>
<td>Prussian¹</td>
<td>mixture</td>
<td>chalk¹</td>
</tr>
<tr>
<td><em>The Card Players</em></td>
<td>lead white in oil</td>
<td>yes</td>
<td>red-brown</td>
<td>lead white</td>
<td>carbon, bone</td>
<td>vermilion</td>
<td>chrome</td>
<td>iron oxide, chrome, Naples</td>
<td>Prussian, cobalt</td>
<td>mixture</td>
</tr>
<tr>
<td><em>Portrait of a Woman</em></td>
<td>lead white in oil</td>
<td>yes, dry and wet</td>
<td>red-brown</td>
<td>—</td>
<td>carbon</td>
<td>vermilion, chrome, red lake¹</td>
<td>—</td>
<td>iron oxide, chrome</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>The Soldier’s Experience</em>²</td>
<td>n/a</td>
<td>yes, dry and wet</td>
<td>no</td>
<td>lead white</td>
<td>bone</td>
<td>vermilion mixture</td>
<td>iron oxide</td>
<td>Prussian</td>
<td>mixture</td>
<td>—</td>
</tr>
<tr>
<td><em>Head of a Soldier</em></td>
<td>lead white in oil</td>
<td>no</td>
<td>red-brown</td>
<td>lead white²,³</td>
<td>carbon, bone²</td>
<td>vermilion</td>
<td>—</td>
<td>iron oxide²</td>
<td>cobalt</td>
<td>—</td>
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<tr>
<td><em>The Cavalier’s Return</em></td>
<td>lead white in oil</td>
<td>grid: dry and wet</td>
<td>red-brown</td>
<td>lead white³</td>
<td>carbon³</td>
<td>vermilion, red lake</td>
<td>—</td>
<td>iron oxide², lemon yellow¹</td>
<td>Prussian</td>
<td>mixture</td>
</tr>
<tr>
<td><em>Portrait of Maria Johnston</em></td>
<td>lead white in oil</td>
<td>no</td>
<td>red-brown</td>
<td>lead white</td>
<td>carbon</td>
<td>vermilion</td>
<td>—</td>
<td>iron oxide</td>
<td>Prussian</td>
<td>mixture</td>
</tr>
<tr>
<td><em>War News from Mexico</em></td>
<td>lead white² in oil</td>
<td>yes, dry and wet; grid: dry</td>
<td>yes</td>
<td>lead white²</td>
<td>carbon,² bone²</td>
<td>vermilion, cadmium, chrome</td>
<td>cadmium, chrome</td>
<td>iron oxide², lemon yellow¹,²</td>
<td>Prussian, copper-based</td>
<td>mixture, copper-based</td>
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(Continued)
<table>
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<tr>
<th>Title</th>
<th>Ground</th>
<th>Underdrawing</th>
<th>Imprimatura</th>
<th>White</th>
<th>Black</th>
<th>Red</th>
<th>Orange</th>
<th>Yellow</th>
<th>Blue</th>
<th>Green</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Politics in an Oyster House</td>
<td>lead white²</td>
<td>yes, wet</td>
<td>red-brown</td>
<td>lead white², bone⁴</td>
<td>vermilion⁵</td>
<td>—</td>
<td>iron oxide², chrome²</td>
<td>Prussian</td>
<td>mixture</td>
<td>magnesium dioxide</td>
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<tr>
<td>Self-Portrait in a Black Coat</td>
<td>lead white²</td>
<td>—</td>
<td>—</td>
<td>lead white³, bone⁴</td>
<td>vermilion, chrome</td>
<td>—</td>
<td>iron oxide, chrome</td>
<td>—</td>
<td>—</td>
<td>barium², magnesium dioxide³</td>
<td></td>
</tr>
<tr>
<td>Self-Portrait with Flowered Wallpaper</td>
<td>lead white²</td>
<td>yes, dry</td>
<td>no</td>
<td>lead white¹, charcoal²</td>
<td>vermilion, chrome</td>
<td>—</td>
<td>iron oxide, chrome</td>
<td>Prussian</td>
<td>mixture</td>
<td>copper-based, quartz²</td>
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<tr>
<td>Old ’76 and Young ’48</td>
<td>lead white²</td>
<td>yes, wet</td>
<td>—</td>
<td>lead white¹, bone⁴</td>
<td>vermilion¹², cadmium, chrome¹</td>
<td>cadmium, chrome¹</td>
<td>iron oxide, chrome¹, cadmium¹</td>
<td>Prussian¹²</td>
<td>emerald³</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Old Woman and Child Reading a Book</td>
<td>lead white</td>
<td>no</td>
<td>—</td>
<td>lead white</td>
<td>carbon</td>
<td>vermilion</td>
<td>—</td>
<td>iron oxide</td>
<td>—</td>
<td>—</td>
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<td>Waiting for the Stage</td>
<td>lead white¹²</td>
<td>yes, wet, bone²</td>
<td>yes</td>
<td>lead white¹², bone⁴</td>
<td>vermilion¹², cadmium, chrome¹</td>
<td>cadmium, chrome¹</td>
<td>iron oxide¹², Naples², chrome¹</td>
<td>Prussian¹³</td>
<td>emerald³</td>
<td>lead sulfate/sulfite drier¹</td>
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</tr>
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<td>The Sailor’s Wedding</td>
<td>lead white¹</td>
<td>yes</td>
<td>yes</td>
<td>lead white¹</td>
<td>carbon¹</td>
<td>vermilion², chrome</td>
<td>—</td>
<td>iron oxide¹</td>
<td>Prussian¹</td>
<td>emerald¹</td>
<td>barium sulfate¹</td>
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<td>The Italian Boy with the Hurdy Gurdy</td>
<td>lead white²</td>
<td>possibly</td>
<td>—</td>
<td>lead white¹, bone⁴</td>
<td>vermilion², cadmium, chrome</td>
<td>cadmium, chrome, mixture</td>
<td>iron oxide², chrome¹, cadmium¹², cadmium, napes²</td>
<td>Prussian³</td>
<td>emerald³</td>
<td>gypsum¹, interlayer varnish</td>
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</tr>
</tbody>
</table>

All pigments characterized by XRF
1. confirmed through Raman
2. confirmed through SEM-EDX
3. confirmed through FTIR
4. Elements Ba, Sr, and Cr were detected, all of which could make up lemon yellow variants
NOTES

1. The Portrait of Edwin Booth, the earliest known painting, which descended in the sitter’s family came to light during the exhibition. 9 15/16 × 6 15/16 in., oil on board.

2. Many of these sketches survive in the Dr. Stedman R. Tilghman Scrapbook collection of the Maryland Historical Society (J. Hall Pleasants Papers, 1773–1957, MHS 194).


4. There is an earlier label hidden underneath this visible label and a layer of tan-colored paint. As Winsor & Newton changed the format of its label in 1844, when it received royal designation from Queen Victoria and Prince Albert, an date could be established for this painting. This panel may have been re-prepared and relabeled in 1844.

5. Twelve pence would equal one shilling. The prices were found in an 1849 artists’ materials catalog duplicated at the end of Templeton’s The Guide to Oil Painting (Templeton 1849).

6. Two paintings have their original stretchers: Head of a Soldier and Portrait of a Woman. There is no evidence of disruption to their tacking edges.

7. The uniform is the same as one worn by a soldier in The Soldier’s Experience; a gouache with a similar narrative to Old ’76 and Young ’48.

8. The Portrait of a Woman was hidden beneath Woodville’s Self-Portrait when it entered the Walter’s collection. The female sitter bears a striking resemblance to the artist’s first wife, Mary Buckler, when compared to a known portrait of Buckler (private collection) by Carl Ferdinand Sohn, Woodville’s Dusseldorf art teacher. The Self-Portrait passed through the artist’s second wife’s family who may not have been aware of the portrait below or who hid it intentionally. In its unfinished state, it provides a window into Woodville’s painting process.

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ABSTRACT

Henri Matisse was one of the great pioneers of modern European painting. His body of work from 1913–17 has been referred to as his most experimental and innovative because of his use of a subdued palette that included the use of black, and a varied working technique comprising complicated layering due to compositional revisions (D’Alessandro and Elderfield 2010). Two of his paintings from the Fogg Museum’s Wertheim Collection, Geraniums, 1910 (originally dated 1915) and Still Life with Apples, 1916, were subject to a technical analysis to understand the materials, development, and structure of these significant works and to determine whether or not they displayed the characteristics of the 1913–17 period. Treatment of both paintings was also completed as part of the project.

1. INTRODUCTION

In June of 2008, the Harvard Art Museums in Cambridge, Massachusetts, closed its doors to the public to remove its collections in preparation for the renovation and reconstruction of the 81-year old building. One of the museums’ most important groups of objects is the Maurice Wertheim Collection, which contains Impressionist and Post-Impressionist paintings, drawings, and sculptures ranging from 1860 to 1930. The body of artwork was originally bequeathed in 1950 to the Fogg Museum with three stipulations: (i) the collection was to remain a single entity, (ii) it was to be placed on permanent exhibition, and (iii) it was to be made available for the use of Mrs. Wertheim for as long as she was alive and still resided at their New York residence on East 70th Street (O’Brien 1988). Ultimately the works remained in New York from 1950 until 1974 when Mrs. Cecile Wertheim passed away (O’Brien 1988). During the summer months when she vacated the townhouse—or when the works were loaned to other museums for exhibitions—however, the artworks were on display in Cambridge (O’Brien 1988). This meant the artwork was traveling quite frequently during this short time span and was not on continuous permanent view at the Fogg Museum until 1974. From that time on, however, none of the paintings has been off view for more than three months at a time, which has never permitted a focused technical examination of their materials and techniques.

This article will focus on the research and treatment of two particular paintings from this collection: Geraniums, 1910 (originally dated 1915) and Still Life with Apples, 1916, both by Henri Matisse. What makes this opportunity for research on these paintings so enticing is the very narrow range of dates between the two, which correspond to a particularly experimental time period in Matisse’s career. Historian Alfred J. Barr wrote about the work from this period as having “a power of invention and an austerity of style scarcely equaled at any other time in Matisse’s career, setting it apart as a period of radical invention” (D’Alessandro and Elderfield 2010). Except for the recent 2010 publication by the Art Institute of Chicago and Museum of Modern Art, New York, entitled Matisse: Radical Invention, 1913–17, very little has been published about the materials and methods used by Matisse during this time.

The goal of the project was to understand the characteristics of Matisse’s 1913–17 work in an effort to define whether Geraniums and Still Life with Apples fit within this period. Historical research and materials analysis guided a technical examination to better understand Matisse’s materials and working methods as exhibited in Geraniums and Still Life with Apples. Through materials identification and understanding Matisse’s technique, various stages of the paintings were recreated with digital image manipulation. Overlapping with the technical research, a proposal was submitted to remove the synthetic varnishes present on both paintings.

2. 1913–17 PERIOD

2.1 Historical Relevance

Looking at the entirety of Matisse’s career, the 1913–17 period correlates with World War I. In the beginning of 1913, Matisse returned to France from his extended trip to Morocco and left...
Matisse had fewer interactions with fellow artists and dealers, relationships which fostered his early work. The influence of the war most likely limited Matisse’s access to artist’s materials, which ultimately may have affected the number of works he produced during this period as well as his method of production.

2.2 Characteristics

One of the distinguishing characteristics of the 1913–17 period of Matisse’s work is his use of a subdued palette (D’Alessandro and Elderfield 2010). Blues, grays, and black become the main characters in his palette (fig. 1). The use of black in a large portion of a composition is new to Matisse. He refers to the use of black as a force, used as a ballast to simplify the construction as well as a color of light, not dark, and compares its luminosity to other colors used at this time (D’Alessandro and Elderfield 2010).

The other distinguishing characteristic of the pieces of the 1913–1917 period is the constant compositional reworking that occurred on the same support (D’Alessandro and Elderfield 2010). A primary example is Bathers by a River (fig. 2), of which there are early photographs documenting the various stages of the painting (figs. 3, 4). Revisions during this period include multiple changes to a composition as well as dramatic changes in color. There are few related sketches for many of the 1913–17 paintings, which support the idea of Matisse working and reworking his ideas out on the same canvas, rather than preplanning with preliminary sketches.
Figure 3. *Bathers by a River* photographed in progress, 1913. The Art Institute of Chicago

Figure 4. *Bathers by a River* photographed in Fifth State, 1916. The Art Institute of Chicago
3. STILL LIFE WITH APPLES, 1916

3.1 Background and Related Paintings

Still Life with Apples is an oil (est.) painted on a mahogany panel (est.) approximately 12 15/16 H × 16 3/16 W and ¼ in. diameter (figs. 5, 6). The panel was most likely commercially prepared (est.), and the ground contains lead white, barium sulfate, and linseed oil (est). The panel, ground, and paint layers are all in good condition. A comparable work was identified in the Barnes Collection entitled Still Life with Lemons and dates to 1917. This painting is also an oil on panel of approximately the same size. When compared with other works from Matisse’s career Still Life with Apples resembles several other works (fig. 1) from the 1913–17 period in both subject matter and palette.

3.2 Technical Analysis

Some indications of a contour line drawing are visible in the IRDP of Still Life with Apples (fig. 7) in the left apple and the front edge of the table, which indicates a previous change in the angle of the table edge. Looking at the x-ray radiograph (fig. 8), however, allows for a great deal of insight into the compositional revisions. Changes seen in the x-ray radiograph include a widening of the mouth of the glass, altering all three angles of the table top, shifts in perspective of the apples, and a smaller perimeter of the plate.
Indications of compositional revisions are also visible through dramatic changes in color detected throughout the painting under magnification, which are confirmed by the layer structure visible in cross sections taken from these same areas. Numbers in cross sections correlate to paint layers and letters correspond to possible varnish layers. Looking at cross section 1 (fig. 9) and macrograph 1 (fig. 10) layers 3, 4, and 5 can be correlated. Layer 4, visible through the apertures of the cracks, indicates the previous extension of the top table edge, which Matisse changed by covering with layer 5’s light gray paint. Cross section 2 (fig. 11) and macrograph 2 (fig. 12) show that no changes had been made to the color of the table top. The ground is visible in the crack apertures, layer 1, in the macrograph with only blue paint, layer 2, applied on top. Cross section 3 (fig. 13) and macrograph 3 (fig. 14) are comparable to cross section 2 and macrograph 2 in that no major color changes or compositional revisions are present. The ground, layer 1, is visible through the crack apertures and the uppermost paint layer, layer 3, is visible on top. Ultimately, multiple layers of paint in the cross sections indicate compositional changes or shifts in color schemes.

Pigment analysis for Still Life with Apples identified a rather limited palette including the use of cadmium red, chrome green, and cadmium yellow, ultramarine blue, bone black, and lead white (fig. 15). This information was based on analytical data collected from cross section analysis with RLM and Raman spectroscopy, and sample analysis using FTIR, as well as in situ XRF.

By surveying and combining all the information collected including the altered composition seen in the x-ray radiograph, noting shifts in color under magnification, and adding pigment identification and paint structure, an approximation of what the painting may have looked like during its construction was...
Figure 13. Cross Section 3 of Still Life with Apples

Figure 14. Macrograph 3 of Still Life with Apples

Figure 15. Palette of Still Life with Apples (from left to right): cadmium red, cobalt green, ultramarine, bone black, and lead white

created. On the basis of color measurements taken in Adobe Photoshop, the image represents just a possible state in the process of Matisse’s revisions. Although the actual progression of the painting is unclear and could only be understood from further cross section analysis, it is likely that the color composite may represent one early state of the painting.

Color composite 1 (fig. 16) shows a change in background color, a shift in perspective of the apple cores and a shape change in the left apple, a wider mouth of the glass, and a smaller plate. The back of the table top is extended and angles of the table are straight. From here, it is possible that the perspectives of the apples, perimeter of the plate, and the mouth of the glass were placed in their final states. The last addition of paint may have been the gray background, seen in the final state (fig. 5).

3.3 Treatment

Still Life with Apples has gone through a significant amount of treatment, most of which involved altering the surface coatings. Viewing the painting in oblique specular light showed the dull, plastic-like quality of the surface coatings (fig. 17). The brush strokes were lost, and the original colors appeared quite yellow and gray because of the poor aging characteristics of the surface coatings. Reading through the conservation file provided a great
deal of insight into what lay on the surface of the painting. The most recent treatment occurred in the mid-80s and involved reducing a natural resin varnish and adding 4–5 brush and spray applications of Winton’s Picture Varnish and Soluvar Matte Varnish. Viewing the UVA-induced visible fluorescence image (fig. 18), a characteristic bluish fluorescence indicative of a synthetic varnish was observed. The surface coating appeared to be quite uneven under the fluorescence, most notable in the lower right corner. FTIR analysis of the surface coating identified both a synthetic and natural resin varnish.

Revisiting cross section 1 (fig. 9), more about the surface coatings could be understood. In figure 9, layer C corresponds to the later additions of synthetic varnishes in the 80s, which is quite thick and yellowed, while layer B corresponds to the natural resin varnish, which is thinner and yellowed. This cross section also provides insight into a painted border that runs around the perimeter of the painting. This material corresponds to the uppermost paint layer in layer 5. Looking at the cross section more closely, a clear interface between the lower layer of paint can be seen, which is Matisse’s original layer of paint, and the subsequent natural resin varnish layer (fig. 20). This interface indicates that the lower paint layer had time to dry and form a film before the natural resin varnish was applied. An SEM image of the same area identifies the two paint layers of similar color in paint layer 5; however, they appear quite different from one another (fig. 21). Although the two contain similar materials, the lower layer of paint, Matisse’s original, has higher pigment content and smaller pigment particles compared with the subsequent layer—the painted border—which has lower pigment content and larger pigment particles.

Viewing macrographs of the painted border further confirms that this material is not original to the painting. In this area of...
Looking into the provenance of the painting French art dealer Paul Guillaume owned *Still Life with Apples* as early as 1925 and likely acquired it directly from Matisse. *Still Life with Apples* is pictured in Guillaume’s dining room circa 1930 (fig. 23). (Note the frame.). It is possible that Guillaume added the natural resin varnish—a popular trend with dealers at that time—and restored the early frame abrasions within 10 years or so after the painting was completed. Perhaps the restoration was necessary when the painting was removed from its frame and ownership of the painting changed to Wertheim. The Wertheim frame the painting is currently displayed in is visibly different from the frame in the photograph (fig. 24). These ideas would explain the presence of drying cracks through the original paint and added border and explain the necessity of why the border was added.

Ultimately, it was proposed to remove the natural and synthetic varnishes, as well as the painted border since they are not original to the painting as identified by analysis. The natural resin varnish has been compromised by a previous cleaning attempt and is no longer a uniform coating. Removing the natural and synthetic varnishes and painted border would reveal the intended colors and textures of the painting (fig. 25). A cleaning approximation of the painting is seen in figure 26, on the basis of color calculations taken in Photoshop of cleaning tests; however, curators of the collection decided not to proceed with this treatment option and a
second option was chosen. After the varnish was slightly reduced with TS-28, abrasions at the top and bottom of the panel were filled with Modostuc. Fills and cleaning tests were locally varnished with mastic. Fills were then inpainted using Gamblin Conservation Colors. The entire painted border was toned to match the surrounding areas using Gamblin Conservation Colors (fig. 27).

4. GERANIUMS, 1915

4.1 Background and Related Paintings

_Geraniums_ is an oil painting on commercially prepared canvas and was originally dated to 1915 based on the curatorial file (figs. 28, 29). The support, ground, and paint are all in good condition. Beyond the obvious difference of the support, a visual difference is immediately noted when comparing this painting to the previous _Still Life with Apples_ and includes color palette and painting technique.

Similar works to this painting all date from around 1910 and have related subject matter, ornate patterning, and bright palette (fig. 30).

4.2 Technical Analysis

Viewing the infrared digital photograph shows the relatively unchanged composition originally constructed by Matisse (fig. 31). Comparing this to the x-ray radiograph confirms that no major changes had been made to the composition on the canvas support (fig. 32). Because the application of paint for this painting was significantly different from _Still Life with Apples_, a
Figure 30. Henri Matisse, *Still Life with Geraniums*, 1910; oil on canvas, 36 5/8 in. × 45 ¾ in. (180 × 220 cm). Munich, Neue Staats Galerie

Figure 29. Back of *Geraniums* under normal illumination

Figure 31. Infrared digital photograph of *Geraniums*

Figure 32. X-ray radiograph of *Geraniums*
A lot of the fluid black paint used by Matisse to construct a loose contour of the composition was visible under magnification in normal light (fig. 33). This technique of sketching the composition in a fluid black paint and continuing on with the painting process with little to no changes being made to the composition is typical of Matisse’s technique early in his career. Because no compositional changes were found in *Geraniums*, it is possible that Matisse had developed the composition in provisional drawings or sketches, which is another characteristic of his early technique. A documented underdrawing of *The Pink Studio*, taken before Matisse began to block in the composition with paint suggests what (figs. 34, 35) the painting may have looked like in an early stage. *Geraniums* may have looked like this when it was first applied to the canvas.

This information began to support the idea that *Geraniums* could possibly be from an earlier date than 1915. Various points came together when curatorial fellow Elizabeth Rudy found a different date and title listed for *Geraniums* with this reference image in Bernheim-Jeune’s published catalog of Matisse archives (fig. 36). The date of the reference image is unknown. Bernheim-Jeune was Matisse’s main dealer in Paris for most of his career and kept fairly accurate records of the works coming through their gallery at the time, which included photographing all of the works.

The paint structure of *Geraniums* is not unlike that of *Still Life with Apples*, in that there are multiple layers of paint and dramatic changes in color; however, it is much easier to view the paint structure under magnification in *Geraniums* because of the different technique utilized by Matisse in his paint application in *Geraniums*: Matisse allows his layering process to be visible in each subsequent layer of paint. The same paint structure is further confirmed in cross sections. Again in cross sections, the numbers correspond to paint layers and letters to possible varnish layers. Cross section 2 (fig. 37) and macrograph 2 (fig. 38) are from the foreground of the painting, which is comprised of a variety of earth colors. Layers 1, 3, and 4 can be correlated in cross section and macrograph. In addition to the 3 paint layers seen in the cross section, there are two additional yellow paint layers, 5 and 6, visible in the macrograph. Paint layers in cross section 3 (fig. 39) and macrograph 3 (fig. 40), taken from the background, correlate directly with one another.

Pigment analysis for *Geraniums* identified a bright extensive palette including the use of lithopone and lead white in the...
ground, vermillion, venetian red, yellow ocher, viridian/chrome green, terre verte, cobalt blue, Prussian blue, ultramarine blue, cobalt violet, bone black, and lead white (fig. 41). This information was based on analytical data collected from cross section analysis with RLM and Raman spectroscopy and sample analysis using FTIR, as well as in situ XRF analysis.
Figure 41. Palette for Geraniums (from left to right): the ground is composed of lithopone, lead white, and linseed oil. The palette includes vermillion, venetian red, yellow ochre, viridian or chrome green, terre verte, cobalt blue, Prussian blue, ultramarine, cobalt violet, bone black, and zinc white.

By surveying and combining all the information collected including the altered composition seen in the x-ray radiograph, noting shifts in color under magnification, and adding pigment identification and paint structure, an approximation of what the painting may have looked like during its construction was created. On the basis of color measurements taken in Adobe Photoshop, these images represent just a few possible states in the process of Matisse’s revisions in color. Although the actual progression of the painting is unclear and could only be understood from further cross section analysis, it is likely that these color composites represent how the painting developed. The first color composite shows (fig. 42) an early state of the painting, with a fluid contour line drawing followed by the initial addition of color to the main design elements in the background and pot of geraniums. Color composite 2 (fig. 43) shows an initial color combination for the table top and background. Color composite 3 (fig. 44) has another possible color combination for the table top and background. Note the use of complementary colors in this version. Color composite 4 (fig. 45) may have been closer to a final state, as the final background color has been...
added and another new color has also been added to the table top. In color composite 5 (fig. 46) the final foreground color has been chosen, with only the additional accent in the upper left edge of the table added in the final state (fig. 28). Here color seems to be the driving force for Matisse, rather than reconstruction of the composition as seen previously in Still Life with Apples.

4.3 Treatment
Geraniums has been through a few treatment campaigns, the most recent of which involved a spray application of PVA varnish. Viewing the painting in oblique specular light (fig. 47) showed the dull, plastic-like quality of the surface coating. The brush strokes were lost and the original colors appeared and gray because of the poor aging characteristics of the PVA varnish. Viewing the UVA-induced visible fluorescence image (fig. 48), a characteristic bluish fluorescence indicative of a synthetic varnish was observed. FTIR analysis of the surface coating confirmed a PVA, and no other materials were present on the surface. Revisiting cross section 2 (fig. 37) further confirms the presence of the spray-applied PVA varnish. This information identified that the varnish was not original to the painting, which most likely meant the painting was not intended to be varnished. The PVA varnish was removed using toluene. During treatment, images show just how subtly the
colors had been yellowed by the varnish (fig. 49). Before- and after-treatment images reveal only a slight change in colors from the varnish removal, which is most noticeable in the blue in the background. Curators were impressed with the subtle improvement of the colors and the revelation of previously hidden brushstrokes on the surface (fig. 50).

5. CONCLUSION

The technical analysis for Still Life with Apples identified a subdued, limited palette, dramatic revisions to the composition, as well as overall color shifts. These characteristics
unquestionably match the 1913–1917 period. The technical analysis for Geraniums identified a diverse palette, no slight shifts to the composition, and dramatic color shifts. Because these characteristics do not match what was found in Still Life with Apples, it is clear that Geraniums does not belong in the 1913–1917 period. Treatment of Geraniums involved removing the unoriginal synthetic varnish and returning it to a more original state. While solubility testing has been performed on Still Life with Apples and testing confirmed that brush strokes and more accurate colors would be revealed, curators decided not to proceed with this treatment. A second treatment option was chosen including slightly reducing the varnishes with TS-28, filling and in-painting abrasions along the perimeter of the painting, and toning the painted border to match Matisse’s original color. The date of Geraniums was changed to 1910 on the basis of the collected data and archival information. What began as an exploration of the 1913–1917 period defining these two works soon became two separate journeys. In the end, great insight into both Matisse’s early work and his innovative and experimental period was gained.

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FURTHER READING


autres techniques d'examen, Colloque VI, 75-80. France: Louvain-la-Neuve, d'histoire de l'art et d'archéologie de l’Université catholique de Louvain et Laboratoire d’étude des œuvres d’art par les méthodes scientifiques.


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What Lies Beneath: Textural Techniques in Diego Rivera’s Cubist Paintings

ABSTRACT

Diego Rivera strove to create complex surfaces in his Cubist works, employing a variety of techniques to achieve them. From 1913 to 1917, Rivera’s forays in Cubist painting yielded dozens of images marked by a significant interest in textural variation. Based on the results of a technical study of thirty-four paintings from this period, this article explores Rivera’s creative use of grounds, sand, and other additives to produce topographic variations uncommon in his paintings up to this point in his career. These works represent a transitional period and sparked an inventive streak for Rivera that extended beyond his time in Europe.

1. INTRODUCTION

The following article is based on the results of a technical study of 34 of Diego Rivera’s paintings from 1911 to 1917 that was performed while the author was the William R. Leisher Fellow in Modern and Contemporary Painting Conservation at the National Gallery of Art (NGA), Washington D.C. At minimum, each painting was examined with 10× magnification: thirteen paintings were examined using stereomicroscopy, eight with infrared reflectography (IRR), seven with x-ray radiography, and two with x-ray fluorescence. Samples were taken of the ground, and paint layers from five paintings ranging from 1911 to 1915 and analyzed using FTIR, and GCMS.

Throughout this study, one thing became clear: whether in portraits or still lifes, Diego Rivera strove to create complex surfaces in his Cubist works, employing a variety of techniques to achieve them. These techniques were largely influenced by Rivera’s academic training, both as a reaction to the styles admired by his professors and as a reflection of the materials with which he was taught to paint. Most important in his development, however, were the 13 years he spent in Europe and the artists with whom he came in contact there. As Pablo Picasso’s and Georges Braque’s dealer Daniel-Henry Kahnweiler predicted in 1915 “every talented young artist will have to come to an understanding with Cubism.” Rivera did just that, borrowing the vocabulary devised by those two artists; but his experiments with Cubism also marked the first time that he developed his own methods of painting, featuring vivid colors and considerable topographic variation in paint. The Cubist works that Rivera made from 1913 to 1917 represent a transitional period, a turning point from his academic training to his later career as a mural painter.

2. DIEGO RIVERA’S EUROPEAN ADVENTURE

Rivera’s first European experiences can be seen as occurring in two phases: an introductory period, 1907–1910, and a period of experimentation, 1911–1921. In the first phase, Rivera brought to Europe the artistic techniques and learning methods acquired during his time at the Academy of San Carlos in Mexico City. His initial impulse was to continue the habit of replicating paintings by other artists, as he had been taught, by going to the Prado in Madrid and copying paintings by Spanish, Flemish, and Dutch masters that he saw there. While these visits were vital for the progression of his education, they resulted in the absorption of others’ styles and derivation of the works he had most recently studied. In 1944, Rivera expressed some regret about his first years in Spain and the lack of progress he made in his painting: “The inner qualities of my early works in Mexico were gradually strangled by the vulgar Spanish ability to paint. Certainly the flattest and most banal of my paintings are those I did in Spain in 1907 and 1908.” Leaving Spain and traveling to Paris and other cities in 1909–1910, Rivera became further acquainted with the European art scene, painting street and canal scenes from life, but he always returned to the great collections of European museums to study the old masters.

Experimentation marked Rivera’s second trip to Europe, beginning with a visit in 1911 to the monastery of Montserrat. There, he tried a new style of painting in three pointillist landscapes, including Monserrat, 1911 (fig. 1). Examination of
this painting revealed that it was created by applying small dabs of oil paint in bright, pastel hues, with the consistency of a buttery paste, side-by-side onto bare canvas using a small brush. The lack of an intermediary layer of ground was unusual for the academically trained artist at that time, and the areas of bare canvas peeking through the impastoed dots of paint added a fresh quality that was lacking in his earlier, more labored, academic works. Before then, Rivera had usually applied paint thinly, with traditional shading, and used glazes and scumbles to define shadows and space. His adoption of the pointillist technique was a dramatic shift from the style and enameled surfaces of his previous works. Rivera spent the next two years expanding his painting vocabulary to reflect the styles of El Greco and Cézanne, which he had begun in Toledo in 1912.

By 1913, he was experimenting with Cubism, but with a Futurist slant. It was at this time that he painted *Woman at the Well* (*La Mujer del Pozo*) (fig. 2), a portrait fractured into multiple views of a woman at a well, influenced by Robert Delauney's theories of simultaneity in painting. The painting was executed with thin layers in a palette of muted, pastel colors, with little visible brushwork and with the canvas weave texture showing through slightly in the more thinly painted areas toward the edges. In a similar style in the same year,
Rivera painted an untitled portrait of a woman in green (fig. 3). First, he applied a thin, even layer of cream-colored ground to the entire surface of the canvas, allowing the canvas weave texture to remain visible while somewhat leveling out the surface. The figure was painted with a muted palette, fracturing the planes, painting her so that her front and back were both visible simultaneously. Rivera used a brush to apply the paint layer, but further defined some areas by scratching into the wet paint with the back of the brush and delineating some of the figure’s curls with a small comb. He carried this interest in texture into his Cubist works, and these two paintings along with Montserrat exemplify his transition into Cubism and his awareness of current painting trends in Paris. Rivera tentatively began his first Cubist works in 1913, and spent the next five years incorporating the various techniques he had used thus far in his career into a new Cubist format for still lifes and portraits.

3. NEW TECHNIQUES FOR CREATING TEXTURE IN RIVERA’S CUBIST PAINTINGS

3.1 Supports
Rivera’s choices of materials and techniques, from support to surface coatings, reflect how important it was to him to create a variety of textures in his Cubist paintings. Rivera’s first choice for painting supports in these works was linen canvas. There was an extreme range in the texture of the canvas weave, with no apparent trend in terms of the use of a particular type according to the works’ date or subject matter. Rather, he seemed to use whatever was available in his studio at the time, including already-painted canvases. For example, while Rivera usually used plain-weave linen, two of his Cubist paintings were executed on canvases with half-basket weaves: Portrait of Marevna Vorobev-Stebelska (fig. 4) and Table on a Terrace Café (fig. 5). Both these paintings are dated 1915, and both have another painting on the reverse of the canvas. Because of the onset of World War I in August 1914, the year 1915 was a particularly lean time for Rivera financially. In letters written in 1915, Rivera noted his concerns about his ability to pay for food for himself and his wife, Angelina Beloff. This lack of money was probably the main reason why he reused his canvases at this time. The earlier paintings, both untitled, have been estimated stylistically to have been painted in 1913 and 1912, respectively, and were among several double-sided paintings that Rivera made. The portrait of the woman in green from an earlier slide is on the verso of Marevna. When Rivera reused a canvas, he removed it from its original orientation on the
manipulation of the paint layer to compensate for the smoothness of the support in order to achieve the textural differences that Rivera valued. These experiments lacked sufficient textural variety, and, as a result, he made far fewer paintings on solid support than on canvas during this period.

3.2 Preparatory Layers: Ground
Rivera prepared his own canvases, employing three different approaches to applying a ground to impart a variety of textures to the upper layers of the painting surface (fig. 7). The first method of preparation was to forgo any ground application and paint directly on the earlier composition, as Picasso often did and incorporating the original paint texture into the new composition. Rivera did not reverse his canvases in an effort to preserve the earlier work, as he usually painted over the earlier composition with a grayish-purple paint and, on that newly painted surface, often signed the title and date of the more recent work (fig. 6). Instead, unlike Picasso, he reversed the canvas to incorporate the texture of the canvas weave into his new painting.

Only three of the 34 paintings examined were executed on solid supports, signifying Rivera's clear preference for painting on canvas. The three panels were from 1916 and 1917, and suggest that he was experimenting at that time with the different effects that could be produced by using different kinds of supports. Two of the panels appear to be solid wood, and one, on which he painted Still Life with Plant (Naturaleza Muerta con Planta), appears to be an artist board with a texture of coarse-weave canvas on one side. In the latter, the textured side was turned to the reverse in an apparent effort to experiment with painting on the smooth side of the support. The paintings on solid support required more

Figure 4. Portrait of Marevna Vorobev-Stebelska, 1915, oil on linen, 146.0 × 114.4 cm (57 ¼ × 45 in.), Art Institute of Chicago

Figure 5. Table on a Terrace Café, 1915, oil on linen, 61.6 × 50.0 cm (24 ¼ × 19 11/16 in.), Metropolitan Museum of Art
Figure 6. Detail of verso of Table on a Terrace Café, 1915, oil on linen, 61.6 × 50.0 cm (24 ¾ × 19 11/16 in.), Metropolitan Museum of Art

Figure 7. Detail of Montsenat, 1911, oil on linen, 125.4 × 145.4 cm (49 1/3 × 57 ¾ in.), National Gallery of Art, Photo Credit: Greg Williams, NGA
surrounding them without a ground, thereby producing greater textural variety throughout the picture plane. In some of these paintings, occasional skips in the paint application reveal both bare canvas and ground layer. In others, the contrast of areas of ground versus no ground is more conspicuous. One example where he used this technique is Portrait of Jacques Lipchitz (fig. 8). Here, Rivera took advantage of the multiple textures afforded him through a selective application of ground by leaving a square of bare canvas in the upper-left corner, while deliberately covering the remainder of the canvas with varying thicknesses of paint. Similarly, in Portrait of Marevna Vorobev-Stebelska, Rivera wrote his signature by scratching into the wet paint and revealing the bare canvas beneath (fig. 9). In these examples, the painting’s lower layers were playfully incorporated into Rivera’s final compositions, and the selective application of ground granted him more freedom in to create a range of textures in the final image.

Rivera’s third method was more practical than playful: applying a thin, even layer of ground to the entire surface of the canvas and barely filling the interstices of the weave.16 The textural effects of painting without a ground layer appealed to Rivera, but he acknowledged a need to seal the canvas in some instances,
possibly as a result of his Mexican training. In fact, while his ground applications lent the appearance of a thin oil paint layer, FTIR/GCMS analysis revealed a proteinaceous binder rather than the oil grounds available at the time. In many cases, this layer was so thin that it was almost imperceptible to the eye although it was visible in the skips of the paint layer. This was a conscious decision on the part of Rivera, who further disguised his grounds by making them the color of linen, with the result that he sealed the canvas while maintaining the appearance of painting on bare canvas, in both its texture and color. He used this technique for several paintings around 1915–1916, including Portrait of a Russian Poet (Maximiliano Volochine)

By choosing to prepare his own canvases in these ways, Rivera was able to control the textures of the support and their effect on his final composition, a factor that seemed to have been less important to Picasso, who did not shy away from commercially primed canvases in his works (fig. 12). Indeed, Rivera started out with a pre-primed canvas for his Portrait of a Russian Poet (Maximiliano Volochine), but reversed the canvas in order to work on the unprimed side, keeping the texture of the pre-primed ground from compromising his final image.

3.3 Preparatory Layers: Underdrawing
In all the paintings examined except for Montserrat, either brush-applied or dry medium underdrawings were present
for the main contours of design, a holdover from Rivera’s academic training. In *Portrait of Marevna Vorobev-Stebelska*, these were hidden by the upper layers of paint and were only visible using IRR. In *Portrait of a Poet*, Rivera left some areas of underdrawing exposed and included them in the final composition (fig. 13). Some of the underdrawings were further reinforced by painting black outlines on the upper layers of paint. Use of underdrawings to this extent reflects Rivera’s education as a draftsman first, and his clear vision of the final composition from the earliest stages of canvas preparation; however, by allowing the underdrawings to remain visible in some of his paintings, Rivera may have been rebelling against his training and mirroring some techniques used by his Cubist contemporaries.

3.4 Paint Application

In his application of oil paint, Rivera employed a variety of tools and nontraditional materials to create different textures in his Cubist compositions (fig. 14). He usually applied the paint layer with very small brushes ranging approximately from ½ to 2.0 cm in width, which is surprising in light of the large size of many of his canvases. The use of small brushes gave Rivera great control over each section as he painted, and afforded him the flexibility to manipulate the paint texture in various ways.

This flexibility was aided by the use of additional tools such as a palette knife and comb. In many of his Cubist paintings, each plane of color displays a different texture, juxtaposing an area of paint applied in an impastoed pointillist technique with one where the paint is dragged by a brush or smoothed with a knife. He generally allowed the paint to dry between layers, avoiding blurring between colors; however, he would often scratch into wet paint with the knife, comb, or back of the brush to create borders and add texture between planes. His clear idea of his compositions prior to paint application is reflected in the lack of pentimenti found in the finished paintings. Rarely, a line has been moved or a plane has changed color from a lower layer to an upper. More often, the paintings were deliberately executed with a map in mind for their final composition.

To add more texture to some of his paintings than tools alone could accomplish, Rivera began to include nontraditional materials such as sand, sawdust, wood, and cork into his works in 1915. Although Rivera was aware of the collage experiments of his Cubist contemporaries, his applications of nontraditional materials were usually more focused than in Picasso and Braque’s Cubist works. When Braque used sand, he often allowed it to drift into areas of more than one color, thus adding texture to his compositions as a whole, whereas Rivera more selectively confined his sand-textured paint to individual planes of color, resulting in the juxtaposition of contrasting textures. For example, in *Woman in Green* (*Mujer en verde*, 1916), Rivera mixed fine grit sand into the navy blue background of the patterned sections of the sitter’s dress, creating a contrast with the surrounding smoothed areas of black paint at the bottom of the painting.
Similarly to Picasso and Braque, Rivera added texture to his paintings using collage elements in both a figurative and literal way, often within the same picture. In *Still Life (Mallorca)*, 1915, Rivera mixed sand with the brown paint in the bottom half of the picture to represent the sand of the beach (fig. 15). In the same picture, however, he also mixed sand into black paint to add texture in areas of the painting unrelated to the beach. Similarly, in *The Telegraph Pole (El Poste de Telegrafo)*, 1916, Rivera incorporated a wooden pole to represent a wooden telegraph post. He also used three fragments of wine cork to represent the insulators, even though real insulators are not made of cork, thus demonstrating a more symbolic approach to collage (figs. 16, 17). Rivera’s combining figurative and literal uses of nontraditional materials in these paintings reflected a playfulness in his approach to painting that extended to his use of tools. In *Portrait of Marevna Vorobev-Stebelska*, the fringed bangs along the sitter’s forehead were defined using a comb as one would be used in real life (fig. 18). Rivera did not exclusively reserve the use of a comb for this literal manner though, as evidenced by its application in the drapes in the upper-left corner of *Woman Sitting in a Theater Seat (Mujer Sentada en una Butaca)*, 1917. In this instance, the comb was instead used to add texture and define a plane, two factors of great importance to him.

Figure 14. Detail of face in *Portrait of a Russian Poet (Maximiliano Vólochine)*, 1916, oil on linen, 111.5 × 91.75 cm (43 7/8 × 36 in.), Museo Carrillo Gil

Figure 15. Detail of sand use in *Still Life, Mallorca*, 1915, oil and sand on linen, 96.5 × 63.2 cm (38 × 24 7/8 in.), Columbus Museum of Art
In addition to textural variation, color played an important role in Rivera’s efforts to create contrast between adjoining Cubist planes. His use of color was usually more than just a splash to accent an area, as it often was in Picasso and Braque paintings in their early stages of Cubism. While Rivera attempted the early approaches of Picasso and Braque in his Portrait of Jacques Lipchitz, with a composition largely defined by neutral tones save for splashes of color representing a serape, by 1915 he followed their lead and abandoned this in favor of brighter colors to produce contrasting Cubist planes. Rivera’s Mexican heritage also possibly made him receptive to the bright, bold colors of Fernand Léger’s version of Cubism, resulting in the more intense color palette and less realistic use of colors in his later compositions.

3.5 Surface Qualities

Like his contemporaries, Rivera, to avoid a uniform gloss on his Cubist pictures, did not usually varnish them. Variations between planes in his Cubist paintings was of the utmost
importance to him, and the application of a varnish layer to these paintings would have obliterated the balance of textures that he had worked so hard to create. To make some of the planes appear glossy, rather than apply a varnish to them, he would smooth out areas with a knife or a cloth to create flat, shiny planes of color, often emphasizing the effect by placing them next to textured planes incorporating nontraditional materials, or planes of color applied with impasto or active brushstrokes. In Rivera’s Cubist paintings that have remained unvarnished by collectors or restorers, a broad range of surface gloss and textures has been preserved.

4. CONCLUSIONS

Influenced by the theories of the inventors of Cubism, Picasso and Braque, Rivera’s experiments with this style of art may be viewed as the first time in his career that he struck out on his own as an artist. In 1913, Rivera embraced the Cubist vocabulary, with its fragmented planes and tactile qualities favored by Braque; however, instead of simply repeating his past and copying the works of those around him, he developed somewhat different methods from his contemporaries to create Cubist compositions with greater textural variation. From his deliberate choices of support and ground application to his application of paint and use of nontraditional tools and materials, Rivera created a variety of surface textures unseen in his works prior to the introduction of Cubism.

While Rivera may not have turned European art on its head, his experiments with Cubism gave him an appreciation for texture, an open mind to new materials, and a boldness in his application of color that he would later assimilate into his mural paintings on a more monumental scale. During his travels in Italy before returning to Mexico in 1921, he saw Italian Renaissance frescoes firsthand. He brought to Italy a new eye for materials and an open mind to new methods of painting gained from Cubism, and took from Italy an appreciation for the art of fresco painting, forever changing the face of Mexican art.

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All images taken by the author unless otherwise noted.

NOTES


2. The 34 paintings examined from this period were from the following years: one from 1911, three from 1912, six from 1913, three from 1914, eight from 1915, eight from 1916, and five from 1917. The 11 institutions to which the paintings belong are the Art Institute of Chicago, Columbus Museum of Art, Los Angeles County Museum of Art, Lyndon Baines Johnson Library and Museum, Metropolitan Museum of Art, Museo Carrillo Gil, Museo Dolores Olmedo Patiño, Museo Nacional de Arte, Museum of Modern Art, National Gallery of Art, and Tate Modern.


4. Marnham, P. 1998. *Dreaming with his eyes open: a life of Diego Rivera*. New York: Knopf. 59. Traditionally, the teachers at the Academy of San Carlos were either trained in Europe or trained by Europeans, and overwhelmingly valued the smooth finish of European old master paintings over the surface textures and vivid colors of Mexican indigenous art. For more on the academic program at the Academy of San Carlos, see Charlot, J. 1962. *Mexican art and the Academy of San Carlos 1785–1915*. Austin: University of Texas Press.


7. FTIR and GCMS performed by Suzanne Lomax, Scientific Research Department (SRD) at the National
AIC Paintings Specialty Group Postprints 26 (2013)

Klaar Walker

Gallery of Art (NGA) confirmed that the paint layer was an oil medium.

8. Observations about the techniques Rivera used in making the paintings are the author’s, unless otherwise noted.


10. According to the Art Institute of Chicago’s painting’s file, Ramon Favela dated it to 1913 because of the stylistic similarities with Woman at the Well, which was dated by the artist.

11. Of the 34 paintings examined by the author (see note 2 earlier), 31 were painted on canvas. Samples taken of canvas fibers from various paintings and examined under polarized light microscopy revealed that the canvases used were linen.

12. Most of these canvases are plainly woven (one warp per each weft), but vary in thread count from a coarse seven vertical by eight and a half horizontal threads per square centimeter (in Portrait of the Poet [Maximiliano Volochine]) to a more finely woven 20 vertical by seventeen horizontal threads per square centimeter (in Angelina and Baby Diego: Maternity). Both these paintings are from the Museo Carrillo Gil, and both were painted in 1916.


14. The dates were determined stylistically, as the original paintings were not dated. Observations for the dating of the painting on the reverse of Table on a Terrace Café at the Metropolitan Museum of Art were made by Charlotte Hale, Painting Conservation Department, in the painting’s file during her conservation treatment of the painting in 1992.


16. FTIR and GCMS performed by Suzanne Lomax, SRD, NGA, have indicated that Rivera used a proteinaceous binder for his grounds. Further analysis is required to determine the exact nature of the proteinaceous binder.

17. Other paintings with this method of application include The Architect—Jesús T. Acevedo (El Arquitecto—Jesús T. Acevado and Angelina and Baby Diego: Maternity (Angelina y el niño Diego, Maternidad. Rivera extended the latter on all four sides to include the original tacking edges in the picture plane. The extended areas do not appear to have been prepared the same way as the original picture, avoiding application of a ground layer, and thereby exposing more of the canvas-weave texture around the painting’s perimeter than in the original picture plane.

18. Two examples of Picasso’s use of commercially primed canvases are his Nude Woman, 1910, and Still Life, 1918, both in the National Gallery of Art.

19. These underdrawings were applied over the ground layer, where applicable.

20. Infrared Reflectogram capture (Inframetrix) and digital composite performed by Julie Simek, Conservation Department, Art Institute of Chicago.

21. FTIR and GCMS performed by Suzanne Lomax, SRD, NGA, on samples from multiple paintings between 1911 and 1915 confirmed the presence of similar proportions of dimethyl azelate, methyl palmitate, and methyl stearate in proportions suggesting a drying oil binder. Results revealed identical spectra from painting to painting, suggesting that either the paint from each painting came from the same proprietary source or were mixed with the same formulations by Rivera. Further analysis is required to determine if these paints were proprietary or were prepared by him.

22. Brush widths were determined by the widths of brush-strokes on the paintings and measured by the author to range in size from 0.5 cm to 2.0 cm.

23. An example of more compositionally widespread use of sand can be seen in Braque’s Fruit Dish, Quotidien du Midi and Picasso’s Small Violin, both from 1912.


25. Karmel, P. 2003. Picasso and the invention of Cubism. New Haven and London:Yale University Press. 104–105. Karmel discusses Picasso and Braque’s use of nontraditional materials in painting to become something they were not. For example, Picasso, in his 1912 Siphon, Glass, Newspaper, and Violin, used newspapers throughout the composition to represent a wine bottle, a violin, and a wineglass, but never a newspaper.
26. Kahnweiler 1949. 10–15, 19. Kahnweiler describes the evolution of Cubism and the use of color by Picasso and Braque as a localized sign to jog the viewer's memory to describe what the painting was trying to represent. Prior to 1913, the two tried to limit their use of color for chiaroscuro only, favoring a neutral palette to form their subject matter with only these localized splashes of color. By 1913, Picasso and Braque agreed to stop using color as chiaroscuro, and instead to incorporate collage elements and a more sculptural approach to painting to create more spatial definition.

27. ibid. 17–19. Léger did not use color to represent an actual visual experience, but rather arbitrarily assigned colors to his Cubist planes as he saw fit.

28. Many of Rivera's paintings have been restored since leaving his studio; however, on his extant paintings that have remained untouched by restorers, no varnish layer is present. For more on the subject of varnishing Cubist paintings, see Richardson, J. June 16. 1983. Crimes against the Cubists. In The New York review of books 30, no. 10.

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THIS ARTICLE HAS NOT UNDERGONE A FORMAL PROCESS OF PEER REVIEW
Hans Hofmann’s Last Lesson: A Study of the Artist’s Materials During the Last Decade of His Career

The talk presented an overview of the doctoral research recently undertaken by the author as part of the Preservation Studies Program at the University of Delaware. This research identifies the late-career materials of Abstract Expressionist painter and teacher Hans Hofmann (1880–1966) and examines the relationship between the artist’s materials, his signature painting style, and the physical and aging characteristics of his paintings (fig. 1). A representative catalog of Hofmann’s late-career materials was built for this research from the analysis of over 500 paint and fiber samples, and a correlation found between condition issues in Hofmann’s work and the combination of new paint materials and traditional art practice common to Abstract Expressionist artists. The results of this research inform the conservation of Abstract Expressionist and other works that incorporate both traditional and modern paint media and reveal a gap in current research and preservation methodology regarding transitional painting practice. This study builds on the author’s earlier analysis of mid-20th century commercial house paints and assessment of the condition issues related to the incorporation of new paint materials by Hofmann and his Abstract Expressionist colleagues in works from the Smithsonian Institution’s Hirshhorn Museum and Sculpture Garden. A detailed presentation of this research will be available as part of the Getty’s Conservation Institute’s Artist’s Materials book series (anticipated publication date: Spring 2016).

In 1992, art historian and University of California, Berkeley professor T.J. Clark gave a public lecture about the university’s renowned collection of Abstract Expressionist art that would become the basis for an essay published two years later. “What you’re going to hear tonight is a defense of Abstract Expressionism,” began Clark, “[and] if there is to be a defense of Abstract Expressionism at all . . . it will have to be cast as a defense of Hofmann in particular . . . . [for he is] the trigger for the line of argument I’m going to present.”

Hofmann was intellectually and physically situated at the nexus of Abstract Expressionist experimentation. For more than four decades, artists and critics from around the country came to hear his synthesis of modern art movements in his “push and pull” theory of color and form.² Art critic Clement Greenberg claimed to have been educated by Hofmann, Greenberg’s ideological opponent Harold Rosenberg claimed Hofmann as the first of his “action painters,” and the Museum of Modern Art called Hofmann the “dean of the abstract-expressionist movement.”³ With students positioned at the forefront of art movements and institutions throughout the United States, Hofmann is a thread running throughout Abstract Expressionism, tying its participants to the efforts of their progenitors and descendants, “which is to say,” according to artist Frank Stella, “all of the twentieth century.”⁴
Hofmann’s popularity as a teacher peaked in the 1950s, a period when his own painting flourished and a new wave of innovation in paint manufacture led to radical shifts in art making. Many of the condition problems conservators face in the treatment of modern paintings first appear in Abstract Expressionist work, and Hofmann is an excellent mirror of this unique historical moment.

Building on the author’s research that revealed incompatibility problems in the incorporation of new materials by Hofmann and his Abstract Expressionist colleagues, this new research tracks Hofmann’s use of materials during the 10-year period just prior to and after the 1958 closing of Hofmann’s schools in New York City and Provincetown, Massachusetts. Using analytical data gathered from the analysis of over 500 paint and fiber samples, this presentation will trace Hofmann’s embrace of industrial paint binders and modern organic pigments, focusing on relationships between the artist’s late-career materials, style, and the impact of these choices on the long-term stability of Hofmann’s work.

NOTES

1. The T.J. Clark (October 15, 1992) lecture to celebrate the reinstallation of the Hofmann paintings at the Berkeley Art Museum and Pacific Film Archive, transcript from museum education department files, n.p. This lecture is the starting point for Clark’s essay “In Defense of Abstract Expressionism,” published in October 69 (Summer 1994) and in a revised format in Farewell to An Idea: Episodes from a History of Modernism (New Haven and London: Yale University Press, 1999).


3. Clement Greenberg, “Art: Review of an Exhibition of Hans Hofmann and a Reconsideration of Mondrian’s Theories,” The Nation 160(16) (April 21, 1945): 469. Rosenberg’s article “The American Action Painters” initially named several early “action” painters that were removed when the article was published for a foreign audience. “I was going to put some names in . . . like Pollock, Hofmann, and de Kooning, but then I didn’t want to put in too many names because it would confuse the issue . . . So I took all names out.” Oral history interview with Harold Rosenberg, conducted on April 7, 1972, with Paul Cummings for the Archives of American Art, Smithsonian Institution, n.p. For “dean” assignation, see Museum of Modern Art, 1963–65 Biennial Report (New York: Museum of Modern Art, 1965), 6, and “The Age of Experiment,” Time Magazine 67(7) (February 13, 1956): 64.


6. Aspects of this research were also presented at the March 2013 international symposium “Issues in Contemporary Oil Paint” organized by the Cultural Heritage Agency of the Netherlands and will be available in the symposium postprints scheduled for release in 2014.

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ABSTRACT

A new aluminum stretcher that does not employ conventional keys, expansion bolts, or springs for tension adjustment has been developed. The tension adjustment is achieved by moving the stretcher bars in each direction independently by turning thumbscrews positioned along the stretcher. This stretcher can be used to strengthen an existing stretcher or as an artist-grade stretcher. Its construction and mechanical properties were analyzed and compared with traditional wooden stretchers with keys to examine craquelure patterns incurred on the canvas and assess any deformation resulting from the two stretcher systems. Expansion by means of movable aluminum bars has greater impact at the center of the canvas and does not bend the stretcher. Further research is required to gain a better understanding of mechanical stresses resulting from expansion and methods of tension adjustment.

1. INTRODUCTION

In his seminal 1969 work on mechanical stress on paint film (1969), S. Keck classified agents that cause a painting to deteriorate as chemical, physical, and biological. These agents generate mechanical stress on paint film that lead to cracking and eventual flaking of the paint. In this investigation, the authors focused on external mechanical stress created by stretcher expansion in an environment with fluctuating relative humidity (RH) that results in aging cracks, and not on internal mechanical stress cracks, or drying cracks, created by incorrect painting technique and/or faulty material. A functional stretcher that has a mechanism for adjusting tension provides a painting on canvas with dimensional stability, without creating undue stress to the painting. Stretchers with expandable joints appeared in the mid-18th century with the introduction of a stretcher key (Buckley 2008). Since 1793, thousands of patents have been issued by the United States Patent Office for stretcher designs and the machinery to produce them (Buckley 2008, AIC Wiki 2007). For two centuries, however, the basic concept of adjusting tension has remained unchanged: opening the corner joints by keying-out, a process of forcing a stretcher key into a mitered corner joint, causing stress via interdependent biaxial expansion (simultaneously between the x and y axes).

Keying-out is typically performed by expanding the stretcher at the corners with wooden wedges, expansion bolts, or springs. If this is done unnecessarily, incorrectly, or ineffectively, the excess stress on the canvas can be transmitted to the paint film, resulting in cracking, cupping, cleavage, and flaking in the paint, or even tears in the canvas. This damage may not be immediately evident, but will become obvious over time. Keying-out can correct loose canvas in smaller paintings but is not recommended for large-format paintings. Slackened canvas in a large-format, vertically hung painting usually results in a bulge in the lower part of the painting that cannot be easily resolved by keying-out (Canadian Conservation Institute 1993). The painting must be dismounted and restretched to achieve its original tautness. Still, while keying-out is not recommended as a routine procedure, it is still commonly used as a means of tension adjustment in the conservation and art communities.

In the latter half of the 20th century, conservators attempted to design a stretcher that would address the problems inherent in traditional keyed stretchers. They created different kinds of joint-adjusting mechanisms, including the ICA spring stretcher and expansion-bolt stretcher (AIC Wiki 2007), but these systems were still grounded in biaxial interdependent expansion.

Physically and chemically inert support materials, such as aluminum, have been investigated as alternatives to wood since 1941 (AIC Wiki 2007). Metal stretchers provide dimensional stability and do not react to changes in relative humidity as wooden stretchers do. Metal stretchers are often used as conservation-grade supports (Buckley 2012), but the higher
cost of material, labor, and fabrication compared with wooden stretchers limits their availability.

The aim of this investigation was to research and design an aluminum mechanism as an alternative to traditional keying-out for tension adjustment. Observational analyses of strain compared the deformation incurred by the new stretcher’s independent dimensional expansion with the deformation incurred by the traditional keyed stretcher’s interdependent dimensional expansion.

2. BACKGROUND

Volume 2 of the Painting Conservation Catalog, “Stretchers and strainers,” published in 2007 by the American Institute of Conservation (AIC) Paintings Specialty Group, is one of the most comprehensive works to date on stretchers and strainers. This monumental work, compiled by Barbara A. Buckley, was the result of the volunteer efforts of 43 authors and 12 editorial boards. Available from AIC to conservators, museum professionals, and the public in both online (AIC Wiki 2007) and print versions (Buckley 2008), this publication includes valuable historical and technical information on materials, design, and applications, and provided the foundation for this current investigation. However, it does not cover the mechanical alteration of painting composites resulting from stretchers and methods of expansion. This is understandable, given that historical data on the mechanical analysis of wooden stretchers are almost nonexistent. Even today, discussions of the design, material, and function of stretchers are mostly limited to the craft and conservation sphere and rarely involve scientific mechanical evaluation. A rare exception is a work by G. A. Berger published in 1984 (Berger 1984), in which he assesses the mechanical properties of his “self-adjusting continuous tension stretcher;” however, it contains no analysis of mechanical behavior.

A painting on canvas is a composite structure composed of a paint film (from the bottom up, the layers are size, ground, paint, and varnish), fabric (primary support) and a stretcher or strainer (secondary or auxiliary support). Stress on the paint film and fabric increases in response to a decrease in temperature or RH, and to the canvas being restrained by a stretcher or strainer. Works by Hedley (1988), Young and Hibberd (1999), Mecklenburg and Tumosa (1991), and Michalski (1991) provided valuable theoretical models and experimental data on the mechanical behavior of canvas paintings and the results of stress and strain on a painting’s composite structure. A. Karpowicz’s study of paint cracks (1990) and personal communication with Karpowicz in 2013 provided essential understanding of humidity-induced movement on biaxially stretched fabric. In the last 20 years, mechanical evaluation of stretchers and strainors by conservators has been rare. Most newly developed stretchers are produced commercially (Alustretch; Simon Liu Inc.; Jackson’s Art Supplies; Rex Art) and rely on tension adjustment through interdependent biaxial expansion of the corner joints. Conservators have sought a solution to the constraints of two-dimensional expansion through independent unidimensional expansion for tension adjustment; however, very little comparative analysis of the mechanical properties of interdependent biaxial expansion (traditional keying-out; expansion with turnbuckle bolts) and independent biaxial expansion has been done, other than the work of S. Philips et al.

2.1 Independent Dimensional Expansion Models to Date

In the past, conservators and craftsmen have tried to solve the problems inherent in keying-out systems that rely on interdependent biaxial expansion by redesigning the stretcher to make it capable of independent dimensional expansion. A search of the literature revealed that at least four stretcher systems have been developed that use independent dimensional expansion.

The first model was designed in the United States by H. Holly in 1873 (Katlan 1992). In his patent entitled “Improvement in Canvas Stretching and Protecting Frames,” he described his invention as having a bar made from a thin, flat sheet of metal “[that] is moved from or toward said fixed end.” In the 1950s, R. Carita designed an expansion system that used springs to move the stretcher along the vertical or horizontal axis, instead of relying on biaxial expansion at the corners. M. Ciatti (2000) and A. Idelson (2009) have made improvements to Carita’s system in the last few years. Ciatta’s system applies constant, controlled tension through the use of rigid materials such as steel and aluminum. Tension is adjusted by means of purpose-built stainless steel springs that are tightened or released by a nut attached to an aluminum strip. In 1984, Berger published an account of his new stretcher system (1984), which he described as a “self-adjusting continuous-tension stretcher” with a horizontal movable part at the top, connected to a rigid frame with springs that enable unidirectional movement. Finally, on June 5, 1992, Philips presented his design for a new expansion stretcher at the Annual Meeting of the AIC Paintings Specialty Group (Philips 1992). As a way to deal with the “unsolved problem of keying-out canvas expansion,” Philips abandoned the miter as the focal point of expansion. Instead, he devised a neutral pivot that allows each bar to move independently in one direction without disturbing the others.

Together, these four expansion systems represent an evolutionary approach to the problems presented by interdependent dimensional expansion and the first important design concepts in independent dimensional expansion, which is the basis of this current investigation.
2.2 Metal Stretchers

To prevent the deformation of wooden frames that results from relative-humidity fluctuation, stretcher bars made from metal began to appear in 1941 (Buckley 2012). The first aluminum stretcher was made by F. Rigamonti in 1966 (AIC Wiki, 2007). Starofix North America, founded in 1984, produces lightweight aluminum stretchers (AIC Wiki, 2007) and Alustretch, based in Vienna, has been a leading manufacturer of aluminum stretchers in Europe since 1990. P. Raich designed a new stretcher for Alustretch as recently as 2008 (Alustretch). A metal stretcher provides dimensional stability, especially for a large canvas, and, unlike a wooden stretcher, does not react to relative-humidity changes. Yet despite their advantages, metal stretchers are less commonly used and not as readily available as wooden stretchers because of the higher costs of material and production, as well as aesthetic concerns.

2.3 The TWP² Stretcher

The TWP² stretcher takes its name from the initials of its designers: Tsang (a paintings conservator), Williams (a furniture conservator), Pelasara (a master cabinet maker), and Patterson (a metal fabricator). This new stretcher was invented by applying the principle of independent dimensional expansion to a newly designed aluminum stretcher that expands a canvas by turning steel thumbscrews attached to the stretcher bar. The design sprang from failed attempts to correct a distorted canvas by the standard methods of moisture, heat, and/or pressure. The team designed a prototype of the TWP² as an insert to strengthen the original stretcher bar. They fitted the insert to the original stretcher, and the resulting tension adjustment was successful. The distortion in the canvas was instantaneously corrected simply by turning the thumbscrews on the expansion stretcher.

The prototype TWP² went through five successive design modifications and improvements. The latest model (prototype #5) is made of aluminum, rigid High density polyethylene, or Delrin, and has thumbscrews for tension adjustment positioned along the stretcher bar rather than at the corners of the frame. This stretcher can be inserted as an adjunct to an existing stretcher or used alone as an artist-grade stretcher. Tsang and Madruga (an engineer and paintings conservator) designed experiments to measure stresses and strains on the canvas, as well as craquelure patterns induced by the new stretcher. Tsang and Madruga compared the mechanical behavior of the new stretcher with that of a traditional wooden keyed stretcher and evaluated theoretical models of the strain on canvas induced by both systems. This report is the result of one year of product design evaluation and fabrication, and an additional year of mechanical behavior analysis. Since then, design and evaluation of the TWP² has focused on bending of the traditional wooden stretcher bar and other problems inherent to the conservation of canvas paintings. The observations and measurements so far derived from such a small test sample have led to valuable insights; however, a larger test sample and more precise equipment for measuring relative humidity and exact changes in tension over longer periods of time will be required to make further advances in research and design.

3. THE TWP² STRETCHER: MATERIALS AND CONSTRUCTION

The TWP² stretcher is designed for use as both an artist-grade stretcher and as an insert to strengthen and provide tension adjustment for an existing stretcher. The name TWP² applies to both systems, which share common features, construction methods, and mechanisms. For clarity within this report, the insert stretcher is referred to as the TWP² insert (fig. 1) and the artist-grade stretcher is referred to as the TWP² artist-grade (fig. 2).

The TWP² is composed of (1) a U-channel, T-bar, and Z-bar made of commercial-grade aluminum, (2) metal fasteners, including stainless steel threaded thumbscrews and spring pins and aluminum L-plates, and (3) rigid HDPE polyethylene or black Delrin® resin strips (fig. 3). The TWP² artist-grade also has a wooden tacking edge for stretching a new canvas. This tacking edge, made from basswood, fir, or poplar, is connected to the moveable aluminum T-bar. (See Materials and fig. 23.)

The TWP² has rigid aluminum parts that can be cut to size and configured as needed. A rigid inner U-channel is fitted

Figure 1. TWP² insert, corner detail
On the TWP Insert, by turning the thumbscrews, the outer T-bar expands the original stretcher by moving the T-bar straight outward. On the TWP Artist-grade, the wooden element attached to the outer moveable T-bar (fig. 24) provides a tacking edge for the canvas.

The rigidity of the TWP stretcher is further reinforced by aluminum L-angle plates that secure the aluminum U-channels to the mitered corners with stainless steel screws. The authors recommend that an aluminum Z-bar screwed to the U-channel be incorporated as a crossbar to provide additional rigidity for stretchers more than 30 inches long.

The placement of thumbscrews is critical for ensuring proper movement and optimal surface contact between the T-bar and the original stretcher (TWP Insert), and the T-bar/wooden element and the canvas (TWP Artist-grade). Thumbscrews should be placed 8–10 inches (20.3–25.4 cm) apart along the stretcher bar, with thumbscrews closest to the edge placed 3–4 inches (7.6–10.2 cm) from the inner corner of the rigid member (e.g., a 30 in. stretcher should have three thumbscrews per side) (figs. 21, 22). The TWP stretcher mechanism ensures that tensioning is imparted gently and is evenly and independently distributed in each direction.

Hanging devices can be secured either to the inner rigid member (U-channel) or to the crossbar (Z-bar). This arrangement can support the weight of the painting, the original stretcher, and the TWP Insert, while maintaining the painting’s historical and aesthetic quality.

4. TESTING

4.1 Preparation of Samples
We prepared four 30 × 30 in. and four 12 × 12 in. painting samples for testing. For each sample, the canvas was attached to the stretcher using stainless steel staples. The size and chalk ground were prepared according to traditional recipes (see Recipes). Two brush coats of size were applied to the stretched canvas, followed by two additional brush coats of gesso. Brush marks were smoothed with sandpaper. The final ground was ~180 µm thick.

4.2 Relative-Humidity Chambers
Five relative-humidity chambers were constructed of expanded polyurethane boards faced with aluminum foil. They were assembled into parallelepipeds measuring ~36.5 in. w × 36.5 in. l × 12 in. h (92.7 cm w × 92.7 cm l × 30.5 cm h). Foil-covered sides faced the interior of the chamber so that experimental relative-humidity levels could be maintained once the chamber was sealed. The relative-humidity chambers were stored at a stable temperature of ~20°C.
4.3 Testing: Samples, Settings, and Methods

We conducted tests to compare mechanical changes induced by expansion of keyable wooden stretchers, the TWP\(^2\) insert, and the TWP\(^2\) artist-grade (table 1). Test samples 1 and 2 were used as controls (tension was not adjusted). Canvas tension was adjusted via keying-out (keyable wooden stretchers) and threaded thumbscrews (TWP\(^2\) stretchers). Samples were placed into relative-humidity chambers and subjected to cycles of extreme conditions of relative humidity, fluctuating between 0% (est.) and 100% (est.), for a total of 14 sets over a six-month
period. The estimated 0% RH level was achieved by placing 0% RH silica gel on a tray at the bottom of the relative-humidity chamber. Moisture in the silica gel was previously evaporated in an oven at 110°C for half a day. The estimated 100% RH level was achieved by placing dampened sheets of blotting paper at the bottom of the chamber.

4.4 Results of Experiments
The objective of the experiments was to assess and compare the mechanical changes induced by expansion with traditional keyable wooden stretchers and TWP² stretchers under conditions of extreme relative-humidity fluctuations. Our assessment focused on the stretchers’ response (dimensional movement or bending) throughout the relative-humidity cycling, as well as craquelure patterns formed on the paintings as a result of expansion and relative-humidity cycling (fig. 6).

Before the relative-humidity cycling experiments began, minor cracks in the 30 × 30 in. samples were observed on the corners and on random areas on the surface of the paintings (see

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Figure 6. Labeled edges and corners of painting samples (front view)
Appendix A). These inherent cracks most likely resulted from canvas preparation and minor defects or creases in the canvas.

Tables 2 and 3 (Appendix A) detail the development of cracks in the painting samples during relative-humidity testing, particularly cracks in the corners of painting samples 1–4 and 5–8 during each set of relative-humidity cycles. In the tables, the terms “cracks” and “faint cracks” represent highly subjective judgments by the testers; however, for our purposes, the term “faint cracks” indicates a lack of both continuous development across the corner and noticeable depth. The wooden stretchers of samples 3 and 4 were keyed-out after each set of lower relative humidity, when the size and gesso layers were more brittle. The TWP 2 stretchers of samples 5–8 were expanded after each relative-humidity set using thumbscrews.

Sample 1 (30 × 30 in. wooden stretcher, no keying-out) developed corner stress cracks from relative-humidity set 4 onwards. After 14 relative-humidity sets, the number of cracks at each corner was AB: 1, AD: 5 (plus an additional faint crack), CD: 2, and BC: 2 (figs. 7, 8). Cracks that developed at corners AB, BC, and CD fell within approximately the same range of distance from the edge of the sample. Cracks that developed at corner AD were more compact, but overall, the crack furthest from the edge fell within a similar range of distance as cracks in the other corners.

Sample 3 (30 × 30 in. wooden stretcher, keyed-out) developed corner cracks earlier than sample 1 (from relative-humidity set 3), but from set 11 onwards no additional cracks developed. After 14 relative-humidity sets, the number of cracks at each corner was AB: 1, AD: 5 plus 1 faint crack, CD: 2, and BC: 2 (figs. 7, 8). Cracks that developed at corners AB, AD, and BC fell within approximately the same range of distance from the edge of the sample. Cracks that developed at corner CD were more compact, but overall, the crack furthest from the edge fell within a similar range of distance as cracks in the other corners.
corner was AB: 1, AD: 3, CD: 3, and BC: 1 (figs. 9, 10). Corner cracks developed symmetrically along the horizontal axis and fell within approximately the same range of distance from the edge of the sample. Some cracks developed on the surface, but there were no cracks radiating from the corners as a result of keying-out.

Sample 5 (30 × 30 in. TWP\textsuperscript{2} insert) developed corner and surface cracks during relative-humidity sets 6–8 and 14. There was no visible symmetry between the corner cracks along the horizontal and vertical axes. Overall, the range of distance from cracks to corner was approximately the same for each corner. After 14 relative-humidity sets, the number of cracks at each corner was AB: 1, AD: 0, CD: 1 faint crack, and BC: 2 (plus an additional faint crack) (figs. 11–13).

Sample 7 (30 × 30 in. TWP\textsuperscript{2} artist-grade) developed no corner cracks throughout the relative-humidity cycling experiment. After four relative-humidity sets, a draw developed at corner AD, which was corrected by detaching the canvas at that corner, reattaching the canvas, and tightening the thumbscrews. After eight relative-humidity sets, two single, fine, surface cracks developed on the lower left quadrant (figs. 14, 15).

None of the small painting samples (12 × 12") developed any cracks after being subjected to the same extreme environmental fluctuations (figs. 16, 17).
Figure 11. Sample 5, showing cracks that developed after 14 RH sets and the distance between cracks. The number of cracks at each corner was AB: 1, AD: 0, CD: 1 faint crack, and BC: 2 plus 1 faint crack. There were also 3 single surface cracks.

Figure 12. Sample 5, corner AD. After 14 RH sets there were no corner cracks, but there was a mechanical surface crack measuring ~10 cm and located ~11 cm from the right edge.

Figure 13. Sample 5, corner BC. After 14 RH sets corner BC had 2 cracks plus 1 faint crack.
Figure 14. Sample 7. After 14 RH sets there were no cracks visible in the corners and only 2 fine single cracks on the surface.

Figure 15. Sample 7, corner AD, after 14 RH sets.

Figure 16. Samples 2, 4, 6, and 8. No cracks developed.

Figure 17. Sample 6, whole front. After 14 RH sets, no cracks developed.

At the end of the relative-humidity cycling, samples 1 and 3 had a total of 11 and 8 corner cracks, respectively. Sample 1, which was not tensioned during relative-humidity cycling, had slightly more cracks than the keyed-out sample. Sample 5 had a total of five corner cracks. (This sample had cracks before the experiment began, which may have affected the development of craquelure). Sample 7 had no cracks. Overall, both types of TWP^2 stretcher (samples 5 and 7) developed considerably fewer corner cracks than the traditional wooden stretchers (samples 1 and 3).
5. DISCUSSION

5.1 Craquelure Patterns

Our analysis of craquelure patterns focused on those initiated by mechanical stresses within the composite structure of the painting (e.g., environmental stresses and stresses induced by expansion of the stretcher) and craquelure patterns created by external mechanical pressure or impacts (Keck 1969). Mechanical cracks develop when the canvas is unable to adequately relieve stress (Mecklenburg 1982; Berger and Russell 1994). At low humidity, wavelike cracks radiate from the corners as a result of increased stress within all layers of the composite structure, including stretcher contraction; by keying-out a stretcher, linear cracks (perpendicular to the wavelike) radiate from the corners (Mecklenburg and Tumosa 1991).

The authors compared the craquelure patterns that developed on the painting samples in their experiments with examples previously described (Colville, Kilpatrick, and Mecklenburg 1982; Karpowicz 1990; Mecklenburg and Tumosa 1991; Michalski 1991). The only pattern that developed in their samples (wooden stretchers and TWP\(^2\) insert) was curved, wavelike lines that radiated from the corners. These cracks were generally fine with narrow apertures; some were very faint, especially the ones closest to the edge. In general, each corner developed a different number of cracks. At most, two corners on the same sample developed the same number of cracks. This relates to the fact that being a human factor, the force applied when stretching a canvas is uneven. Some fine surface cracks developed on our samples, possibly resulting from the application of the coating layers and/or minor defects (creases) in the fabric support. Though they are practically invisible when the canvas is under tension, these fine cracks can propagate through the gesso layers. No tacking cracks, middle bisector cracks, or bias cracks developed (Michalski 1991). (None of the paintings became slack enough to make contact with the stretcher bars, ruling out the possibility of stretcher bar edge cracks.)

Sample 3, which was keyed-out, did not develop linear cracks that radiated from the corners, as previously described (Keck 1969; Colville, Kilpatrick, and Mecklenburg 1982; Mecklenburg 1982; Karpowicz 1990; Mecklenburg and Tumosa 1991), even though the keys were driven in at the end of 0% RH cycling, when size and gesso layers are brittle. Possible explanations for the lack of this type of craquelure include: (1) the expansion provided by keying-out was not effective; (2) exposure to too few relative-humidity sets; (3) in the experience of conservators, this type of cracking is uncommon (Karpowicz 2013); and (4) radial corner cracks are subtle (Michalski 1991).

At the end of the relative-humidity cycling experiment, sample 1, the painting that underwent relative-humidity cycling without further tensioning of its wooden stretcher, had slightly more cracks than the keyed-out sample 3, showing that the extent of deformation is slightly higher. Nonetheless, canvases with both the TWP\(^2\) insert and the TWP\(^2\) artist-grade (samples 5 and 7) developed considerably fewer corner cracks than the canvases with traditional wooden stretchers (samples 1 and 3). This shows that the magnitude of canvas deformation is greater with a traditional wooden stretcher system than with a TWP\(^2\) stretcher. Deformation occurs when the stretcher expands or contracts, or when the canvas cannot be made uniformly taut. Our experiments demonstrated that adjusting the thumbscrews on the new TWP\(^2\) stretcher provides uniform tension over the entire surface of a canvas more effectively than keying-out the corners of a wooden stretcher. Keying-out creates excessive tension primarily at the corners, increasing the number of corner cracks without adequately transmitting tension to the center of the canvas. Thus, the TWP\(^2\) stretcher can prevent corner cracks while providing superior structural support that protects the integrity of the paint surface and the painting as a whole. Our tests also led to improvements in the prototype, such as adjusting the distance between the thumbscrews and their distance from the edge of the rigid aluminum member, which provided better contact throughout the length of the stretcher bar and evenly distributed tension.

None of the 12 × 12 in. painting samples (without or with keys, TWP\(^2\) insert, or TWP\(^2\) artist-grade) developed cracks, showing that size affects the development of stress cracks. RH-induced deformations are less pronounced on small-scale paintings; however, it is possible that craquelure would eventually develop over time.

Sample 7 (30 × 30 in.) had a corner draw. Corner draws are caused by expansion of the fabric and in response to environmental fluctuations. They may also be caused by forces exerted on the bias of the fabric, which creates greater stretch (Young and Jardine 2012). The TWP\(^2\) stretchers used in our tests had only two thumbscrews per bar. Our experiments revealed the need to add one additional thumbscrew per bar to provide better contact throughout the length of the stretcher and possibly prevent corner draws.

Time and budget constraints dictated that samples be examined visually and measured with simple equipment. Further testing is needed to provide more objective data that will clarify comparisons of the traditional wooden stretcher and the TWP\(^2\) aluminum stretcher. Testing could be improved by extending the relative-humidity cycling to assess the long-term effects of extreme relative-humidity fluctuations; evaluating the extent of craquelure patterns and deformation of the canvas; and experimenting with temperature variables. The use of optical systems such as electronic speckle pattern interferometry or digital image correlation could provide systematic and thorough assessments of strain fields (which would allow the calculation of the stress fields) (Dulieu-Barton et al. 2005; Young 2012).
5.2 Expansion of Stretcher Bars: Traditional Wooden Stretcher versus TWP2 Aluminum Stretcher

Successive cycles of temperature and relative-humidity fluctuations can undermine a canvas’s original tension and cause it to slacken. This is the most common reason for periodic keying-out (Berger and Russell 1994). However, keying-out expands a conventional stretcher only at the corners, not along the edges, which causes further variations in the overall tension of a painting (Berger 1984). Repeated or excessive keying-out of the stretcher does not resolve the problem of overall slackening, particularly with large-scale paintings (Chiantore and Rava 2013). It does, however, concentrate stress at the corners, which can ultimately fracture the canvas in those areas. The tension focused at the corners of the canvas, along with the tension exerted by the canvas along the stretcher bar, prevent the bar from moving freely and may cause it to bend. High tension in the corners will not be evenly distributed across the surface of the painting. This ineffective tensioning will be especially noticeable in the center of the canvas. Expanding on work by Mecklenburg (2012), the authors analyzed strains on the corners and center of a canvas induced by keying-out of a wooden stretcher (fig. 18). The stretcher measured 760 × 635 mm, with bars 75 mm wide. For our investigations, the authors assumed a deformation (δ) of 1.5 mm vertically and horizontally on each corner, and defined strain (ε) as deformation (δ) in relation to the original length of the bars.

In the figure above, solid lines indicate the stretcher bars before expansion, and dotted lines indicate deformation after expansion. Assuming the stretcher bars bend, vertical strain will diminish from 0.00395 to 0.00263 or 0.00197, depending on whether displacement at the center of the bar (x) is 2/3 (0.00263) or ½ (0.00197) of total displacement (1.5 × 2 = 3 mm). (Values of magnitude of bending should be taken as estimations.) Center strain is directly proportional to the amount of bending in the stretcher bar; that is, if the bar deflects half of the corner displacement (x = ½ δ), the center strain will be half what it would be if there were no bending. To overcome this ineffective tensioning in the center, the tendency is to increase expansion at the corners, but this just creates even higher strains, and thus stresses. Assuming the bar deflects half of the displacement, to achieve higher strain in the center, expansion at the corners would need to double; i.e., strain at the corners would need to go from 0.0196 to 0.0393. Focusing expansion at the corners inevitably shifts the canvas in the bias direction, where tensile strength is lowest, and thus stretch is greater and tensioning is least effective (Young and Hibberd 1999). Center strain is directly proportional to the amount of bending in the stretcher bar; that is, if the bar deflects half of the corner displacement (x = ½ δ), the center strain will be half what it would be if there were no bending. To overcome this ineffective tensioning in the center, the tendency is to increase expansion at the corners, but this just creates even higher strains, and thus stresses. Assuming the bar deflects half of the displacement, to achieve higher strain in the center, expansion at the corners would need to double; i.e., strain at the corners would need to go from 0.0196 to 0.0393. Focusing expansion at the corners inevitably shifts the canvas in the bias direction, where tensile strength is lowest, and thus stretch is greater and tensioning is least effective (Young and Hibberd 1999). Center strain is directly proportional to the amount of bending in the stretcher bar; that is, if the bar deflects half of the corner displacement (x = ½ δ), the center strain will be half what it would be if there were no bending. To overcome this ineffective tensioning in the center, the tendency is to increase expansion at the corners, but this just creates even higher strains, and thus stresses. Assuming the bar deflects half of the displacement, to achieve higher strain in the center, expansion at the corners would need to double; i.e., strain at the corners would need to go from 0.0196 to 0.0393. Focusing expansion at the corners inevitably shifts the canvas in the bias direction, where tensile strength is lowest, and thus stretch is greater and tensioning is least effective (Young and Hibberd 1999).

Next, the authors inserted a TWP2 insert stretcher into an original wooden stretcher with the same dimensions as the stretcher in the previous experiment. Then they expanded the stretcher bars in each direction by turning the thumbscrews (fig. 19).

In the previous figure, solid lines indicate the original and TWP2 insert stretcher bars before expansion. Dotted lines indicate their position after expansion. Thumbscrews are positioned along the stretcher bar, including in the center, allowing uniform movement of the outer aluminum T-bar, which imparts evenly distributed tension. Turning the thumbscrews expands the aluminum T-bar in a straight line in conjunction with the original wooden stretcher bar, eliminating any bending of the bars. Assuming a 1.5-mm δ in both directions, the vertical and horizontal strains in the center will be 0.00395 and 0.00472, respectively. Because there is no bending of the stretcher bar, the strain field will be evenly distributed throughout the painting’s surface, except at the corners, where strain distribution is heterogeneous (Young and Hibberd 1999). Strain at the corners (same location as on the previous example) will be 0.0196. According to our two theoretical models, compared to the keyed-out wooden stretcher, the TWP2 insert achieved the same magnitude of strain in the center of the canvas, while creating less strain at the corners. Thus, the self-adjusting TWP2 offers a more effective way of distributing tension over the entire surface of a canvas, making the TWP2 the best option for oversize paintings where tensioning is more problematic at the center. Furthermore, the TWP2 can effectively maintain that tension over a long period of time.

5.3 Response to Changes in Relative Humidity and Temperature

After analyzing the comparative strains incurred on a canvas painting by the expansion of wooden and aluminum stretchers, the authors compared how paintings with wooden stretchers and aluminum stretchers respond to changes in relative humidity and temperature.

5.3.1 Composite Layers of a Painting

Paintings on canvas lose tension with moisture absorption until relative humidity reaches approximately 80–85%, at which point the tension begins to increase. This inflexion is related to the canvas’s tendency to shrink (Hedley 1988). If a painting is attached to a stretcher, stresses on all of its composite layers increase in response to a change in either temperature or relative humidity. Of all painting materials, glue is most sensitive to relative humidity (Mecklenburg and Tumosa 1991). Glue responds quickly to environmental changes; hence, in a sized painting, glue is responsible for the majority of damage due to changes in relative humidity. Size and glue respond to fluctuations in relative humidity within minutes to hours. By comparison, it takes days to weeks for stretcher bars to respond to the same fluctuations (Michalski 1991). Therefore, in their tests, the authors decided to run each relative-humidity set for 1–3 weeks. In addition, size and glue ground show greater increases...
Traditional keyable wooden stretcher

Strains in the corner
\[
\begin{align*}
\delta_{108} &= 0.0196 \\
\delta_{24} &= 0.0393 \\
\delta &= 1.5 \\
\delta &= 3
\end{align*}
\]

Strains in center
\[
\varepsilon = \delta / L
\]

Comparing strains in the center when keying-out in the corners and assuming there is bending of the stretcher bar
If:  
(1) There is no bending
(2) \( x = \frac{2}{3} \cdot \delta \)
(3) \( x = \frac{6}{2} \)

Figure 18. Theoretical model of strains in the center and corners of a canvas caused by keying-out of a traditional keyable wooden stretcher.
Theoretical model of strain in the center and corners of a canvas after expanding the stretcher bars of an aluminum $TWP^2$ insert via thumbscrews.

Figure 19. Theoretical model of strain in the center and corners of a canvas after expanding the stretcher bars of an aluminum $TWP^2$ insert via thumbscrews.
in tension in response to low levels of relative humidity than to low temperatures. Thus, to minimize variables, temperature variations were not considered in our tests (Michalski 1991).

5.3.2 Wooden Stretchers versus Aluminum Stretchers

The expansion or shrinkage of a stretcher will be reflected in strains in the painting it supports. The dimensional response of wood to moisture and temperature is different depending on the direction in which wood is cut (tangential, radial, or longitudinal). The authors calculated moisture coefficients of expansion (γ) for different species of wood assuming a tangential cut (table 4, Appendix B). If it was a radial cut, the dimensional change would be approximately half, and therefore the moisture coefficient of expansion would be roughly half (Mecklenburg 2012). On the other hand, aluminum does not respond to relative-humidity changes. The thermal expansion coefficient (α) for aluminum is $24 \times 10^{-6}$ per °C (Nave 2013). The coefficients of thermal expansion for different species of wood are outlined in table 5 (Appendix B). Wood’s radial response to changes in temperature is generally higher than aluminum. A comparison of the values listed in tables 4 and 5 reveals that the moisture coefficients (γ) of wood are much greater than the thermal coefficients (e.g., for cottonwood, γ = 0.042 and α = 0.000023), meaning that wood is more sensitive to changes in relative humidity than to changes in temperature. Fluctuations in relative humidity lead to greater expansion and contraction of a wooden stretcher, which ultimately leads to higher stresses and strains in the canvas painting.

An aluminum stretcher can greatly reduce the strains imposed on a painting by environmental fluctuations. Since there is a wood component to both the TWP² insert and TWP² artist-grade, strains due to environmental fluctuations cannot be entirely avoided; however, the width of the wood member in the TWP² artist-grade can be varied as needed, since structural support is provided by the aluminum members. Another advantage of an aluminum stretcher is that it does not warp in response to changes in relative humidity, as wooden stretchers do.

6. APPLICATIONS

The TWP² insert is designed to fit inside an existing or original stretcher. It can strengthen a weak original stretcher and provide dimensional stability. Tension can be adjusted by turning thumbscrews that exert gentle, even pressure across the entire surface of the painting. The TWP² insert also provides effective tension adjustment at the center of a painting, where traditional expansion via keying-out of the corners is least effective. The TWP² is well suited for large-format, traditional, or contemporary paintings. In addition, the magnitude of deformation on a canvas supported by a TWP² stretcher is less than that seen with a traditional wooden stretcher. The TWP² can be fitted and dismounted simply by loosening the thumbscrews.

When the authors fitted a 150-year-old painting with the newly designed TWP² insert as an auxiliary support inside the original stretcher, planar distortion in the canvas was immediately corrected (fig. 20). No heat, moisture, or weight was necessary to correct this planar distortion, thus preserving the character and integrity of the painting. They are currently investigating the use of a TWP² artist-grade in a contemporary painting with heavy impasto, which makes tension adjustment even more critical.

7. CONCLUSIONS

Extreme fluctuations in relative humidity can cause rapid and significant changes in tension that produce craquelure on the surface of a painting. The results of this study demonstrated and confirmed this phenomenon. The theoretical models of strain in both the TWP² stretcher and a traditional keyable wooden stretcher increased our understanding of the problems arising from bending in a wooden stretcher caused by expansion. The major advantages of the TWP² stretcher are its capacity for independent directional expansion and its construction of stable aluminum that does not react to relative-humidity fluctuation. Our tests demonstrated that the TWP² stretcher helps to prevent corner cracking, which can ultimately propagate further deterioration. The self-adjusting TWP² stretcher offers a more effective way of tensioning the canvas and maintaining tension for a longer term. Our innovative stretcher design could not only transform strategies for preserving at-risk and large-format paintings.
paintings, but could also influence the design and fabrication of large-scale canvases. Further research with a greater number of samples and more precise measuring instruments will improve our understanding of the mechanical stress and strain resulting from stretcher expansion.

APPENDIX A

Before the relative-humidity cycling, samples 1 and 3 had a maximum of 1 or 2 minor cracks in one corner. Samples 2 and 4 (12 × 12") had no cracks.

Table 1. Experimental Development of Corner and Surface Cracks on Painting Samples 1–4 (Wooden Stretchers)

<table>
<thead>
<tr>
<th>Samples Sets</th>
<th>1 Wooden Stretcher, 30 × 30&quot;, No Keys</th>
<th>2 Wooden Stretcher, 12 × 12&quot;, No Keys</th>
<th>3 Wooden Stretcher, 30 × 30&quot;, Keyed-Out</th>
<th>4 Wooden Stretcher, 12 × 12&quot;, Keyed-Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: 0% RH</td>
<td>Minor cracks</td>
<td>No cracks</td>
<td>Minor cracks</td>
<td>No cracks</td>
</tr>
<tr>
<td>2: 100% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>3: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>AB: 1 crack</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 2 cracks</td>
<td>CD: 1 crack</td>
<td>BC: 1 crack</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 4 cracks</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 1 crack (+ 1 faint crack)</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 2 cracks</td>
<td>BC: 1 crack</td>
<td>BC: 1 crack</td>
<td>No change</td>
</tr>
<tr>
<td>4: 100% RH</td>
<td>AB: 1 crack</td>
<td>No change</td>
<td>AB: 1 crack</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 2 cracks</td>
<td>CD: 2 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 3 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 4 cracks</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 2 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 2 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>5: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>6: 100% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>7: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>AB: 1 crack</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 2 cracks</td>
<td>CD: 3 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 3 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 4 cracks</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 2 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 2 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>8: 100% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>9: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>10: 100% RH</td>
<td>AB: 1 crack</td>
<td>No change</td>
<td>AB: 1 crack</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 4 cracks</td>
<td>AD: 3 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 2 cracks</td>
<td>CD: 3 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 2 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>11: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>(cracks on corners)</td>
<td>(cracks on corners)</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>Cracks on surface</td>
<td>Cracks on surface</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>12: 100% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>13: 0% RH</td>
<td>AB: 1 crack</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 5 cracks</td>
<td>AD: 3 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 2 cracks</td>
<td>CD: 3 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 2 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>14: 100% RH</td>
<td>AB: 1 crack</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>AD: 5 cracks</td>
<td>AD: 3 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>CD: 2 cracks</td>
<td>CD: 3 cracks</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 2 cracks</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
</tr>
</tbody>
</table>
Before relative-humidity cycling, samples 6 and 8 (12 × 12 in.) and 7 (30 × 30 in.) had no cracks. Sample 5 had a slightly noticeable crack on corner BC. Three mechanical surface cracks may have been related to indentations on the back of the canvas (possible fabric defect), to ground application, or to the fact that the TWP2 insert was fitted approximately one month after the canvas was prepared.

Table 2. Experimental Development of Corner and Surface Cracks on Samples 5–8 ($TWP^2$ insert and artist-grade).

<table>
<thead>
<tr>
<th>Samples Sets</th>
<th>5: $TWP^2$ insert, 30 × 30&quot;, Expanded Via Thumbscrews</th>
<th>6: $TWP^2$ insert, 12 × 12&quot;, Expanded Via Thumbscrews</th>
<th>7: $TWP^2$ artist-grade, 30 × 30&quot;, Expanded Via Thumbscrews</th>
<th>8: $TWP^2$ artist-grade, 12 × 12&quot;, Expanded Via Thumbscrews</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: 0% RH</td>
<td>BC: faint crack</td>
<td>No cracks</td>
<td>No cracks</td>
<td>No cracks</td>
</tr>
<tr>
<td>2: 100% RH</td>
<td>BC: 1 crack</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>3: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>4: 100% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>5: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>6: 100% RH</td>
<td>AB: faint crack</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 1 crack</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7: 0% RH</td>
<td>AB: faint crack</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>BC: 1 crack</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CD: faint crack</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8: 100% RH</td>
<td>AB: 1 crack</td>
<td>No change</td>
<td>No change</td>
<td>Fine surface cracks</td>
</tr>
<tr>
<td></td>
<td>BC: 2 cracks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CD: faint crack</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface crack</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9: 0% RH</td>
<td>No change (cracks on corners)</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>Surface cracks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10: 100% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>11: 0% RH</td>
<td>No change (cracks on corners)</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>Surface cracks: one crack expanded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12: 100% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>13: 0% RH</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>14: 100% RH</td>
<td>BC: 2 cracks (+ 1 faint crack)</td>
<td>No change</td>
<td>No change</td>
<td>No change</td>
</tr>
</tbody>
</table>

Modernized Stretcher for Paintings on Canvas: Assessment and Observation

AIC Paintings Specialty Group Postprints 26 (2013)
APPENDIX B

Table 3. Moisture Coefficients of Expansion ($\gamma$) for Different Types of Wood (Tangential Cut Assumed) at Relative-Humidity Intervals of 20%–50% and 50%–80%

<table>
<thead>
<tr>
<th>Type of Wood</th>
<th>Moisture Coefficient of Expansion ($\gamma$) 20% → 50% RH</th>
<th>Moisture Coefficient of Expansion ($\gamma$) 50% → 80% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cottonwood (European poplar)</td>
<td>0.042</td>
<td>0.067</td>
</tr>
<tr>
<td>White oak</td>
<td>0.038</td>
<td>0.046</td>
</tr>
<tr>
<td>Red oak</td>
<td>0.039</td>
<td>0.059</td>
</tr>
<tr>
<td>17th-century Scots pine</td>
<td>0.043</td>
<td>0.077</td>
</tr>
<tr>
<td>Maple</td>
<td>0.046</td>
<td>0.085</td>
</tr>
<tr>
<td>Ash</td>
<td>0.044</td>
<td>0.078</td>
</tr>
<tr>
<td>Aircraft spruce</td>
<td>0.024</td>
<td>0.026</td>
</tr>
<tr>
<td>Sugar pine</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>Spruce</td>
<td>0.025</td>
<td>0.025</td>
</tr>
</tbody>
</table>

*The moisture coefficients of expansion are approximate values calculated using the graphs, “Free Swelling Strains vs. Relative Humidity,” provided in (Mecklenburg 2012)*

Table 4. Thermal Expansion Coefficients ($\alpha$) for Different Types of Wood (Weatherwax and Stamm 1956; Wood Science and Technology archive)

<table>
<thead>
<tr>
<th>Wood</th>
<th>Thermal Expansion Coefficient per °C [50°C–0°C], $\alpha_{radial} \times 10^{-6}$</th>
<th>Thermal Expansion Coefficient per °C [50°C–0°C], $\alpha_{parallel} \times 10^{-6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow poplar</td>
<td>27.2</td>
<td>3.55</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>23.3</td>
<td>3.17</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>27.1</td>
<td>3.52</td>
</tr>
<tr>
<td>Oak</td>
<td>54</td>
<td>5</td>
</tr>
<tr>
<td>Pine</td>
<td>34</td>
<td>5</td>
</tr>
</tbody>
</table>
APPENDIX C

Figure 1. *TWP*² insert, elevation. Dimensions are in millimeters, based on a recent prototype inserted into a 30 × 30 in. (762 × 762 mm) painting sample.

Figure 2. *TWP*² insert, section 1 (see fig. 21)

Stainless steel knurled-head thumbscrew, slotted
Figure 3. TWP² insert, elevation, exploded, based on a recent prototype inserted into a 30 × 30 in. (762 × 762 mm) painting sample.
ACKNOWLEDGMENTS

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REFERENCES


Adam Karpowicz. 2013. Personal communication.


SOURCEs OF MATERIALS

**TWP<sup>2</sup> insert and TWP<sup>2</sup> artist-grade**

Anodized architectural aluminum (alloy 6063) U-channel: ½ in. base, 1 in. legs, 1½ in. thick (T), 6’ L (McMaster-Carr 4592T12)

Multipurpose aluminum (alloy 6061) T-bar: 0.125 in. T, 7/8 in. H, 1-1/2 in. W, 8 ft. L (legs machined down to ½ in. W) (McMaster-Carr 1668T14)
Black Delrin® acetal resin strip: 0.031 in. T, 1 in. W (reduced to ¾ in. W) (McMaster-Carr 638T21)

Rigid HDPE polyethylene: 0.040 in. T, 1 in. W, 10 ft. L (McMaster-Carr 8619K714)

18-8 stainless steel slotted spring pins (100 count packs): 1/8 in. diameter, ½ in. L (McMaster-Carr 92373A177)

Knurled-head thumbscrews with shoulder brass: 10–32 thread, ¾ in. L (McMaster-Carr 92421A645)

Clean Seal® ribbed section

Ultra-high molecular-weight (UHMW) polyethylene tenon (TWP® artist-grade)

Poplar, fir or basswood strips

Aluminum Z-bar (crossbar): ½ in. × ½ in. × ½ in. × 3/32 in. T (Outwater Plastics Industries ALUZ5-M)

18-8 stainless steel knurled-head thumbscrews (slotted): 10–32 thread, 1 in. L, ¼ in. diameter head, ½ in. H (McMaster-Carr 91746A888)

18-8 stainless steel truss head Phillips machine screws (black-oxide plated, 25 count packs): 10–32 thread, ½ in. L (McMaster-Carr 94779A750)

18-8 stainless steel flat head Phillips machine screws (black-oxide finish; 100 count packs): 8–32 thread, ¾ in. L, undercut (McMaster-Carr 96640A122)

18-8 stainless steel flat head Phillips machine screws (100 count packs): 10–32 thread, ¾ in. L, undercut head (McMaster-Carr 91771A825)

Testing

Wooden stretcher bars by Fredix, 30 in. (76.2 cm) and 12 in. (30.5 cm) L

Cotton fabric

Animal hide glue

Chalk from Champagne, France, whiting, natural calcium carbonate (CaCO₃), supplied by Kremer Pigmente (247 West 29th Street New York, NY 10001)

Aluminum foil-faced expanded polyurethane board (polyshield sheeting/underlayment): 48 × 96 × ¾ in. T

Aluminum tape

Blotting paper

Silica gel

RECIPES (Massey 1967)

Animal hide glue solution

Ingredients

1 part powdered animal hide glue (115 g)
10 parts water (500 mL)

Preparation: Powdered animal hide glue (rabbit skin, cowhide, parchment, etc.) was soaked overnight, then warmed in a double boiler until fully dissolved.

Application: Warm glue solution was brushed over the cotton canvas. Two layers of size were applied to each sample.

Chalk ground (gesso)

Ingredients

2 parts chalk (see above specifications) (1180 g)
1 part animal hide glue solution (590 mL)

Preparation: Glue solution was warmed in a double boiler. Chalk was added a bit at a time, and solution was stirred to remove any lumps before adding more chalk.

Application: Warm gesso solution was brushed onto the canvas in one direction. Gesso was left to fully dry (usually overnight) before sanding. A second coat was applied in the opposite direction from the first coat, left to dry, then sanded. An average of two gesso layers was applied to each sample canvas.

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AIC Paintings Specialty Group Postprints 26 (2013)
LAURENT SOZZANI, ANTONIO IACCARINO IDELSON, CARLO SERINO, and LISETTE VOS

Practical Applications of a Constant Tension Elastic-Stretching System

ABSTRACT

Constant elastic tension attachment for paintings on fabric, allows even overall tension across the entire picture plane. Small forces (1.8–3.2 N/cm) via soft springs reduce and/or eliminate fluctuations of tension in the paint layers. Theory, development and use are described. Case studies within the Rijksmuseum Amsterdam illustrate the use of a purpose built strainer (Equilibrate, Rome, It) and an adapted stretcher. A Dutch Landscape (1776), by J. Andriessen (wax/resin lined, 3.29 × 5.4 m) with stiff and brittle distortions was flattened and stretched onto a keyable stretcher, approximately 80% elimination of distortions. A superstructure with spring tension resulted in further reduction. For J.W. Pienemans’ The Battle of Waterloo (1824, wax/resin lined, 5.66 × 8.23 m), a custom-made aluminum strainer was utilized for crucial fit between floor and ceiling. A perimeter free rolling tube for constant tension made height reduction safe and reversible. An independent framing system is necessary.

1. INTRODUCTION TO CANVAS TENSION

Over the centuries, canvas paintings have been produced with little concern for tension. Some were unstretched and free hanging, as painted cloths and banners, including the Fayum funerary cloths and similar artifacts. The stretched ones were mounted on fixed strainers with minimal initial tension, and planar distortions were generally tolerated. When a painting is nailed on a fixed strainer, a closed system is formed in which forces confront each other: at high relative humidity, canvas contracts and wood expands, increasing tension, whereas at low relative humidity hide glue contracts and wood shrinks, reducing the overall tensions. When relative-humidity fluctuations are not extreme, the balance is relatively stable. If the buildup of tensions exceeds the mechanical resistance of the material, tension is released with cracks, plastic deformations and creep. This also implies that crack formation will increase at a slower rate when tension has been reduced by previous stress release.

In the second half of the 18th-century, corner expansion stretchers were introduced. This happened at a special moment in conservation history, which saw the consolidation of some of the techniques that have characterized this particular field until recent times. The first documented linings date from around the second half of the 17th century (i.e., Carlo Maratti’s lining of the Natività della Vergine by Annibale Carracci in 1672) (Conti 2002). Also impregnation techniques, described by T. de Mayerne in 1632, became increasingly popular. Impregnations and lining make the painting stronger than when it was new and have allowed the use of much higher tensions without immediate visible damage. This slowly changed the attitude toward the choice of tension values for restored paintings and allowed for the general use of corner expansion stretchers (Iaccarino Idelson 2009). Flattening distorted paintings became a major concern, and expandable stretchers were conceived to do this without complete re-stretching (Capriott 2004). Pushing the stretcher bars apart is rather simple, and only required custom designed corner joints; however, with the canvas kept in a fixed position along the tacking margins stress concentration builds in the corner areas of the painting (fig. 1). Numerous corner configurations have been designed but none has eliminated this problem.

Scientific data has been available on the distribution of forces in the corner areas since the early 1980s (Mecklenburg 1982; Hedley 1988; Berger and Russel 1990), and it is now generally accepted that corner expansion is not beneficial for the conservation of canvas paintings. Moreover, when restretched or tensed through keying out—the process that has seen it lose tension with environmental cycles—starts anew, bringing about new damages. Changing keys for springs does not modify the distribution of forces when expanding corners, as the problem is in the localized expansion of the corners, which is not eliminated when the canvas is fixed all along the edges.
2. ELASTIC TENSION: CONCERNS AND CONSIDERATIONS

The history of stretchers contains a wealth of ingenious corner expansion mechanisms. Along with key or screw-operated systems, some are spring loaded, and many patents were registered in the United States since the 19th century (Buckley 2008). Spring-operated corner expansion systems have proven to be dangerous if the springs are too stiff and/or when there is strong friction between movable parts. Either of these two conditions can lead to the same effect: the painting’s contraction cannot counteract the stretcher’s expansion, thus leading to damage of the painting itself. This can be illustrated with a painting on a spring activated “Wright and Gardner” stretcher patented in 1875. Excessive constant tension and strong frictions caused the unlined canvases to tear along the tacking margins and crack extensively in the paint layers (fig. 2).

Nonetheless, the presence of springs in the corners proves to be beneficial if the springs are soft enough to release some of the tension when the painting’s materials contract. A good example is the Starofix elastic stretcher (1982), which does not have very strong internal friction and has springs that can be adjusted to push gently. Another interesting example is the Rigamonti stretcher (1966), which has flexible stretcher bars that can bend outwards with the spring-loaded crossbars. Though too strong for unlined paintings, the Rigamonti design allows tension to reach the central area of the painting without acting on the corners alone.

The question, “Is constant tension dangerous for a painting?” is often asked. And the answer is: “Yes, but only if the stretcher design results in forces that exceed the mechanical resistance of the painting.” This can be due to mechanical frictions or to the stiffness of springs. Instead, if the painting is always able to “win” over the stretcher and contract without excessive constraint, constant tension is not only harmless, but also actually beneficial. Alain Roche has proven this with his 1993 paper on Studies in Conservation (Roche 1993) (fig. 3).

3. ELASTIC TENSION: DEVELOPMENT, RESEARCH, AND DEFINITIONS

In the early 1950s, at Instituto Centrale per il Restauro (ICR) in Rome, Roberto Carità proposed a new method for elastic tension of paintings (Carità 1957a). The idea was to allow the canvas free movement across and along the stretcher bars with little friction, pulled by springs placed on the back of a strainer with rounded profiles. Among the first applications of this
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but probably the most innovative advantage comes from not fixing the painting to the strainer, which results in equal distribution of tension over the entire painting surface. Finite elements analysis showed even distribution and consequent elimination of stress concentrations in the corner areas (Accardo, Santucci, and Torre 1992) (fig. 4). Carità’s method has been further developed through the work of Equilibrate. Equilibrate has studied the effects of known values of elastic tension and applied it to several hundred paintings since the late 1990s. A thorough study was necessary to evaluate what value of tension (N/cm) best suited which type of painting (Caprioti and Iaccarino Idelson 2004). The first step had to be the quantification of the “touch of the hand” of the conservator, when assessing a painting’s tension. This was done with a load cell (for measuring force) and a displacement sensor on a screw-driven device, mounted on the back of the painting. The resulting curves provide an efficient representation of the effects of tension on the painting’s ability to maintain a planar surface during the tension assessment test (fig. 5). When testing a painting with different tensions in the same environmental conditions, something unexpected and useful was noticed. Very low tensions correspond to an ample displacement of the area of force application; increasing

Comparison between corner expansion and Carità’s stretcher. Beyond line, lining canvas.
tension, displacement reduces consequently. But this is true only for a first part of the curve, which bends after a certain tension limit. This means that tensions above that relatively low value become less influential on the painting’s tendency to keep a flat and planar surface. The experiment was repeated on different paintings, with different conservation histories, materials, and dimensions, and the threshold value of tension was found to be ranging between 2 and 2.5 N/cm (fig. 6).

The second step was that of defining the characteristics of the elastic-response system. Knowing the tendency for plastic deformation and creep of the paintings’ materials (Tassinari 1973; Berger and Russel 1990), the first concern is to always keep the force below the yield point in the stress-strain curve, and in a safe region for resistance to creep. Experiments on actual paintings would not be possible. Moreover, the variability of painting materials and that of the materials added during previous treatments would require an enormous database to try to develop a comprehensive definition of the “correct” value of tension for each of the numerous combinations.

The solution was found in the practical knowledge of the eight experienced conservators involved in the research project. Aiming for the minimum amount of tension they found suitable for each painting, the actual results were always in the range of low and safe values. These values, validated by previous researches (Tassinari 1973; Mecklenburg 1982; Berger and Russel 1990), could be kept as stable as possible over time and in different environmental conditions. This is obtained using soft and relatively long springs, for which small dimensional changes, when either expanding or contracting, do not result in large force variations (Accardo, Santucci and Torre 1991; Iaccarino Idelson 1996; Serino and Serino 2002).

Basically, with such an elastic-response system, the painting is always able to make dimensional changes, avoiding any local stress concentration.

During the following years, a survey and experimental study was undertaken among Italian conservators. They were asked to determine the correct value of tension for the same mockup painting being mounted onto a stretcher. The stretcher was designed to allow an even distribution of forces and record the precise measurement of the chosen force applied. As many as 106 conservators, with at least 10 years of experience on canvas paintings, chose values ranging from 0.7 up to 7 N/cm (fig. 7). They had different training and professional backgrounds, and
Figure 6. The range of maximum useful tension

Figure 7. Results of survey of values of tensions chosen by 106 Italian conservators for the same mockup painting
it should be noted that those specializing in modern and contemporary art chose the lowest values, while the more traditional conservators, used to frequently lining, chose the highest. The distribution of the values was such that 46% of the choices were between 1.6 and 2.2 N/cm, with an average of 1.82; a very small, almost subtle variation. 74.5% of the choices fell in the wider range of 1–2.8 N/cm, with an average of 1.78. The two average values are very close and correspond to a safe value according to all previous research, and are below or equal to what has been found to be the “maximum useful tension” (fig. 7).

4. EXAMPLES OF VARIOUS CONFIGURATION OF THE SYSTEM

The canvas painting by Rubens Diana’s Rest at the Art and History Museum in Geneva (Switzerland) was transferred to a new canvas during the 19th century in France. In 2007, after replacing the transfer canvas, the painting was restretched with the elastic system adapted to the existing stretcher. The stretcher was retained as the supporting structure, during the conservation undertaken at the Museum with the coordination of Victor Lopez.1

To minimize the friction, free rolling aluminum tubes mounted on roller bearings were placed on the front and on the back of the stretcher. Springs were attached to the backs of the stretcher bars, with small custom-made pulleys that allow the force to act perpendicular to the perimeter. Thin steel wires connect the springs to the painting. The value of tension of 2

Figure 8. Ball-bearings support for the rolling profiles at canvas edges

Figure 9. Corner of the stretcher, before and after stretching the painting

N/cm was chosen in accordance with the materials, the weight and the thickness of the painting (figs. 8, 9).

The 18th century canvas paintings in the ceiling of the Galeria Dorada, in the Ducal Palace of Gandía (Valencia, Spain), are very large and cover a surface of approximately 250 square meters; most of them were still mounted on their original stretchers in 2009. The stretchers were conserved and reinforced, then adapted to elastic tension with the addition of aluminum rolling tubes on roller ball bearings (fig. 10). Physically freeing the paintings from the stretcher bars with the elastic attachment is particularly useful in reducing sagging of a ceiling painting, as the even distribution of tensions also implies sufficient force in the central area. A tension value of
3.2 N/cm was chosen corresponding with the particular materials, the weight and the thickness of the lined paintings. Overall the sagging is as little as 7 cm, which over the 10 meter length, is hardly perceptible from the floor level observation (Iaccarino Idelson and Serino 2012) (fig. 11).

Two 17th century canvas paintings in the Oratorio del SS. Crocifisso in Recco (Genova, Italy) were mounted on concave cylindrical strainers during the 19th century. These were in very poor condition and were changed to custom-made concave aluminum strainers with Teflon® coated edges.
and an elastic-tensioning system (Iaccarino Idelson et al. 2003). When stretching a canvas on a concave structure, the force acting along the concave profiles (thus in the direction of the axis of the cylinder) imposes the concave shape, while the perpendicular force (along the straight sides) tends to pull the central area of the painting toward the observer. This was resolved by applying different values of tension in the two directions, allowing the painting to maintain the shape with a good balance between directional forces (figs. 12a, 12b).

5. CASE STUDIES AT THE RIJKSMUSEUM AMSTERDAM

The two paintings in the case studies presented in this paper can be counted among the very first art objects installed in the main building of the newly renovated Rijksmuseum. This “favoritism” was due to their large dimensions, in combination with restricted freedom of movement within the museum. To best present the treatment decisions made, different phases of the two case studies are described here in chronological sequence (fig. 13, 14).

6. JURRIAAN ANDRIESSEN A DUTCH LANDSCAPE

In winter 2011, a group of curators, art historians, and painting conservators evaluated in the depot of the Rijksmuseum, located outside Amsterdam, six canvas paintings, A Dutch Landscape (fig. 13), attributed to, Jurriaan Andriessen (1742–1819) (Rappard 2001; Baarsen 2009; Harmanni 2009), a specialist painter of wall coverings. The paintings, dated 1776, originally formed an ensemble decorating a room in an Amsterdam residence. The Rijksmuseum planned for three of these paintings to be installed: one large center piece, flanked by two narrow side pieces. Owned by the city of Amsterdam, the two smaller paintings were on stretchers, however, the large wax/resin lined center piece, measuring $3.29 \times 5.4$ meters, had been in storage for decades, loosely rolled on a poor quality tube made of wood slates. It was not tightly rolled and was sagging in the middle (fig. 15) with folds and planar distortions clearly visible. The painting was unrolled face up on the floor of the Rijksmuseum depot. Once unrolled, the distortions became more evident (fig. 16). It was immediately realized that the wax/resin lined canvas was very stiff and brittle. It would not be very easy to manipulate as it was not even safe to re-roll it to turn it face down. Several softening and flattening treatments, combining heat and pressure, had to be performed with the painting face up (fig. 17) so that it could eventually be turned over by rolling and unrolling on a large diameter newly purchased cardboard concrete tube. The painting was then treated with heat and flattening from the back (fig. 18). To facilitate eventual stretching a strip-lining with Beva-371 was attached. Once relatively flat and flexible the painting was rolled onto the new tube for transport to the museum. Tight, smooth rolling in itself was meant to be an additional flattening treatment.

In spring 2012 A Dutch Landscape was transported to the Rijksmuseum, becoming the very first free hanging painting brought into the “new” Rijksmuseum (fig. 19). The building and renovation work was not yet completed, but the painting had to be stretched in place in the gallery before
Figure 13. J. Andriessen, attr., Dutch landscape, 1776, oil on canvas, 326 $\times$ 538.5 cm, permanent loan Amsterdam Museum (inv. no. BK-2011-42). Photograph taken after unrolling, when the painting was laying on the floor of the Rijksmuseum depot.

Figure 14. J.W. Pieneman, The Battle of Waterloo, 1824, oil on canvas, 566 $\times$ 823 cm, signed right on gun carriage: J.W. Pieneman A. 1824, permanent loan Dutch Royal House (inv.no. SK-A-1115). Photograph taken after final stretching (2012), before framing.
the completion of an additional wall, a dropped ceiling and the installation of permanent vitrines, all of which would reduce the possible working space. It would have been impossible to get the painting in and stretched at a later stage. After the unrolling a new wood and aluminum keyable stretcher (fig. 20) was placed on top of the back of the canvas (using ropes) and the painting was attached, “stretched” face down in a normal, “traditional,” fashion (fig. 21). After attachment, sheets of Tyvek (nonwoven polyethylene) were stapled to the stretcher as a backing protection. The painting was lifted and the results were evaluated (fig. 22). Deformations that remained in local areas of the painting were luckily somewhat hidden in the shadows of the trees (fig. 23). Not overly distracting, the treatment of the distortions was considered to have been only 80% successful. As the museum was still “under construction” the painting had to be wrapped and boxed for its protection while the room was being completed (fig. 24).
7. JAN WILLEM PIENEMAN THE BATTLE OF WATERLOO

During that same period another big project was about to lift off. That was the installation of the largest free-hanging painting of the Rijksmuseum, *The Battle of Waterloo*, a wax/resin-lined canvas painting measuring 5.66 × 8.23 m (fig. 14). *The Battle of Waterloo* was painted in 1824 by Jan Willem Pieneman (1779–1853) as a commission of King William I for his son Prince William, later to be King William II. Prince William was supposedly wounded in the battle and is depicted being carried on a stretcher in the lower left. Upon completion, the canvas was exhibited in Amsterdam, Ghent, Brussels, and London (Harmanni 2006). Later it was installed in the Royal Palace. In 1885, the painting became part of the collection shown at the Rijksmuseum, most recently in the History Department (fig. 25). The Rijksmuseum was emptied for the major renovation in 2002 at which time *The Battle of Waterloo* was tightly rolled onto a large diameter, purpose-built wood tube and placed in a depot where it remained until 2012.
Figure 23. The left middle part of the painting after lifting in raking light

Figure 24. The painting after being boxed, construction work in the room continued

Figure 25. The former installation of *The Battle of Waterloo* in a gallery with a lowered ceiling in half of the area in front of the painting; the large size has always presented a problem.
During the planning phase for the reinstallation of the Rijksmuseum there was considerable curatorial discussion as to where The Battle of Waterloo would hang. It was necessary that the picture’s theme fit into the historic context of the new installation. One of the first rooms considered was neither large enough to lay the painting out flat for stretching, nor positioned where the stretched painting could be brought from another room. A second room was out of the circuit and away from the curators’ choices of related objects. The room finally chosen was big enough for stretching, but the ceiling height allowed little play and no room for using the original frame. A mockup of the actual size of the stretcher used to test the height, showed that there was also no allowance for keying out. The possibility of making a slit in the floor of the galley was discussed, but for esthetical and conservation reasons, primarily the accumulation of dust and/or moisture and the risk of mold formation, which could rot the canvas, this idea was abandoned. During the discussions, L. Sozzani had contact with A. Iaccarino Idelson about the possibility of utilizing a constant tension elastic-stretching system. By using this type of system, not only would the stretching itself benefit, but it would also be helpful in dealing with the unfortunate fact that the painting would have to be reduced 20 cm in height to be in the chosen room. When weighing on one hand, leaving the painting in storage without public access, and on the other hand, putting the painting on exhibit slightly reduced in size, the scale tipped toward the latter. One important component of the strainers used in the elastic-tension system is a free rolling tube on each edge. A custom aluminum strainer was made in Italy by Equilibrante with extra wide tubes 5 cm in diameter (fig. 26). This made the decision easier. Normally only the tacking edges or strip lining edges are rolled over. The 5 cm diameter allowed the 20 cm of original canvas at the top of the picture to be rolled over to the back in the safest and most reversible way possible. Another especially important aspect is that the strainer was designed and built with extra components provided, that would allow it to be easily reworked, extending the height to the actual original size of the painting, if the painting is ever moved to another larger location (fig. 27).

In the summer of 2012, The Battle of Waterloo was transported to the museum and rolled out onto the floor of the gallery (fig. 28). Fortunately this painting when unrolled was in a good flat state. In contrast to the Andriessen painting, Pienemans’ painting had been well rolled and stored, the tube had been turned a quarter of a turn each season to prevent any distortion that could occur if the tube sagged. Once fully assembled (fig. 29), the aluminum strainer was raised into position utilizing ropes and pulleys attached to custom made brackets that attached to ceiling I-beams (fig. 30). This was to test the ease of lifting, and to double check the size.

To prepare the painting for the attachment to the spring system, it is necessary to fold over the edges of the canvas to receive the stainless steel rod that is pulled by the springs. In this case the existing lining canvas was wide enough to fold over and seal closed with Beva-371 film (fig. 31). The exact location of the tube was measured and marked out on the reverse of the canvas. After making the pockets, the strainer was

Figure 26. The 5-cm wide tube along the perimeter of the strainer. When stretched, the painting canvas holds it in place; here quick ties temporarily hold it.

Figure 27. The different attachment components for the new aluminum strainer designed and made by Equilibrante; and all the extra components necessary for any future extension of the strainer.
Figure 28. The painting unrolled in the NEW Rijksmuseum

Figure 29. The assembling of the strainer, ready to be lifted (the strainer is laying on top of cardboard sheets). Custom made brackets are attached to ceiling I-beams to receive the ropes.

Figure 30. The strainer is lifted as a test of handling and size
The Battle of Waterloo

**Edges of canvas before closing pocket:**

![Schematic drawing of “pocket” of The Battle of Waterloo](image1.png)

- **Top**
- **Bottom/edge**

Canvas (wax resin lining with excess lining canvas)

Beva371-film for closing pocket

Fold for pocket (placement of rod)

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Figure 32. The positions of the springs are marked on the pockets at regular intervals

Laid on top of the canvas and the positions of the springs were marked on the pockets at regular intervals (fig. 32). Incisions were made in the canvas to facilitate the insertion of the wire and spring onto the rod. Along the top strip this unfortunately had to be done on the original tacking edge, at all other edges the slits were made only in the lining canvas (fig. 33).

Stainless steel wire was used to bridge the space between the each spring and the bar holding the canvas. To facilitate rolling the canvas over the aluminum tube, both the canvas and the tube were slightly heated with hot air guns. This was especially important at the top edge where, in the end, approximately 14 cm of original paint was being bent over. Along the top, as protection from dust
Figure 34. (a) Bottom with one of the feet that stand on the floor; (b) top with one of the hangers going over the false wall; both show after attachment with configuration of springs. The rolled-over top of the painting is covered with a protective layering of Japanese tissue.
and grime accumulation, the rolled over original was faced with Japanese tissue using methylcellulose adhesive.

Strips of silicon paper were positioned between the tube and canvas to reduce friction. After attachment the elongation of each spring was set to reach a force of 3.2 N/cm along the entire perimeter of the painting. Other important components of this strainer are feet and hangers attached to the top and bottom on the back of the strainer that allow the painting to stand on the floor and hang on the wall. These elements are positioned to let the canvas move freely behind them in all directions, x and y separately (fig. 34).

The attachment of the spring system proved to be very easy to apply and very gentle when compared to normal stretching. It is actually impossible to stretch a wax/resin lined painting of this size, and one must rely on keying out the picture. In this respect the spring system is a great improvement. After lifting (fig 35) *The Battle of Waterloo*, it could immediately be seen how the springs very gently and very evenly pull the painting taut (fig. 36).

8. TAKE 2—JURRIAAN ANDRIESEN A DUTCH LANDSCAPE

The experience of the stretching of *The Battle of Waterloo* stimulated motivation to improve the initial results of *A Dutch Landscape*. Plans were made for adapting the existing stretcher into an elastic-tension strainer (fig. 37). These were then discussed with Equilibrate, who would supply springs and other necessary components. And Iaccarino Idelson would return to Amsterdam to supervise the attachment. The curators and direction agreed to the changeover. Between the time the wall and ceiling construction was finished and the vitrines were to be built in on the side wall there was just enough time, and
The result after lifting, *The Battle of Waterloo* in its permanent position. All the staples that were holding the canvas to the stretcher were taken out. The strip-lining was ironed flat and used to make pockets for the insertion of the metal rod, again using Beva-371 film to seal them shut (figs. 38, 39). To prepare the strainer, all the corner and crossbar joins were fixed with steel L-plates and strips. Since the aluminum rolling bars were not being used it was necessary to round the edges of the strainer. The front edges of this stretcher were made with rounded aluminum profiles already attached, so it only necessary to attach quarter-round wood strips along the edges on the reverse (fig. 40). Rounding the edges was necessary to allow the canvas to slide. To reduce friction, Teflon® film was stapled to the sides of the wooden strainer (fig. 41). Smooth free movement allows the canvas to overcome any friction that might built up on the edges of the strainer, caused by differences in the thick, stiff, package of the original canvas, the wax-lining canvas and/or the strip-lining.
Practical Applications of a Constant Tension Elastic-Stretching System

Figure 38. Schematic drawing of 'pocket' of A Dutch Landscape, how the strip lining would be folded and sealed

Figure 39. Preparing the pockets with holes punched on the fold line for spring attachment to the stainless steel bar
Figure 40. Side of the stretcher with quarter-round wood strip nailed to back side. This is the Hoopman stretcher designed with the rounded aluminum tension edge on the front transformed into a strainer for the elastic tension system.

Figure 41. The pocket before attachment to the stainless steel superstructure, Teflon film is stapled at the side of the strainer.

Figure 42. Overview of the painting before attachment of the spring system.
Practical Applications of a Constant Tension Elastic-Stretching System

Strips of stainless steel with an L-shaped profile were attached along each length of the back of the strainer approximately 20 cm from the edge (figs. 42, 43). These were predrilled to hold the springs at 20 cm intervals. Initially the spring tension was set at 2.8 N/cm. Again a big difference was experienced in attaching the painting with the springs compared to the first “traditional” stretching attachment with staples. The springs proved to be much gentler for the painting, and a more relaxed and controlled method. After lifting *A Dutch Landscape*, it was immediately apparent that the overall even tension being applied had reduced the distortions. The canvas was still quite loose so the decision was made to increase the tension to 3.2 N/cm to reduce the distortions even more. This did prove to be beneficial. Our previous sensation of 80% satisfaction had now increased to +/−95%.

After the stretching the structure had to be prepared for the attachment to the wall and receive framing. It is important to realize that the spring system requires a complete noninterference, meaning no contact or pressure at the edges of the painting, in order to facilitate the sliding of the canvas. Wooden blocks, both functioning as spacers, as well as attachments for

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Figure 43. Corner of strainer with springs attached to L-profile (sheets of Tyvek attached to strainer underneath)

Figure 44. Wood blocks, at the corners and spaced perpendicular to the edges at intervals, function as spacers protecting the springs from interference and as blocking for frame attachment

Figure 45. The wooden profile of the frame was attached to blocks that were attached to the wall
The size of these two paintings, the condition of the Andriessen painting and the logistics for the reinstallation of the art works in the newly renovated building combined, presented out-of-the-ordinary challenges. The restretching of the two paintings using the elastic-tension system developed by colleagues in Italy will secure and enhance their long-term conservation in the permanent collection of the Rijksmuseum (figs. 47, 48).

The basic mechanical components, used in differing configurations, for canvas attachment in the constant tension elastic-stretching systems allow adapting the system to a wide variety of strainer types (fig. 49).
Figure 48. *A Dutch Landscape* presented in the new Rijksmuseum

Figure 49. Basic mechanical components for fabric attachment

Basic mechanical components for fabric attachment:

- **Fastener**: Attached to strainer
- **Adjustment screw**: For setting tension (attached through fastener with nut)
- **Spring**: Attaches to metal rod/canvas (poss. via wire extension)

The two basic strainer edge types:

- **Roller edge and Teflon corners**: Either type can be custom made or adapted to an existing stretcher or strainer.
- **Teflon covered side without roller**
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NOTE

1. Emiliano Ricchi worked on the paint layers, Matteo Rossi Doria on the lining, Antonio Iaccarino Idelson and Carlo Serino on the tensioning system.

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Carità, R. 1957b. Aggiunta sui telai per affreschi trasportati. Bollettino dell’Istituto Centrale per il Restauro, n. 31-32.


SOURCES OF MATERIALS

Aluminum strainer for Waterloo and all springs, connectors, etc. Equilibrarte BV, Rome Italy.

Ceiling brackets for lifting Waterloo c/o Loek Mevisen, Bronnenberg BV, Heerlen, Holland

Wood stretcher with aluminum front profile Hoopman Art Supplies, Amsterdam, Holland

Stainless steel L-profile for spring attachment, adapting Andreissen stretcher to strainer c/o Loek Mevisen, Bronnenberg BV, Heerlen, Holland

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THIS ARTICLE HAS NOT UNDERGONE A FORMAL PROCESS OF PEER REVIEW

AIC Paintings Specialty Group Postprints 26 (2013)
The Restoration and Conservation of the Baroque Mechanism on the Altar of St. Ignatius in the Church of Gesù in Rome

ABSTRACT

In the Chapel of St. Ignatius in the Church of Gesù in Rome is housed one of the few remaining important altar machines in Catholic Europe. Out of use and forgotten during the last decades, the mechanism needed to be submitted to an urgent conservation treatment. The goal was to conserve and repair as much as possible, replacing only what was necessary to bring it to working order. A deep understanding of the original structure was crucial, as it was necessary to make some difficult decisions to assure future safe and efficient operation of the machine.

1. INTRODUCTION

The Church of the Gesù in Rome is the mother church of the Jesuit order and among the most important baroque churches in Italy. It hosts a wealth of wonderful and important works of art, such as the paintings and stuccoes in the vault of the nave, all depicting the triumph of the Name of Jesus: the works of Giovan Battista Gaulli (known as Baciccia)—paintings, stuccoes, and three-dimensional reliefs—combine in an astonishing way giving the illusion of images stepping out of the walls.

The Chapel of St. Ignatius, completely renovated by Andrea Pozzo after the competition held in 1695 for reshaping the left transept arm, is among the most significant creations of the late baroque. It is decorated with frescoes by Baciccia, lapis lazuli, marble, and gilt bronze sculptures by Pierre II Le Gros and J.P. Théodon, and the splendid bronze balustrade designed by the same Pozzo. An earlier gilt bronze urn by Alessandro Algardi conserves the body of the saint and is hosted in the altar.

The Jesuit Andrea Pozzo, architect artist and fresco painter, is one of the geniuses and creators of the Italian baroque. He wrote an important treatise on perspective addressed to artists and architects.

Among the most interesting aspects of his work is the construction of ceremonial machines—simple or complex apparatuses with moving parts. Some of them were clearly ephemeral, as was common in the baroque age, but many were made with such care and competence that they have survived nevertheless.

The machine on the altar in the Chapel of St. Ignatius was conceived and built as a permanent installation. A large statue of the saint is hidden behind a canvas painting (6.5 × by 3 m) also by Andrea Pozzo. The painting is made to slide vertically down and out of sight, disappearing under the altar to reveal the statue of St. Ignatius in its precious niche on certain holy days (figs. 1 and 2). The sculpture was only rarely shown, usually on July 31st, the day of the celebration of the feast of the saint.

Figure 1. The altar (Courtesy of Zeno Colantoni)
Both the sculpture and the painting represent the saint. The sculpture represents him standing in glory among angels and cherubs, and was made of silver. In the painting, St. Ignatius is depicted as receiving from Jesus the flag with his monogram, symbolizing the mission he’s been given to conquer the world (fig. 3). On the lower side of the painting, an angel holds a book with an inscription that reads, “In the name of Jesus every knee will bend.” Opposite that, another angel points the book out to personifications of the known continents (Europe, Africa, America, and Asia).

The painting and the sculpture are the starting steps of a symbolic narration that continues throughout the decoration of the vault, the chapel, and the cupola painted by Baciccia—all following the project of Andrea Pozzo.

2. THE MACHINE

The machine is very simple and works like a theatre curtain; the painting, aligned by tracks, hangs on a rope with a counterweight. Almost all parts were original, and before the recent restoration started, the machine could still be operated, even though the poor state of conservation of some of its elements made it quite dangerous. The stretcher of the painting had two brass wheels on either side (fig. 4) that ran inside rails that were partially hidden behind the gilt bronze frame and partially in the pit under the altar. The stretcher is mounted on a stem that allows it to be pushed up until it fills the opening in the niche. A large steel pulley (fig. 5) allows the weight to reverse up and down counterbalancing it with a lead block weighing about 250 kg (fig. 6). The space under the ground floor, where the painting becomes hidden, is quite deep, and the original slot on the altar for its passage is only as wide as needed.
Figure 4. A brass wheel

Figure 5. The steel pulley
3. THE STATE OF CONSERVATION OF THE MACHINE

The painting had been repeatedly overpainted to hide the scratches that occurred from rubbing against the stone wall as it traveled in its narrow passage behind the altar (fig. 7). Scratches due to contact with the slot wall were also visible on the wood of the stretcher itself; the problem is an old one, and in the past someone had painted the missing, rubbed away areas of the painting onto the wooden stretcher bar. Moreover, numerous discolored varnishes and heavy deposits of dirt and grime hid the bright colors of the original composition. Insects had heavily attacked the stretcher and some of its elements had almost completely lost mechanical resistance. It had been reinforced with large and heavy steel plates and bars during interventions in the 19th and 20th centuries (fig. 8). This in turn had required the addition of a supplementary stone counterweight, hanging under the original (fig. 6). The guide rails, which had been carved from 6 m long chestnut logs only to form the hidden lower part, were distorted, warped, and damaged.

These were among the main causes of damage to the painting because its direction was not controlled when running in the narrow slot. The painting had been lined while on the original stretcher instead of using a larger temporary lining strainer; therefore, the distribution of the lining adhesive was extremely uneven.

It seemed remarkable that there had been so many additions made to the machine during previous restorations because these clearly altered the original conception and modified the original weight balances. The initial idea for the conservation intervention was quite simple: de-restore the machine and return it to its original state.

4. THE CONSERVATION TREATMENT

The conservation treatment started with very accurate documentation, but knowledge and understanding of the machine increased greatly while working on it. The first step
It was an internal project defect of the machine itself that had deformed the stretcher and had pushed the painting against the stone wall as it passed through the narrow slot. Understanding this made the interventions of previous restorers more comprehensible. The hidden problem, hard to detect during the close observation allowed in the pit, was indeed the off-center load of the rope of the counterweight (fig. 11). The force acting on the whole structure (stretcher, wheels, and rails) had resulted in a sideways displacement causing the warping of the stretcher and deforming over time the wooden elements with this constant solicitation (creep). The wheels were another important problem—they had needed periodic lubrication that resulted in grease stains on the painting.

As part of the overall conservation treatment, while the machine was being restored, the painting was removed from the stretcher, cleaned, unlined (fig. 12), and relined. The stretcher was disassembled and treated in an anoxic environment to stop all insect activity. The parts that were too damaged were removed and replaced in laminated oak, that is very stable and robust, and

was the removal of the painting from the altar. This had to be done with great care considering that the stretcher had been severely damaged by insects and was very heavy due to the steel additions that made it approximately 100 kg heavier than when first built. Scaffolding was placed in front of and around the altar. It was first used for the removal of the gilt bronze frames and for preparing the painting for the operation. The scaffolding was reconfigured to allow the painting to come out with its stretcher (fig. 9). For the removal, the counterweight was blocked in position and the stretcher released from the lifting pole underneath.

During the whole process of approaching, understanding, and at last disassembling the machine, it became clear that something unexpected had been going on. The most evident problem was the narrow slot that had imposed the elements of the machine (stretcher, wheels, and rails) to overlap; also the stucco decoration—for instance, the knee of an angel—in the niche had always interfered with the stretcher (fig. 10), resulting in some elements of the stretcher having been carved away from the very beginning.
much more resistant to insects (fig. 13). Original joints were reproduced to avoid losing technological information.

The perimeter of the stretcher was adapted to receive a new elastic tensioning system. The perimeter was covered with Teflon film, thus allowing the lining canvas to freely move along the stretcher bars. Springs were mounted on the rear of the stretcher and attached to stainless steel rods enclosed in the lining canvas around the entire perimeter, distributing

Figure 10. Proximity of the painting with the stucco reliefs

Figure 11. The effect of the off-center load of the counterweight on the stretcher

Figure 12. The mechanical removal of the \textit{colla pasta} glue
tension evenly throughout. In this case, 2.4 N/cm was the force that assured continuous planar stability of the lined painting. The arched top profile of the stretcher required special attention, as the canvas would not move freely if folded over on itself. It was necessary, therefore, to cut out of the lining canvas, at regular intervals—V-shaped pieces perpendicular to the curvature of the stretcher (figs. 14 and 15). During the intervention on the machine, we were faced
Figure 14. The installation of the new elastic-tensioning system

Figure 15. A detail of the stretcher arched top profile
The original tracks, warped and worn out in the housing of the rail, were replaced with new ones made with stainless steel profiles, which provide the required rigidity and durability.

The original wheels were replaced with new sliding elements with sealed stainless steel ball bearings almost frictionless and requiring no maintenance (fig. 16). Custom-made to fit the tracks, they have a very small tolerance, allowing a smooth movement of the machine through the tight space.

A new central track was installed to eliminate the problem of the off-center load that deformed the stretcher, preventing the vertical pole from bending. For extra safety, all metal and stone elements which jutted out into the slot behind the altar were covered with a low-friction Teflon coating to reduce the risk of damage to the painting’s surface in case of future deformations of the structure.

Before reinstalling the painting in its position, it was judged necessary to run some simulation to test the machine. First, the distances between the painting and any of the fixed obstacles were checked, especially the stucco sculpture behind it, by running on the tracks a bar reproducing a section of the painting. Then, a trial run with the stretcher alone, without the painting (fig. 17), was carried out thus

Figure 16. The new sliding elements with sealed stainless steel ball bearings
Figure 17. A trial run with the stretcher alone, without the painting
revealing a small underestimated deformation of the stretcher that needed to be corrected as it implied interference with the stone wall (fig. 18).

The final installation of the painting needed extra care and had to be done during the night to avoid closing the church to both worshippers and visiting tourists (fig. 19). The trial run without the painting helped greatly as exercise in preparing for the final installation to take place in a completely safe way.

The movement of the machine functioned beautifully and could be used for the final retouching of the painting, moving the painting up and down as needed for working from the altar (fig. 20).

The movement of the counterweight is now produced with an electric winch. A priest's push of a button on a handheld remote control has replaced workers in raising and lowering the painting, and sensors located at key points assure its safety.

Since the inauguration of the machine after conservation, it is now operated every day at 5:30 p.m.
Figure 19. The final installation of the painting
Figure 20. The final retouching of the painting
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NOTES

1. During Napoleon’s occupation of Rome, it was stolen and later reproduced by Antonio Canova’s workshop in silver-plated gesso.

2. Work performed in 2007 with the sponsorship of the Jesuit Order under the supervision of the Dr. Maria Pia D’Orazio. The conservation team was led by Paola Tollo. Painting restoration: Paola Tollo and Carla Raffaele. Lining: Ilir Shaholli and Carlo Serino (Equilibrarte s.r.l.). Structural intervention on the stretcher and the machine: Carlo Serino and Antonio Iaccarino Idelson (Equilibrarte s.r.l.). Collaborators: Sabrina De Sio, Natalia Gurgone, Giorgia Pinto, and Valeria Valentini.

3. See also, in the same AIC Indianapolis 2013 annual meeting proceedings: Laurent Sozzani, Antonio Iaccarino Idelson, Carlo Serino, and Lisette Vos, Practical Applications of a Constant Tension Elastic-Stretching System.

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Reuniting Poussin’s Bacchanals Painted for Cardinal Richelieu through Quantitative Canvas Weave Analysis

ABSTRACT

The desire to more fully characterize Poussin’s Triumph of Bacchus (Nelson-Atkins Museum of Art, 31–94) for a forthcoming catalog of the French painting collection prompted an automated analysis of canvas weave variations among Nicolas Poussin’s three bacchanals commissioned by Cardinal Richelieu for his chateau in Poitou, France (1635–6). Although there has been general consensus that Triumph of Pan (National Gallery of London, NG6477) is an original work, doubt has at times been cast upon Bacchus, and though the third painting has defenders, Triumph of Silenus (National Gallery of London, NG42) is today classified by the National Gallery as a painting “after Poussin.” Warp spacing variations were found to match very closely among all three works, providing compelling evidence that all three paintings were executed on the same bolt of canvas. Methodological developments made in the course of this effort have significantly strengthened the weave comparison procedures. This outcome requires a reassessment of the relationship between Silenus and the other paintings, as well as the workshop practices of Poussin whose engagement of assistants remains unclear.

1. INTRODUCTION AND BACKGROUND

In 1635, Nicolas Poussin received a prestigious commission from Armand-Jean du Plessis, Cardinal de Richelieu, to paint a series of bacchanal scenes devoted to Bacchus, Pan, and Silenus. The series is known from the Triumph of Bacchus (31–94, Nelson-Atkins Museum of Art), Triumph of Pan (6477, National Gallery of Art, London), and Triumph of Silenus (42, National Gallery of Art, London), although the attribution of the first and third of these as the original versions by the hand of Poussin has been the subject of debate. The series was destined for Richelieu’s chateau in Poitou, France, where it was installed in his Cabinet du Roi alongside earlier works by Perugino, Mantegna, and Costa.

As early as 1665, a number of high-quality copies were produced of the successful series. Although little is known about the copyists, Hugh Brigstocke (1994) points out that Poussin probably did not make the copies, since he was more likely to have improved upon or slightly modified a successful composition rather than faithfully replicate it, as was the case with his numerous variants of the popular holy family subject. By the mid-18th century, Poussin’s original paintings at the chateau de Richelieu were themselves replaced by a set of copies now located at the Musée des Beaux-Arts, Tours. For Bacchus alone, at least seven copies exist today. Over the years, the presence of so many 17th- and 18th-century copies gave rise to complicated attribution questions for a number of Poussin paintings, including the Richelieu Bacchanal series.

The National Gallery classifies Silenus as an excellent early copy, referencing the fact that certain passages lack the level of quality displayed by Pan, and that its provenance can be traced no earlier than 1824. In addition, there has been a general belief that Poussin, described as a perfectionist who neglected nothing, worked independently and would not have risked engaging studio assistants for such an important commission and patron (Wine 2001). This belief has led many art historians to rule out the possibility that, as an explanation for perceived differences in quality, other hands may have been involved in the creation of the painting.

Opinion on the attribution of Silenus is somewhat divided among Poussin scholars in the recent literature; most art historians regard it as a copy, while others allow for the possibility that Poussin may have worked on the Richelieu commission with studio assistants.

Although the authenticity of the National Gallery’s Pan is unchallenged today, it too was once deemed a copy. A painting in the Louvre, now firmly classified as a copy of Pan, was considered the original version at the time of an exhibition held at the Petit Palais in 1925. The National Gallery painting was exhibited as the autograph version in 1960 and
became widely accepted following an exhibition at the National Gallery of Scotland in Edinburgh in 1981, which included a reunion of the Richelieu Bacchanal series (Wine 2001, p. 364, f62).

Doubt was initially cast on the Nelson-Atkins painting during the 1925 exhibition mentioned earlier, and Anthony Blunt expanded on these concerns in his 1966 catalogue raisonné, publishing for the first time the attribution of Bacchus as a copy: “It is cold and mechanical in handling, and has nothing of the delicacy and sensitiveness of the [National Gallery] picture” (Blunt 1966, 98). In addition to overlooking the fact that Pan and Bacchus shared an identical provenance until 1850, Blunt implied that when the paintings left the Richelieu family in the mid-18th century, a dealer replaced the original Bacchus with a copy to profit from two sets of bacchanals, each containing an original Poussin.

Pierre Rosenberg called for the reinstatement of Bacchus as the original in 1977, but it was not until the 1981 Edinburgh exhibition that the painting was reassessed and accepted by a majority of scholars as autograph. The entry for the painting in the exhibition catalog addresses the inconsistency of certain passages and the authenticity question: “On balance it seems likely that The Triumph of Bacchus is an original. It is difficult to imagine any copyist achieving the vigour of the centaur holding a torch and flowers, the warmth of the landscape background under a golden sky, or the subtle and lively handling of the ivy, vine leaves, and other foliage which surrounds and decorates the foreground figures. At the same time, condition alone cannot explain the extremely poor modeling of certain figures, most notably the putto in the left foreground and the dancing female, seen from behind, at the extreme right” (National Gallery of Scotland 1981, 52). Blunt (1982) eventually reversed his earlier opinion but proposed that, despite Poussin’s apparent standard practice, studio assistants were involved in the making of both Pan and Bacchus. Since 1981, most Poussin scholars—Pierre Rosenberg, Hugh Briggscoke, and Christopher Wright, to name a few—accept the Nelson-Atkins painting as original, but questions persist in the literature. In 1994, Jacques Thuillier (18) described Bacchus as a copy that “has found defenders.” Given that the three paintings in the Richelieu commission were executed at roughly the same time and intended for the same location, he strongly urged a comparative study of the canvas, preparatory layers, and brushwork in anticipation of new findings that might settle the ongoing debate.

In preparation for a scholarly catalog of its French paintings collection, the Nelson-Atkins has undertaken a series of scientific investigations in support of curatorial and conservation questions about certain works. The Nelson-Atkins partnered with the Thread Count Automation Project (TCAP), initially to make a comparison of the canvas of Bacchus with that of Pan, for which the National Gallery had existing x-radiographs. In the event that a direct correlation could be demonstrated between the canvas of Bacchus and that of Pan, whose authenticity is no longer questioned, lingering concerns about the Nelson-Atkins painting could be assuaged in a way that mere similarity of painting materials and technique would be unlikely to do. Since the weave comparison is inherently independent of the technique of painting or differences in the condition of the works, the complications that might arise for other forms of technical study due to surface losses or over-painting are overcome in this approach. In the event of a direct match between the canvases, questions of connoisseurship related to the use of studio assistants or the role of a copyist would take on a fundamentally different character. The weave analysis posed the additional advantage of utilizing existing x-radiographs without requiring significant time from museum staff or a disruptive period with the paintings off view. In the event of a lack of correlation between the canvases, other means of comparison would have been required whose completion might not have been feasible in advance of the catalog deadline. On the basis of the success of the method described later, and with further cooperation of the National Gallery, the canvas of the third painting in the series, the strongly doubted Triumph of Silenus, was added to the study.

X-radiographs of the three Richelieu Bacchanal paintings are fairly similar. All are dominated by the canvas weave and reveal low contrast among the compositional forms. Although all three paintings are lined, and the original canvases are thus hidden from inspection, the x-radiographs confirm that the original canvas is a coarsely woven, plain-weave fabric with variations in thread thickness. The canvases are primed with a double ground, and on the basis of published technical notes for the National Gallery paintings, the ground colors on Bacchus (lower reddish-brown and upper beige) appear to be comparable to those of Pan (lower reddish-brown and upper buff-color) and Silenus (lower red-brown ochre and upper buff-color) (Wine 2001). The minimal contrast of the x-radiographs can be attributed to the added density of the double ground and the artist’s thin paint applications. Although the low contrast and prominent canvas weave interfere with the identification of artist changes and indications of painting technique, these features provide ideal conditions for computer-automated canvas weave analysis.

2. AUTOMATED AND MANUAL CANVAS ANALYSIS

Consider the set of average thread counts taken in evaluation squares surrounding test points on a grid covering an entire painting. The result was first visualized in (Johnson, Hendricks, et al., 2009) using colors to represent thread counts above

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(redder) and below (bluer) the average for the painting. Stripes of color appeared because of the weaving process with bundles of adjacent threads retaining their relative spacing as they traverse the canvas. Matching these striped patterns reveals original canvas rollmate candidates (Johnson, Hendricks, and Johnson, 2013). In combination with other knowledge of the artist’s studio practice and stylistic development, such weave patterns provide evidence useful in addressing art historical issues in studies of the paintings of Van Gogh (van Tilborgh et al., 2012), Velázquez (Perez d’Ors, Johnson, and Johnson, 2012), and Vermeer (Liedtke, Johnson, and Johnson, 2012).

Previous efforts at automating whole-painting canvas analysis have utilized a Fourier transform approach for the extraction of thread density from small square swatches of the x-radiograph (Johnson, Erdmann, and Johnson 2011; Johnson, Johnson, and Erdmann, 2013), but this technique has two main weaknesses: it requires manually selecting a small window of wave vectors in Fourier space, and it encounters difficulty when analyzing irregular canvas weaves, such as those arising from erratic spacings or from twill, or swatches with nonthread features. The three canvases studied here were too irregular to be successfully analyzed with the previous technique. To overcome this weakness and to create an analysis technique with less need of human intervention, we developed a new, more robust, automated-analysis technique on the basis of autocorrelation analysis and pattern-recognition algorithms. The new technique and its application to the canvases of Pan, Bacchus, and Silenus are described subsequently, with full details of the algorithm provided in the Appendix.

To validate the results of the automated analysis and also to obtain thread-level correspondence among the three canvases, we also developed a quantitative procedure for manual comparison of thread spacings among canvases. In this method, the user manually marks the locations of all of the threads crossing a “guide thread” in each canvas, so that the local thread spacings are known for every thread. This method, and its application to the three canvases studied here, is also presented subsequently.

2.1 AUTOMATED-ANALYSIS PROCEDURE

The automated analysis of a canvas proceeds in three main phases. First, the individual overlapping x-radiographs tiling a painting are digitized and stitched into a single whole-painting x-radiograph using a multiscale image-analysis technique. Second, the whole-painting x-radiograph is decomposed into a large number of strongly overlapping small square swatches, each of which is analyzed to extract its so-called canvas basis vectors, from which the dominant spacing and orientations of both horizontal and vertical threads can be extracted. Third, these geometric parameters from each patch are assembled and visualized using whole-canvas thread spacing and angle maps, from which the similarity of the spacing patterns among a set of canvases can be assessed visually.

2.1.1 Step 1: Multiscale X-Radiograph Stitching

For each canvas, the analysis begins with a collection of digitized high-resolution x-radiographs. These must be stitched into a whole-painting x-radiograph free of artifacts such as visible seams or ghosts. We have described our procedure for stitching the x-radiographs elsewhere (Johnson, Erdmann, and Johnson 2011), but we summarize here for completeness. First, each scanned x-radiograph is analyzed to mask out the bright nonradiograph border region which occurs when the x-radiograph film is not perfectly aligned to the scanner bed or in the typical case where it has rounded corners. The PCA-SIFT algorithm (Ke and Sukthankar 2004) is then used to detect and catalog approximately 20,000 characteristic features in each source x-radiograph. The collection of characteristic features across all source x-radiographs is then analyzed to find features with similar appearance such as those resulting when the same feature is captured by more than one overlapping source x-radiograph. These apparent matches are then filtered to remove false positive matches using the RANSAC statistical algorithm (Fischler and Bolles 1981). Next, a global optimization is performed to determine the optimum placement of each source x-radiograph relative to the others such that the root-mean square (r.m.s.) distance over all pairs of matching feature points is minimized. Each source image is then resampled using high-order Lanczos interpolation, and the collection of images is blended into a single image using a multiscale Laplacian pyramid (Burt and Adelson 1983) to ensure that subtle exposure differences between the x-radiographs do not result in visible seams or other artifacts.

2.1.2 Step 2: Analysis of Individual X-radiograph Swatches to Extract Thread Spacing and Orientation

Once a whole-painting x-radiograph is assembled, the next step is to extract the characteristic canvas geometry from each of a large number of strongly overlapping square x-radiograph swatches. The desired geometry is shown schematically in Figure 1. The basic model is that for a small swatch of the x-radiograph, the canvas spacings and orientations should be approximately constant, in which cases there will be a characteristic horizontal offset vector, $\mathbf{h}$, needed to move from one thread crossing to another along a horizontal thread, and a vertical offset vector, $\mathbf{v}$, needed to move from one thread crossing to another along a vertical thread. These two vectors form the bases for a local grid of thread crossings, and are sufficient to extract the local trajectory angle for the horizontal and vertical threads, $\theta_h$ and $\theta_v$, the spacing between the horizontal and vertical threads, $d_h$ and $d_v$, and the area $A$ associated with each thread crossing.
Figure 1. Schematic illustration of a local patch of canvas with threads indicated by light gray bars and thread-crossings indicated by dots; the canvas basis vectors, \( \mathbf{v} \) and \( \mathbf{h} \), are extracted from the local x-radiograph patch. From these, the angles of the horizontal and vertical threads, \( \theta_h \) and \( \theta_v \), respectively, and the spacing between the horizontal and vertical threads, \( d_h \) and \( d_v \), respectively, and the area per thread crossing, \( A \), can be computed.
The grid of overlapping patches is chosen with a large degree of overlap in order to be robust to small anomalies in the canvas since a median filter is applied in step 3 after the results are assembled. We utilize a uniform grid of 2 cm^2 swatches with horizontal and vertical center-to-center spacing of 8 pixels (339 µm at 600 dpi). Thus, any given pixel in the interior of the x-radiograph is actually contained in 592 = 3481 different swatches. Each swatch can be analyzed independently of the others, so that the analysis of the entire canvas can be easily decomposed into many smaller tasks and performed simultaneously across a large array of processors in order to keep the overall time for the analysis manageable.

2.1.3 Step 3: Assembly of Canvas Geometry and Visualization

The final step of the automated-analysis procedure is the assembly of the local canvas basis vector \( h \) and \( v \) for each of the many square swatches, followed by geometry extraction, filtering, and visualization. First, the results from the analysis of each swatch are collected from the parallel analysis procedure and reassembled into their original grid. Next, simple trigonometry is used to obtain \( \theta_h, \theta_v, d_h, d_v, \) and \( A \) at each grid point in a two-dimensional array covering the original x-radiograph. Each array is then filtered using a 5 x 5 moving window median filter to remove noise and artifacts arising from irregularities in the original x-radiograph. Finally, histograms and summary statistics are generated for each of the fields along with whole-painting “canvas maps” showing the local spacings and angles for the horizontal and vertical threads, along with thread intersection angles and local areal thread intersection densities.

A comparison of the summary statistics for the mean and standard deviations of the horizontal and vertical thread spacings serves as a first crude indicator of whether a pair of canvases may have matching spacing patterns and whether an alignment between them would require rotating one of the canvases by ±90°. Next, a comparison of the histograms can further reveal differences in the textures between a pair of canvases; it can also provide evidence within a single painting about which of the two thread directions is the warp and which is the weft because the weft typically shows greater variation (van der Wetering, 2000). Finally, a visual inspection of the thread spacing maps can quickly reveal qualitatively whether a pair of canvases shares a characteristic spacing pattern, and individual canvas angle maps can reveal the pattern of secondary and primary cusping within an individual painting.

### 2.2 RESULTS OF AUTOMATED ANALYSIS FOR PAN, BACCHUS, AND SILENUS

The x-radiographs for Pan and Silenus were provided by the National Gallery in London at 600 dpi (236 pixel/cm) and 1200 dpi (472 pixel/cm), respectively. The x-radiographs for Bacchus were provided by the Nelson-Atkins Museum of Art at a resolution of 500 dpi (197 pixel/cm). Each collection was stitched into a whole-painting x-radiograph using the procedure described previously. Bacchus was then upsampled to 600 dpi and Silenus was downsampled to 600 dpi to ensure consistency of analysis across all three canvases. A sample of the source x-radiograph overlap structure for Pan is shown in Figure 2.

#### 2.2.1 Thread-Spacing Statistics

The autocorrelation-based analysis procedure was performed across each whole-painting x-radiograph, resulting in the histograms and summary statistics shown in Figure 3 and summarized in Table 1. The mean spacings all match closely for the horizontal, vertical, and horizontal thread spacings for Pan, Bacchus, and Silenus, respectively, with mean thread spacings close to 1.48 mm in all three. The values for vertical, horizontal, and vertical mean thread spacings for Pan, Bacchus, and Silenus, respectively, are also very similar, with values of around 1.08 mm. These are well within the 1 thread/cm difference under which canvases can be considered to possibly match (van der Wetering, 2000). The statistics also indicate that the Pan and Silenus are very similar, with mean thread spacings close to 1.48 mm in all three. The values for vertical, horizontal, and vertical mean thread spacings for Pan, Bacchus, and Silenus, respectively, are also very similar, with values of around 1.08 mm. These are well within the 1 thread/cm difference under which canvases can be considered to possibly match (van der Wetering, 2000).

The grid of overlapping patches is chosen with a large degree of overlap in order to be robust to small anomalies in the canvas since a median filter is applied in step 3 after the results are assembled. We utilize a uniform grid of 2 cm^2 swatches with horizontal and vertical center-to-center spacing of 8 pixels (339 µm at 600 dpi). Thus, any given pixel in the interior of the x-radiograph is actually contained in 592 = 3481 different swatches. Each swatch can be analyzed independently of the others, so that the analysis of the entire canvas can be easily decomposed into many smaller tasks and performed simultaneously across a large array of processors in order to keep the overall time for the analysis manageable.

<table>
<thead>
<tr>
<th>Painting</th>
<th>Mean Horizontal Thread Spacing ± Std. Dev. (cm)</th>
<th>Horizontal Thread Density and [Mean ± 1 Std. Dev. Range] (thread/cm)</th>
<th>Mean Vertical Thread Spacing ± Std. Dev. (mm)</th>
<th>Vertical Thread Density (thread/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan</td>
<td>1.47 ± 0.10</td>
<td>6.8 [6.4 – 7.3]</td>
<td>1.08 ± 0.08</td>
<td>9.2 [8.6 – 9.9]</td>
</tr>
<tr>
<td>Bacchus</td>
<td>1.07 ± 0.07</td>
<td>9.4 [8.7 – 10.0]</td>
<td>1.49 ± 0.09</td>
<td>6.7 [6.3 – 7.1]</td>
</tr>
<tr>
<td>Silenus</td>
<td>1.50 ± 0.14</td>
<td>6.7 [6.0 – 7.3]</td>
<td>1.11 ± 0.13</td>
<td>9.0 [7.9 – 10.1]</td>
</tr>
</tbody>
</table>

AIC Paintings Specialty Group Postprints 26 (2013)
Figure 2. X-radiograph overlap structure of *Triumph of Pan*. Units are in pixels. Small circles show the locations of shared key points. When a pair of images is known to share key points, their centers are connected with a solid black line. Each x-radiograph is rendered using a translucent blue to indicate the locations and extent of the overlap.
Figure 3. Histograms and summary statistics from the analyses of Pan, Bacchus, and Silenus. Blue-shaded ranges indicate mean plus and minus one standard deviation. Values within 1 thread/cm of each other are considered to indicate a possible canvas match. The bimodal distribution of the vertical threads of Silenus corresponds to the fact that there are two distinctive regions of vertical thread spacing as shown in Figure 4 (bottom right panel), approximately divided by the line $x = 85$ cm, each of which has a unimodal distribution.
an alignment of the thread spacing patterns among the three canvases.

2.2.2 Canvas Maps

Whole-canvass thread-spacing maps created for all three canvases are shown in Figure 4. Several observations can be made immediately. First, comparing the horizontal and vertical spacing maps of Pan shows that the vertical spacing presents a more splotchy appearance, with features persisting for less than the entire height of the canvas. By comparison, the horizontal thread spacings are smoother in appearance, with features persisting with only slight variation across the entire width of the canvas. This difference is consistent with the theory that the horizontal threads in Pan correspond to the warp threads and that the vertical threads belong to the weft. This is consistent with the observation of higher standard deviation of the vertical thread spacings compared with the horizontal ones. This pattern of distinct difference in appearance between horizontal and vertical threads is also observed in Bacchus, where it appears that the vertical threads belong to the warp, and in Silenus, where the horizontal threads apparently belong to the warp.

It is also immediately observed that the horizontal, vertical, and horizontal thread-spacing patterns for Pan, Bacchus, and Silenus, respectively, bear a strong similarity to each other. As a first qualitative comparison, the three spacing maps were resized to scale and then rotated and aligned to obtain the best visual match, resulting in Figure 5. To obtain this alignment, Bacchus was rotated 90° clockwise and Silenus was rotated 180°. The visible images for the three paintings are also shown, scaled, rotated, and translated in the same fashion as the spacing maps. All of the features of the spacing pattern, from the large-scale trends down to the individual small details, appear to match precisely, giving us very strong evidence that the canvases were cut from the same bolt of cloth. This observation is consistent with the previous identification of these aligned threads as the warp threads: the center-to-center spacings of the apparent warp threads are manually extracted along a cross-painting cut that intersects all of the warp threads (a vertical cut across each of the canvases in their aligned orientations as shown in fig. 5), the particular horizontal location of the cut should be relatively unimportant because we would expect to observe nearly the same pattern of spacings from any vertical cut across the same painting. Thus, the sequence of center-to-center warp-thread spacings for the warp threads in a canvas should provide a good characteristic sample of the “canvas fingerprint” for the warp threads in that canvas. Extraction and quantitative analysis thus addresses each of the preceding criticisms: (1) the thread spacings are directly measured, so their statistics can serve as the ground truth for validating the automatic method; (2) the similarity between two spacing sequences is easy to quantify and interpret; and (3) the method operates at the level of individual threads so even single-thread anomalies can be detected.

The striking similarity among the three spacing maps shown in Figure 5 provides strong evidence that the canvases were cut from the same bolt of cloth, but three possible criticisms of the whole-canvass automated-analysis method immediately arise: (1) the method has not been validated against canvases with known spacing, (2) both the alignment among the canvases and the apparently high similarity of their spacing patterns are only qualitative, and (3) the analysis procedure operates on swatches of canvas containing many threads, rendering the method unable to detect patterns of thread spacing at the scale of single threads.

To address these criticisms, we developed a simple and straightforward method for direct thread-level manual comparison between a pair of canvases. It is seen from Figure 5 that the pattern of spacing of the (apparent) warp threads persists nearly unchanged over the entirety of each painting. Thus, if the center-to-center spacings of the apparent warp threads are manually extracted along a cross-painting cut that intersects all of the warp threads (a vertical cut across each of the canvases in their aligned orientations as shown in fig. 5), the particular horizontal location of the cut should be relatively unimportant because we would expect to observe nearly the same pattern of spacings from any vertical cut across the same painting. Thus, the sequence of center-to-center warp-thread spacings for the warp threads in a canvas should provide a good characteristic sample of the “canvas fingerprint” for the warp threads in that canvas. Extraction and quantitative analysis thus addresses each of the preceding criticisms: (1) the thread spacings are directly measured, so their statistics can serve as the ground truth for validating the automatic method; (2) the similarity between two spacing sequences is easy to quantify and interpret; and (3) the method operates at the level of individual threads so even single-thread anomalies can be detected.

The analysis of these so-called canvas fingerprints proceeds in two stages. In the first stage, we extract individual thread spacings across each of the canvases to be analyzed, and in the second phase we compare these spacing sequences to obtain a quantitative metric of the similarity of two canvases in a given orientation.

The manual extraction of the thread spacings from a canvas proceeds as follows:

1. The whole-painting x-radiograph is loaded into the nip2 image analysis program or a program with similar capabilities. This program is chosen because it is free, it allows for easy navigation and viewing of very large x-radiograph images, and it enables the user to manually
Figure 4. Horizontal and vertical thread spacings for all three canvases shown in their usual orientations. The color scales for the horizontal, vertical, and horizontal threads for Pan, Bacchus, and Silenus, respectively, are identical. The color scales for the vertical, horizontal, and vertical dominant thread spacings for Pan, Bacchus, and Silenus, respectively, are also identical.
Figure 5. Manually rotated and aligned thread spacing maps for all three canvases. To be put into alignment, Bacchus was rotated 90° clockwise and Silenus was rotated 180°, so the horizontal, vertical, and horizontal dominant thread spacings for Pan, Bacchus, and Silenus, respectively, from Figure 4 are juxtaposed here. Note that the ordering shown here is arbitrary. Also note the matching canvas dimensions and the matching alignment of thread spacing patterns relative to the canvas edges between Bacchus and Silenus. Pan and Silenus images courtesy of The National Gallery, London, and Bacchus image courtesy of the Nelson-Atkins Museum of Art.
record the locations of arbitrarily many positions within
the image conveniently.)

2. A warp thread is chosen after visual inspection of the
whole-painting x-radiograph according to the criterion
that all of the intersections of the given weft thread
with the warp threads in the canvas can be visually
identified. This weft thread will serve as a “guide
thread” along which thread intersections will
be marked.

3. Starting at the edge of the canvas, the user manually
marks the best estimate for the exact center of the
first identifiable thread crossing of the guide thread
with a warp thread. The software displays the intersection
and records the coordinate \((x_0, y_0)\).

4. The user then proceeds in a similar fashion, marking
every intersection of the guide thread with successive
crossing threads until the opposite edge of the canvas
is reached. A screenshot from this phase of the analysis
is shown in Figure 6. The sequence of intersection
coordinates \((x, y)\) is saved to disk for subsequent
analysis.

5. The same procedure can be repeated using any other
guide thread on any canvas in any orientation for which
quantitative comparison is desired.

The comparison phase of the analysis then proceeds as
follows:

a. The crossing coordinates of the intersections,
\((x_i, y_i)\), are extracted and projected onto the axis
along which the guide thread runs; for example,
in the case of a primarily vertical guide thread,
the sequence of \(y\)-coordinates \(y_i\) of the
intersections of the guide thread with the crossing
threads is extracted. The same procedure is
followed for the second guide thread to which
the first is to be compared. We designate the
projected coordinates for the second guide
thread as \(Y_i\).

b. A sequence of thread-to-thread spacings is
determined by computing the differences
of the \(y\)-coordinates of successive intersections,
\(s_i = y_{i+1} - y_i\). This sequence comprises the
so-called canvas fingerprint with which the canvas
can be compared with others. The spacing sequence
is extracted for both canvases to be compared.
The spacing sequence for the second thread is
designated as \(S_i\).

c. The spacing sequences for the two canvases are
exhaustively compared for all possible relative
offsets, including those where there is only
partial overlap among the sequences but for
which at least 300 threads overlap. For each relative
offset, the root-mean square difference between the
two shifted sequences is determined and recorded:
\[
\delta = \sqrt{\frac{1}{n} \sum (s_i - S_i)^2}
\]
d. After all relative offsets are compared, the offset with
the lowest r.m.s. difference among the two
sequences is taken as the best relative offset between
the two sequences. An example comparison is
shown in Figure 7. Each sequence is truncated at its
ends as necessary to retain only those threads
occurring within the overlapping portion of the
sequence.

e. The end-to-end distance between the first and last
thread in each sequence is found. For the sequence
with the lower end-to-end distance, the sequence is
uniformly scaled up to match the span of the longer
one. This is motivated by two considerations. First,
either a slight misalignment of the angles of the two
x-radiographs with respect to each other or a
nonorthogonal trajectory of the guide thread
relative to the edge of the painting could both result
in compression when the sequence of intersections
is projected onto the \(y\)-axis. Second, it is anticipated
that differences in handling of two canvases after
they are cut will result in differences in their
accumulated length after they are cut. Direct
comparison between two canvases to determine
whether they were cut from the same bolt should
then compare their spacing sequences in a same-
span normalized form. We scale up the shorter of the
two sequences rather than scaling down the longer
one to obtain a pessimistic estimate of their
difference.

f. The r.m.s. difference between the two sequences
(one in its original form and one stretched to
give it the same length) is computed and recorded
for direct quantitative comparison of the two
sequences.

2.4 RESULTS OF MANUAL ANALYSIS FOR PAN,
BACCHUS, AND SILENUS

The preceding procedure for manual comparison of a pair of
thread sequences was performed for five guide threads on each
of the Pan, Bacchus, and Silenus canvases in the orientations
shown in Figure 5, corresponding to approximately 15,000
manually marked thread intersections. For each canvas, the five
vertical guide threads were chosen at locations near the left
dege, at approximately \(\frac{1}{4}, \frac{1}{2}, \text{ and } \frac{3}{4}\) of the distance from the
left to the right edge, and near the right edge of the canvas.
We avoid the extreme edges because of the severity of cusping
there because it is not known to what extent cusping affects
the sequence of spacings for threads approaching the edge
Figure 6. Screenshot from the extraction phase of the manual analysis showing manually marked estimates for the locations of warp threads crossing the vertical weft guide-thread in the whole-painting x-radiograph of Bacchus.

Figure 7. Result of step 3 of the comparison of the spacing sequences along the center guide threads of Pan and Silenus showing the r.m.s. difference between the overlapping portions of the sequences at different relative offsets. The best offset is shown with a vertical line.
Figure 8. Exhaustive comparison of the best match between spacing sequences along each of five guide threads in each of the three canvases. The matches among all threads are very close, and the intercanvas matches are of similar quality to the intracanvas ones.
of the canvas. Summary statistics for the manually extracted thread spacings for the center thread on each canvas are shown in Table 2. The mean spacings are very similar, as are the standard deviations for all three. The mean values are slightly higher than those obtained through the automated procedure, but the differences are well within one standard deviation. It is also noted that the standard deviations for the manually extracted thread spacings are higher than those from the automated procedure. We hypothesize this is because the automated procedure extracts the dominant spacing over an area of canvas rather than the spacings of the individual threads, resulting in a reduced variance because of the aggregation of several spacings in the estimate for one swatch.

Figure 8 shows an exhaustive comparison among all possible pairs of threads from each of the five guide threads for each of the three canvases. It shows that the choice of guide thread has little effect on the quality of the match, with all spacing sequences matching quite well. The mean r.m.s. difference between thread-to-thread spacings among all pairs of threads is 0.243 mm (standard deviation 0.019 mm; self–self comparisons are omitted from these statistics). As can be seen by comparison with Figure 7, this figure is considerably lower than the typical r.m.s. mismatch between a pair of misaligned sequences such as would be found between a pair of thread sequences having similar statistics but mismatched patterns. Figure 8 also shows that the quality of match between pairs of spacing sequences between two paintings is similar to the match quality found between spacing sequences within one painting.

The selection of multiple guide threads at different locations within the same painting was motivated by a desire to further investigate the relationship between spacing sequences and distance along the roll. If the spacing sequences along two closely spaced guide threads within the same canvas tended to exhibit greater similarity than those along distant guide threads, we might infer something about the roll spacing of two canvases from the similarity of their spacing sequences. At this time, however, we do not observe an apparent decay in the quality of the match between spacing sequences in the same painting as their separation increases, so the match results obtained here are unable to resolve questions about the relative sequence of the paintings on the bolt or of their proximity to each other on the bolt.

3. DISCUSSION

Computer-automated weave analysis has established compelling evidence that the canvases of Pan, Bacchus, and Silenus are contemporaneous and were cut from the same bolt of cloth. For the purposes of the Nelson-Atkins study, the close warp thread match between Bacchus and Pan, a painting that is unchallenged today, strengthens the widely held view that Bacchus is indeed an autograph work.

The surprising weave match between Pan and Bacchus and the debated Silenus confirms a much closer connection among the canvas materials of the Richelieu Bacchanal series than was previously known. Considering that all three canvases originate from the same bolt, the National Gallery Silenus, whether it is the original version or not, must have been painted around the same time period as Pan and Bacchus. While the results of the weave analysis yield important new information about the Richelieu Bacchanal series, further research on Poussin's studio practice is necessary to resolve the complex attribution issues of Silenus.

In the National Gallery catalog, Wine (2001) provides a measured summary of the Silenus debate and emphasizes that the primary objection to the painting is its lack of quality in localized areas: “Given the nature of the double ground and the composition of the pigments, similar to those in NG 6477 [Pan] (see Technical Notes), the quality of the paintwork in parts and the fact that assessment is made difficult by the picture’s overall wear, the view that NG 42 [Silenus] is autograph is not unreasonable. However, the technical evidence is not conclusive – it may be that NG 42 [Silenus] was executed soon after the original by someone with access to Poussin’s studio…” (Wine 2001, 380). This possibility, however, remains ambiguous given the lack of information available on Poussin’s studio. The fact that connoisseurs have identified both inferior and acceptable passages on Silenus raises the question of whether Poussin and assistant(s) may have cooperated in the execution of the third bacchanal.

Poussin’s slow and systematic method of painting has lead supporters of the National Gallery painting to speculate that Poussin may have struggled to complete the Richelieu Bacchanal series in a timely manner (Brigstocke 1994). Letters document the arrival of two bacchanals, assumed to be Pan and Bacchus, to

Table 2. Summary Statistics for the Spacings Manually Extracted along the Center Guide Thread for All Three Canvases

<table>
<thead>
<tr>
<th>Painting</th>
<th>Mean Warp-Thread Spacing ± 1 Std. Dev. (mm)</th>
<th>Mean Thread Density ± 1 Std. Dev. (thread/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan</td>
<td>1.52 ± 0.20</td>
<td>6.59 ± 0.87</td>
</tr>
<tr>
<td>Bacchus</td>
<td>1.54 ± 0.20</td>
<td>6.51 ± 0.86</td>
</tr>
<tr>
<td>Silenus</td>
<td>1.54 ± 0.20</td>
<td>6.50 ± 0.94</td>
</tr>
</tbody>
</table>
Richelieu’s chateau shortly after their completion in May of 1636. However, the original *Triumph of Silenus* may have been completed and delivered at a slightly later date (Wine 2001). One argument in favor of the authenticity of the National Gallery painting is that time constraints may have impacted *Silenus* in terms of quality or level of finish, perhaps even prompting Poussin to engage studio assistants to expedite the completion of the commission (Brigstocke 1994). On the other hand, most art historians agree that it is unlikely that Poussin would have allowed a substandard painting to enter Richelieu’s collection.

If Poussin diverged from the studio tradition of his 17th-century contemporaries and did in fact work alone—leaving the production of replicas to independent copyists—under what circumstances could he and a copyist have painted from the same bolt of cloth? One explanation for the *Silenus* weave match is that a copyist purchased canvas from Poussin’s supplier around the time of the Richelieu commission. That a copyist would begin a reproduction so close in time to the original is feasible given the fact that Poussin completed *The Plague at Ashdod* (7276, Musée de Louvre) in 1631 and the existence of a copy by Angelo Caroselli was documented in a court trial (7276, Musée de Louvre) in 1631. However, the original *Silenus* painting is that a copyist may have acquired a scrap of canvas lying about Poussin’s studio, but this is also problematic given the size of the canvas, which is roughly equal to the dimensions of *Pan and Bacchus* and well suited to any number of projects.

4. CURRENT TECHNICAL STUDIES UNDERWAY AND FUTURE WORK TO BE UNDERTAKEN

Scientific analyses of the palette of *Bacchus* and idiosyncrasies that can be found among its pigments have been undertaken and will be the subject of a future publication. These results will be reviewed in the context of similar studies undertaken on Poussin’s works by the scientific staffs of the National Gallery London and the Louvre. Further investigations into automating the thread-level spacing extraction using machine learning techniques are also underway, as are investigations into the spatial evolution of the canvas fingerprint as a function of separation distance.

ACKNOWLEDGMENTS

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APPENDIX 1. DETAILED DESCRIPTION OF AUTOMATED CANVAS-ANALYSIS PROCEDURE

For completeness, we provide the details of the algorithm for extraction of the canvas geometry from a single x-radiograph swatch here.

1. A square patch 2 x 2 cm is extracted from the stitched x-radiograph centered on the point of interest. Its mean brightness is subtracted from all pixels for subsequent computation of the autocorrelation.

2. The patch is Gaussian blurred with standard deviations of 4 and 8 pixels, respectively, and the difference of these blurred patches is computed. Gaussian blurring with a standard deviation of pixels results in an image with features smaller than pixels effectively removed (Witkin 1984). Thus, the difference image contains primarily only those features from the original patch having length scales between approximately 4 and 8 pixels. This removes small features such as those arising from paint particles and small cracks, and also removes large features such as macroscopic brightness variations arising from the paint layer, stretcher bars, or other large non-canvas components of the x-radiograph.

3. The autocorrelation (Lin, Wand, and Yang 1997) of the difference image is computed after padding with zeros and center weighting with a circular Gaussian of standard deviation 0.7 cm so that the computation procedure does not include any influence from the wrap-around portion of the image and so that areas near the point of interest are more heavily weighted.

4. The peaks of the autocorrelation correspond to offsets of a copy of the image relative to itself which would yield strong agreement between them. Quadratic refinement is used locally to refine the estimate of the peak location by fitting each autocorrelation function with a local quadratic form and extracting the peak location therefrom.

5. The collection of peaks is analyzed to extract the vector offsets from each peak to its four nearest neighbors. While some anomalies may occur, these should contain a repetition of the dominant canvas basis vectors \( \mathbf{h} \) and \( \mathbf{v} \). Only vectors with positive projections on the \( x \)- and \( y \)-axes are retained to avoid double-counting offset vectors.
6. The DBSCAN algorithm (Ester et al. 1996) is used to perform cluster analysis on the collection of offset vectors. The parametric input to the algorithm include the minimum distance within which points are considered to be “connected”, which we take as 3 pixels, and the minimum number of connected points needed to constitute a cluster, which we take as 6 points.

7. The cluster centroids are computed, and the cluster centroid lying in the range ±45° which is closest to the origin is taken as the horizontal basis vector \( \mathbf{h} \), while the cluster centroid lying in the range 45°–135° closest to the origin is taken as the vertical canvas basis vector \( \mathbf{v} \).

NOTES

1. There is some debate as to whether a fourth painting, The Birth of Venus (E1932–1, Philadelphia Museum of Art), often referred to as Triumph of Neptune, was part of the series. Although the painting was also commissioned by Richelieu and may date to the mid-1630s, its format differs and it was not installed in the Cabinet du Roi. Its connection to the Richelieu Bacchanal series remains unclear.

2. At this time, the double ground layers of the Richelieu Bacchanal series have not been compared in terms of their pigmentation and binders.

3. “[I]f the average number of warp threads per centimetre differs by more than one thread, one can practically discount the possibility of the canvases in question coming from the same bolt of cloth. The number of weft threads, with their often more varying thicknesses, can differ a great deal more within a single bolt.” on p. 96 from chapter 5 of (van der Wetering, 2000).

4. “In canvases where for other reasons one can be certain of the warp direction, it can be seen that the number of warp threads/cm shows a great deal more constancy than does the number of weft threads/cm.” on p. 100 from chapter 5 “The Canvas Support” of (van der Wetering, 2000).

5. Caroselli’s copy of Plague at Ashdod has been attributed to a painting at the National Gallery of Art, London (NG 165). It has been suggested that Caroselli may have copied directly from the original painting and, in the process, recorded an earlier version of Poussin’s background architecture (Wine 2001). While this scenario could supply an example of a copyist working in Poussin’s studio, there is no connection between the pentimenti on the Louvre painting and the architecture of the National Gallery copy. Poussin’s Plague at Ashdod was completed and delivered to Fabrizio Valguarnera in February or March of 1631, and an inventory of Valguarnera’s possessions at the time of his court trial in July of 1631 included the Caroselli copy (Costello 1950). Rather than painting in Poussin’s studio, Caroselli could have simply executed the copy in the five or six months between Valguarnera’s acquisition of the original painting and the date of the trial.

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Note: This article was originally published with missing illustrations, by no fault of the authors. This revised version contains the correct figures. Publisher revised this document on August 27, 2021.
INTRODUCTION

Conservators sometimes wish to work on paintings vertically, standing to reach center areas in large paintings or to access the front and reverse of a canvas at the same time. Using a lateral side arm for a camera tripod, a conservator can work vertically even by themself. Figure 1 explains how to construct the system.

Figure 1. Construction details for free standing support system
Treatments done in the studio using the free standing support system

1. Consolidation of a large painting. The painting was leaned on two extension poles and the free standing support was placed behind the painting. Cracks in the center of the painting were consolidated from the front.

2. Tear mending. Due to active flaking and paint texture, the painting couldn’t be placed face down. The painting was on an easel and the free standing support was placed at the front of the painting. This treatment also required weight treatment so rare earth magnets were used. One magnet was taped behind the wooden plank screwed on the side arm. After making good contact between the painting surface and the wooden plank, a metal plate was placed at the back of canvas. A second magnet was placed to hold the plate in place.

3. Of course, the side arm can also be used to hold your camera when you need to photograph an unstretched canvas lying flat on the floor or table.

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Proximal dental saws are thin and flexible stainless steel serrated strips used by dentists for finishing work and fine shaping of fills (fig. 1). A strip, acquired from Brad Epley, Chief Conservator of the Menil Collection, during a trip to his dentist, helped release acrylic blocks that were glued to painted fiberglass panels as secondary (and inappropriate) hanging devices. The saw was thin and flexible enough to slip under the edge and disrupt enough of the adhesive to release the block. There are probably other ways in which these saws could prove to be useful as well.

The proximal saws at the top of Figure 2 are identical to the one presented, but the listed websites require a login to view prices.
and order. It is possible that access is limited to dental profession-
als so it may be worth making friends with your dentist!

The small proximal saws at right in Figure 2 appear to be miniature
versions of the one presented. They may not be as useful because of
their smaller size and the handle attachment. Or perhaps they'd be
more useful for some applications. They come in different thick-
nesses and hardnesses and you can even get a variety box. They're a
bit expensive at $168 to $178 for a box of 32, but if they're just what
you need for a particular project they may be worth the price.

The third saws listed in Figure 2 are replacement blades for
dental saws used for slightly less precise work on bone, etc.
They appear to be coarser and less flexible than the proximal
saws, but may be useful under certain circumstances.

SOURCES
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40859-Jiffy-Proximal-Saw/


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STUDIO TIP: Suction Cup Tape

Suction Cup Tape is a non-adhesive material that can provide a tight bond on smooth clean surfaces (fig. 1). It would probably prove useful for a number of applications but in this case it is used to temporarily install data loggers on gallery walls. The loggers are placed to collect representative data during days of the week when the galleries are closed and then taken down for the remainder of the week. The walls are smooth plaster so they cannot have fasteners of any kind that would cause permanent marks and adhesives could leave residue. The suction cup tape provided a way to temporarily install the...
loggers on the walls and then remove them each week without leaving residue or risking damage to the walls.

The material has suction on one side and regular adhesive on the other. The suction side requires a smooth surface and the plaster walls of the gallery work well. Full contact between the surface, suction tape, and mounted item are ideal so pieces of basswood cut to the size of the data loggers were used as the main mounts. The wood mounts provide a flat, full contact surface for the wall but are lightweight and flexible enough for repeated application and removal. Velcro tape was used to attach each logger to the other side of the basswood mounts. The mount is placed on the wall, and after a tight bond is established, the datalogger is attached to the Velcro.

The product can be found at the website listed under: SOURCE. One thing worth mentioning is that the website says the effectiveness of the suction can be reactivated with regular tape, presumably by removing residue or grit accumulated on the surface. This wasn’t found to be very successful. Some tape stuck to it and almost tore the material and other tape did not do enough to reactivate it. An effective alternative is to wipe them down really well with a damp and slightly soapy sponge. Once dry the adhesive works almost as well as when it was brand new.

SOURCE
https://www.inventables.com/technologies/suction-cup-tape
[Accessed 3 April 2017]

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STUDIO TIP: Zip Wall Spray Booth

Zip Walls are a system of expandable poles used to hold up plastic film by painters and carpenters for creating temporary dust barriers. They can be found at most hardware and home improvement stores like Lowes or Home Depot. Whitten Proctor Conservation have used them to set up both temporary spray booths and mold remediation rooms in situ. The poles are also handy when used without the plastic. For example, they can be used to hold clip lamps or backdrops when photographing.

SOURCE
http://www.zipwall.com/

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STUDIO TIP: Icepack for Releasing a Painting from a Metal Frame

To help release a painting stuck to a metal frame, an icepack was placed over the area where the painting was stuck to the inside of the tight metal frame (fig. 1a, 1b). The icepack was left in place for several minutes to safely loosen the bond of the frame stuck to the paint/ground (figs. 3, 4). Although no particular brands of ice packs are recommended, the ones that are wrapped in soft plastic are more malleable and in some situations may be preferable.

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