

Modigliani's studio practice revealed by MA-XRF and non-invasive spectral imaging techniques

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Funding information

DRAC Haut-de-France; LaM Museum; Lille Metropole; Service of the French Museums

Amedeo Modigliani (1884–1920) is an artist highly valued by the public. However, his works have been little studied by natural scientists. The project “Modigliani and His Secrets” follows two closely correlated purposes: a better knowledge of the materiality of the works and a better understanding of the studio practice of the artist. The corpus (25 paintings and 3 sculptures, works belonging to French museums) covers the entire work of Modigliani in France from 1908 to 1920. The present article will focus on the beginning of Modigliani's artistic life through the analyses of two paintings dated from 1909 to 1913. The same multi-analytical approach was implemented for each painting. It enables us to determine Modigliani's color palette, but also to unveil pentimenti and previous compositions. Complementary two-dimensional imaging techniques operating in different spectral ranges (MA-XRF, SWIR reflectance hyperspectral, X-ray radiography...) were successful examining Modigliani's masterpieces to reveal the artistic know-how and intentional strategy of the cursed and legendary artist.

1 | INTRODUCTION

Amedeo Modigliani (1884–1920) was a brilliant artist, whose works are highly valued by the public and the art market. Nevertheless, very few documentary sources are available and only two technical research projects have been undertaken on his paintings: one by the C2RMF in 1981 (almost 40 years ago)^[1] and one by the Tate Museum in 2018.^[2] His artistic process remains thus largely unknown.

The ongoing research project “Modigliani and His Secrets”^[1] aims at studying all Modigliani's works of art from the French public collection. Eleven museums are collaborating with us for the project. The corpus is composed of 28 Modigliani's works (25 paintings and 3 sculptures), completed with two paintings that are no longer attributed to Modigliani.

The present article focuses on the analysis of Modigliani's paintings by means of complementary techniques with different spectral ranges, including macro-

fluorescence X (MA-XRF) and SWIR reflectance hyperspectral imaging techniques. Among the 25 paintings that were studied, our paper will focus on two paintings from his early period, dated from 1909 to 1913. The examination of the paint matter together with all the scientific data obtained through all techniques enables us to determine the palette, as well as the pictorial technique and the studio practice at the beginning of Modigliani's artistic life.

2 | MATERIALS AND METHODS

2.1 | Paintings

The two paintings discussed here are *Jean-Baptiste Alexandre au crucifix* (Figure 1a) and *Paul Alexandre devant un vitrage* (Figure 1b), dated, respectively, from 1909 to 1913, from the Musée des Beaux-Arts de Rouen from the donation Blaise and Philippe Alexandre. The doctor



FIGURE 1 Visible light photography reproduced with the same relative scale (a) Amedeo Modigliani, *Jean-Baptiste Alexandre au crucifix* (Jean-Baptiste Alexandre with a crucifix), 1909, oil paint on canvas, 92 × 73 cm, Musée des Beaux-Arts de Rouen, INV. November 1, 1988, donation Blaise and Philippe Alexandre ©C2RMF/Philippe Salinon; (b) Amedeo Modigliani, *Paul Alexandre devant un vitrage* (Paul Alexandre in front of a window), 1913, oil paint on canvas, 81 × 45.6 cm, Musée des Beaux-Arts de Rouen, INV. November 2, 1988, donation Blaise and Philippe Alexandre © C2RMF/Gérald Parisse. The location of the two micro-samples are marked with a white circle on both paintings

Paul Alexandre was Modigliani's first patron from the end of 1907 to 1914, when he was sent to the front in the medical corps during the First World War. He purchased some drawings and paintings.

In 1909, for his first official order,^[3] Modigliani painted Paul Alexandre's father, Jean-Baptiste Alexandre, near a crucifix and in front of what seems to be his bed (Figure 1a). Modigliani also painted a portrait of Paul Alexandre's brother, Jean Alexandre, as well as five portraits in five years of Paul Alexandre, including the one dated 1913 under our study (Figure 1b). Between 1910 and 1914, Modigliani decided to devote himself to sculpture. His experience as a sculptor is highly visible in the painting of 1913 with smooth outlines and an elongated face. Indeed, the simplification of the lines, for example, with a continuous line from the eyebrows to the nose recalls many of his drawings inspired by African masks and Khmer sculptures.

2.2 | Analytical methods

A multi-analytical non-invasive and micro-invasive approach was set-up using different spectral ranges including macro X-ray fluorescence (MA-XRF), visible near-infrared (VNIR), and short-wave infrared (SWIR) reflectance hyperspectral imaging, X-ray diffraction (XRD), scanning electron microscopy coupled with an energy dispersive spectrometer (SEM-EDS), visible/raking light/UV/IR-photography and IR-reflectography, X-ray radiography, optical microscopy and 3D digital microscopy. Eye-

tracking experiments were performed to collect the focus or gaze point of several persons during their observation of each painting.^[4,5] Moreover, two paint micro-samples were taken on the edge of each painting to study the stratigraphy and to determine the nature of the binder using very high-resolution mass-spectrometry.

Among the collected data set, the following paper will focus on the contribution of three highly complementary imaging techniques—MA-XRF, SWIR reflectance hyperspectral and X-ray radiography—to access Modigliani's pictorial technique. Given the complexity of both paintings, the results obtained on the cross-sections will also be discussed.

MA-XRF was performed using equipment developed in house.^[6,7] The X-ray tube (Moxtek) is composed of a Mo-anode with a maximal power of 40 W, a voltage ranging from 10 to 50 kV, an intensity of 0.5–1.5 mA. Depending on the used collimator, the beam diameter is 200, 650, or 1000 μm . A X-flash Röntec detector cooling by Peltier is positioned at 45°. The equipment is mounted on a X-Y-Z motor stage (OWIS LTM80) with a maximum travel range of 60 × 50 cm (h × v). The set-up used for the analysis of all paintings is 45 kV, 800 mA, with a pixel size of 1 mm², a time per pixel of 50 ms and a working distance of circa 1.5 cm. Thus, the mapping of the painting *Paul Alexandre devant un vitrage* (81 × 45.6 cm) lasted almost 9 hours including an overlapping area of few centimeters. The system is running with an in-house data acquisition software, MA-XRF-Cntrl.^[8] All MA-XRF data were processed and stitched using the PyMCA software, developed at the ESRF^[9] and Datamuncher.^[10]

The short-wave infrared (SWIR) camera used is composed of an ImSpector N25E imaging spectrograph (Specim, Finland) and a Peltier-cooled MCT detector. The analyses were performed in the 1000 to 2500 nm spectral range with a spectral resolution of 12 nm and a spatial resolution of around 1 mm. Analyses were performed horizontally at a working distance of around 50 cm, with an integration time of 3,5 ms. Two rows of three halogen lamps (35 W) placed on each side at 45° from the vertical were used as illumination sources. The calibration is made using a white reference (99% reflectance Spectralon®) and a dark measurement by closing the shutter (electronic noise) by means of the Specim plug-in in the ENVI software (Harris Corporation, Melbourne, Florida). A noise level of circa 0.5% for the white reference and circa 0.3% for the black was measured. The data processing was done using the ENVI software.^[11] The NMF images were obtained using the whole spectral range, on the whole painting and on smaller specific areas to achieve a better contrast.

X-ray radiography was performed at 35 kV and 7 mA, with an exposure time of 3 minutes for *Paul Alexandre devant un vitrage* and 4 minutes for *Jean-Baptiste Alexandre au crucifix*. Each X-ray film was digitized using the Medi-6000 Plus (Microtek) with a 300dpi resolution.

All paint micro-samples were embedded in a mixture composed of the polyester resin SODY 33 with the catalyst SODY 33 C at 4% in volume (both purchased from E.S.C.I.L, France). After drying, the inclusion was cut using a circular saw and dry polished with successive silicon carbide papers and tissues from P1200 to P12000 (purchased from Micro-Mesh, Micro-Surface, Finishing Products, Inc.). The cross-sections were then observed by optical microscopy in visible light (bright field) and in fluorescence with B-2A and UV-2A filters (Nikon Labophot-2 coupled with a Nikon DS-Ri1 camera). The carbon-coated cross-sections were analyzed by SEM-EDS on a Philips XL30CP controlled by the XL30 Microscope Control software. Back-scattered electron (BSE) images and EDS spectra were collected using the Aztec software (Oxford Instrument) at 15 kV at a 10 mm working distance.

3 | RESULTS AND DISCUSSION

3.1 | Jean-Baptiste Alexandre au crucifix

The painting *Jean-Baptiste Alexandre au crucifix* (Figure 1a) is executed on a canvas, stretched on a five-member stretcher using wooden keys at each angle. Its size, 92 by 73 cm, corresponds to a 30 F (size 30, Figure) standard size canvas according to the French system of

standardized stretchers and canvases.^[12] A stamp from the purchaser “Hardy-Alan” is applied at the back on the canvas (Figure 2). The address mentioned is 36 rue du Cherche-Midi in Paris. According to the Guide Labreuche, the art supplier moved from the 36 rue du Cherche-Midi to the 92 Boulevard Raspail in Paris on the July 15, 1907.^[13] It means therefore that the canvas used for the painting was bought at the latest in 1907.

A white ground layer was applied on the canvas. It is worth mentioning that the lower edge of the canvas contains no ground layer. This suggests that the painting was executed on a raw canvas that was not prepared by an art supplier but certainly by Modigliani himself. According to the Pb-L MA-XRF maps (Figure 3), the ground layer is composed of lead white, what was confirmed by SEM-EDS analyses of both cross-sections.

MA-XRF analyses (Figure 3) enabled us to map the different elements. Based on those results, the technical imaging and the visual examination, the palette of the portrait of Jean-Baptiste Alexandre was identified. It allows us to infer a repartition of the different pigments. In the paint layers, the joint use of lead (Pb-M) and zinc must be underlined. For the head of the portrait, Modigliani used first lead white to define its shape and then a zinc-based pigment to paint in detail the facial features. MA-XRF together with SEM-EDS analyses confirm the use of lithopone, a mixture of barium sulfate and zinc sulfide. The skin tones were mainly obtained using vermilion. Modigliani's colorist virtuosity is expressed in the jacket. While it could appear black at a first glance, it was made using a large variety of pigments: bone black,



FIGURE 2 A, Modigliani, *Jean-Baptiste Alexandre au crucifix*. Visible light photography of the stamp from the art material supplier “Hardy-Alan” that is affixed to the back of the canvas ©C2RMF/Philippe Salinson

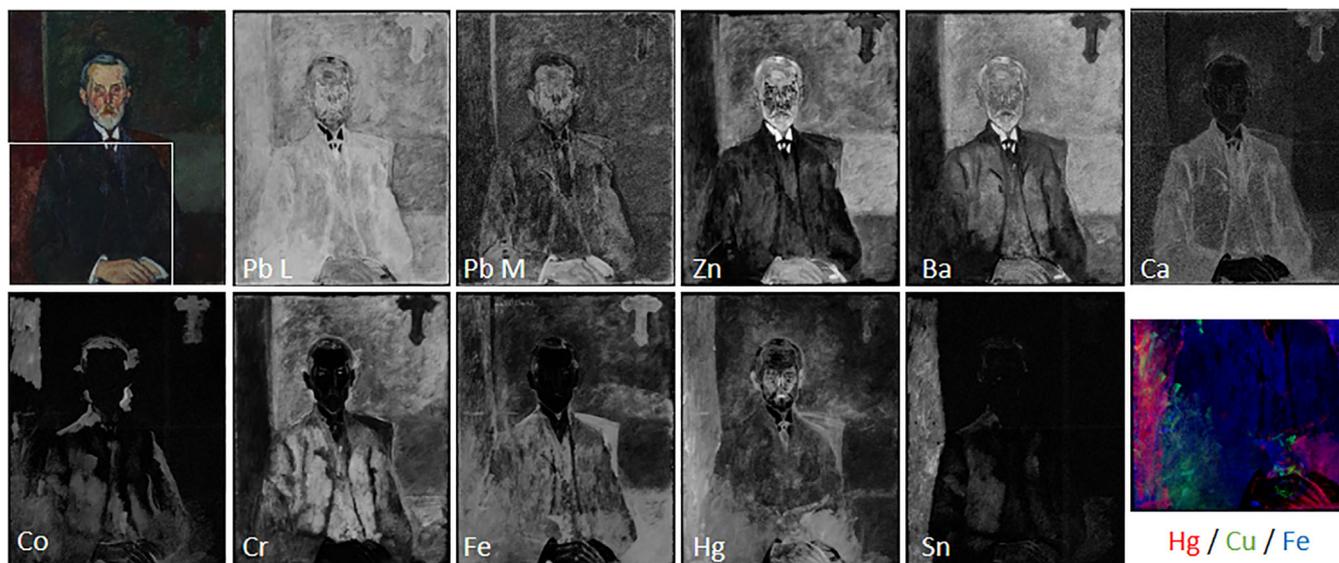


FIGURE 3 A, Modigliani, Jean-Baptiste Alexandre au crucifix. The white rectangle materializes the detail area of the combined map. MA-XRF maps showing the elemental distribution of the lead (Pb-L and Pb-M, corresponding to the lead coming only from the surface layers), the zinc (Zn), the barium (Ba), the calcium (Ca), the cobalt (Co), the chrome (Cr), the iron (Fe), mercury (Hg), tin (Sn), and a detailed of combined map with mercury (in red), copper (in green), and iron (in blue). The copper and arsenic map are identical and only the copper map is represented. The images are displayed in a logarithmic scale

Prussian blue, cobalt blue, chrome green, and also a bit of vermillion and red lake. The background was mainly composed of chrome green pigment on the dextral part and a red lake on the senestral part. Some cobalt blue was added on the red lake in the upper part of the red strip. Moreover, blue-green highlights based on cobalt blue and/or green chrome pigments were applied around the head of Jean-Baptiste Alexandre. The cross was made of cobalt blue pigment, bone black, earth pigments and vermillion. The chair back was painted using vermillion and earth with a little green chrome pigment.

The X-ray radiograph revealed the presence of an underlying portrait (Figure 4b). It must be notified that the head is not really discernible on the radiograph. The round area above the shoulder corresponds to the head of Jean-Baptiste Alexandre. His beard and his shirt collar are clearly perceptible on the X-ray radiograph. A close examination of his jacket with a binocular microscope highlights some roughness in the surface linked to the very thick texture of the paint used in the underlying portrait. Moreover, the analyses performed with MA-XRF and SWIR reflectance hyperspectral imaging unveil the presence of a second underlying composition. The of a bearded man appears upside-down, near the lower edge, under the hands of Jean-Baptiste Alexandre. According to MA-XRF analysis, the head of the underlying man may contain an iron-based pigment, vermillion and emerald green. The background may also be painted with an iron-based pigment, vermillion and emerald green,

but also cobalt blue. Regarding the pigments that we infer for the background, there are some brushstrokes on the maps that are not associated with the current portrait (visual examination) and that are not related to the shape highlighted by the X-ray radiograph for the other underlying portrait. Based on the cross-sections, it would be difficult to assess whether ground layers were applied between the three different compositions. There is no evidence of an additional ground layer in the cross-section 1 (Figure 4d). However, on the cross-section 2 (Figure 4e), the white layer made of lead white and barite could possibly be a ground layer.

The use of a multi-analytical method with different spectral ranges was determinant to unveil two underlying portraits. Indeed, the man portrait is not visible on the X-ray radiography and the other one is not perceptible on the MA-XRF and SWIR analyses. The depth of analysis differs for all these techniques. Indeed, the X-ray radiography is collected in transmission, so that the entire thickness of the painting is analyzed. In SWIR, the volume analyzed is more superficial. Regarding MA-XRF, the analyses were done in reflection mode, so that the chemical elements coming from deep layers are thus hardly collected by the detector, except for heavy metal elements such as lead or mercury. The X-ray radiograph of the portrait of Jean-Baptiste Alexandre revealed an underlying composition executed with heavy elements. However, it was not detected by MA-XRF. It suggests that this composition is deep in the stratigraphy. The second

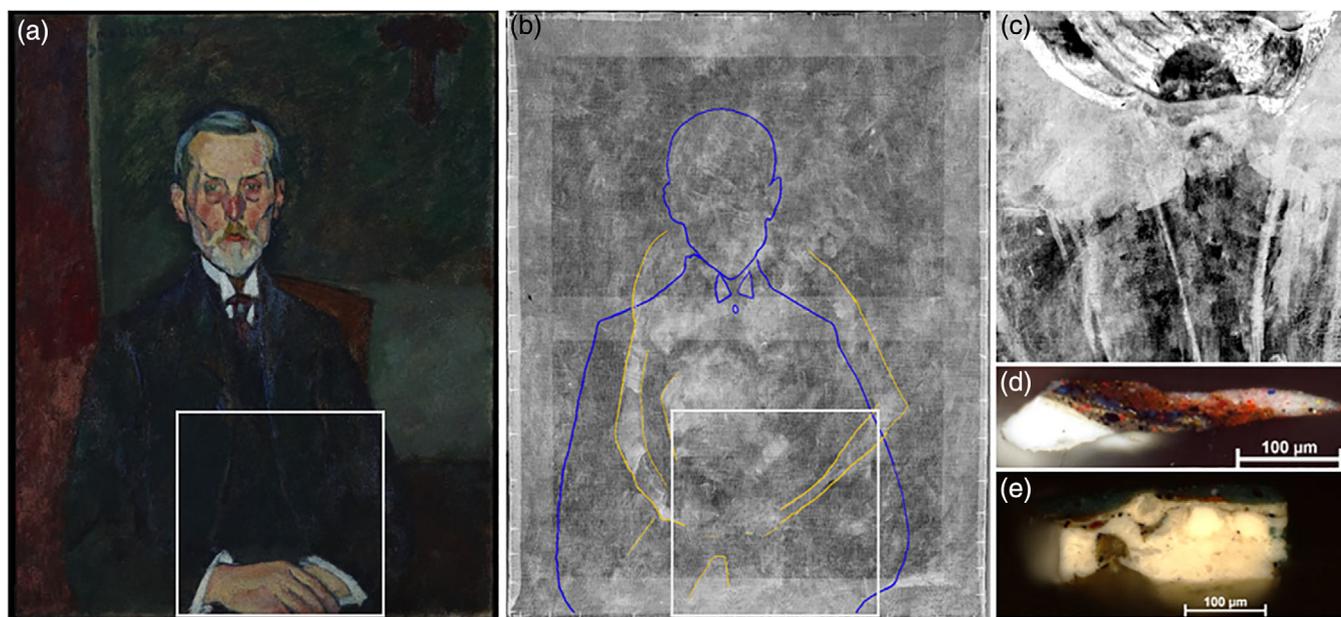


FIGURE 4 A, Modigliani, *Jean-Baptiste Alexandre au crucifix*. The white rectangle materializes the detail area of the SWIR analysis presented in Figure 4c. (a) visible light photography; (b) X-ray radiograph revealing an underlying woman portrait; (c) SWIR reflectance hyperspectral MNF two image of a small area around Jean-Baptiste Alexandre hands, showing an underlying man portrait (after a 180° rotation). A minimum noise fraction (MNF) algorithmic transformation was performed on the data set to enhance the portrait visualization; (d, e) optical microscope images of the paint micro-sample 1 (d) and 2 (e)

one is visible by MA-XRF and SWIR, which enables us to propose that it is less deep in the stratigraphy. It can therefore be supposed that the canvas was first used to paint the first underlying portrait, turned 180° to paint the underlying man portrait, turned 180° again and finally re-used to paint the portrait of Jean-Baptiste Alexandre. It is highly surprising that Modigliani re-used an already painted canvas to honor his first order, for which he was paid 500 francs gold by Jean-Baptiste Alexandre.^[3]

The underlying man portrait could be a first version of the portrait of Jean-Baptiste Alexandre that Modigliani would have painted. Both are wearing a beard and have a pronounced brow bone. Regarding the second underlying portrait, the presence of the stamp at the back suggests that the painting might have been executed at the latest in 1907 or in 1908. Indeed, it is unlikely that the canvas purchased certainly before the 15th July 1907 was kept unpainted by an artist for months at that period. The attribution of the portrait is still uncertain. Nevertheless, the composition recalls the one of the *Young Gypsy* painted by Modigliani. The painting is estimated to be dated from 1915 by Pfannstiel^[14] and later from 1909 by Lanthermann^[15] and Ceroni.^[16] This review is based on a watercolor, which is related to the painting and dated from 1909. However, as it is not based on any historical reports, the painting's dating might be uncertain. Indeed, in both paintings, the position of the arms and hands is

highly similar. Moreover, the underlying portrait seems also to wear pants and to be seated with the legs slightly opened. The visual examination of the paint surface and the X-ray radiograph revealed the presence of highlights rich in lead, mainly on the arms, executed with a thick matter that reminds those in the *Young Gypsy* of the technique of execution.

3.2 | Paul Alexandre devant un vitrage

The work *Paul Alexandre devant un vitrage* (Figure 1b) is painted on a non-standard size canvas (81 × 45.6 cm) and stretched on a five-member strainer with fixed joints, with which the canvas tension cannot be adjusted. The use of non-conventional canvas size seems to be frequent in Modigliani's paintings. Indeed, among the 76 paintings displayed in the last Modigliani retrospective exhibition at the Tate Museum in London in 2018, 21 paintings (circa 30%) were non-standard sizes.^[2] It is worth noting that the painting was not executed on a stretched canvas. The close examination of the painting revealed the presence of pin holes at each angle (Figure 5). The paint topography beneath the pins was not flattened but a little damaged by the pin edges. It proves that the paint matter was still fresh, when the painting was hanged on a wall.

The paint was executed on a canvas with a commercial white ground that is visible on the lower and upper

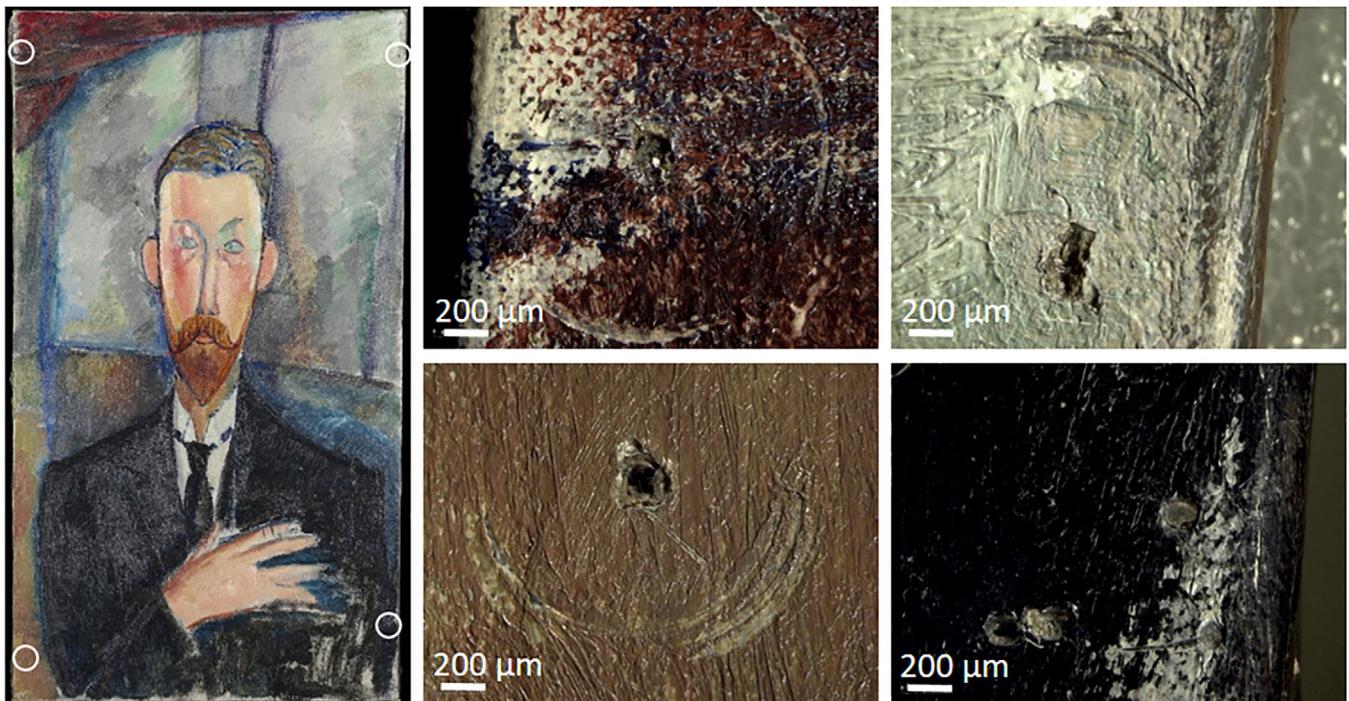


FIGURE 5 A. Modigliani, *Paul Alexandre devant un vitrage*. Binocular images of the four pin holes visible at each angle of the painting. The white circles on the painting photograph materialize their exact locations



FIGURE 6 A. Modigliani, *Paul Alexandre devant un vitrage*. MA-XRF maps showing the elemental distribution of the lead (Pb L and Pb M, corresponding to the lead coming only from the surface layers), the zinc (Zn), the barium (Ba), the calcium (Ca), the cobalt (Co), the chrome (Cr), the iron (Fe), mercury (Hg), tin (Sn), and copper (Cu) and arsenic (As). The copper and arsenic map are identical and only the copper map is represented. The blue arrow on the mercury map indicates the architectural background. The images are displayed in a logarithmic scale

edge of the painting. The left edge is covered by a brown wash. The right edge, however, is painted. The MA-XRF lead map (Figure 6) and the cross-section analyses by SEM-EDS reveal that the ground is made of lead white.

The elemental analyses performed by MA-XRF highlight the nature of the pigment used in the portrait of Paul Alexandre and their distribution. As for the previous painting, the joint use of lead (Pb-M) and zinc white pigments in the paint layers is evident. By contrast, the distribution of the zinc and the barium map are different. It revealed that Modigliani used three white pigments for the execution of his painting: lead white, zinc white, and also barite. The skin tones are made of vermilion and ochre. It is worth noting that the flesh colors are constructed differently for the face and the hand. Indeed, no vermilion was used for the hand, except two contour lines. The black jacket was again painted using several pigments including bone black, chrome green, Prussian blue associated with barites and emerald green. The background is composed of cobalt blue, chrome green, Prussian blue, ochre, and emerald green and bone black. The presence of calcium carbonate in the background

and the face is also conceivable. The presence of several red ochre dots under the hand is interesting as it reminds one of the techniques he used as a sculptor. Indeed, on the *Woman head* from the Centre Pompidou (inventory number AM 903 S), dated 1911–1913, the back presents an unfinished head, where the outlines are marked with several holes made using a point chisel. The portrait of Paul Alexandre is not a unique occurrence in Modigliani painted works. The use of dots to outline the shapes is visible on several paintings dated around 1915, among which *Teresa*, dated from 1915, conserved in the LaM Museum (inventory number 976.4.139) is a prime example.

Regarding Modigliani's practice, a pentimento is highly visible by SWIR and MA-XRF on the dextral shoulder of Paul Alexandre that was a little higher in a previous version. Moreover, the XRF mercury map reveals a hidden architectural element in the background behind the window. Some lines are also visible in the X-ray radiograph but without the mercury map, it would have been impossible to understand the composition.

Finally, a man portrait is unveiled by X-ray radiography after a 90° clockwise rotation (Figure 7a). The

FIGURE 7 A, Modigliani, *Paul Alexandre devant un vitrage*. (a) X-ray radiograph revealing an underlying man portrait after a 90° clockwise rotation. The white arrows show the hand and a circular form continuing on the painting edge; (b) SWIR reflectance hyperspectral PC 1 image obtained through a principal component analysis of the data set. (c, d) B-2A optical microscope images of the paint micro-sample 1 (c) and 2 (d). The blue arrow indicates the varnish layer



underlying portrait is not visible by SWIR (Figure 7b) and only his hand is perceptible on the MA-XRF mercury map (Figure 6). It proves once again that the use of multi-analytical techniques is crucial to reveal hidden paintings. The analyses of the cross-sections revealed that the first portrait was varnished (Figure 7c) and that a second lead white ground layer was applied between the underlying composition and the portrait of Jean-Baptiste Alexandre (Figure 7c,d). As the upper and lower edges of the canvas are not painted, it is obvious that the horizontal dimension of the underlying painting was 81 cm. Regarding its vertical dimension, nothing can be concluded, as the underlying portrait continues on the dextral edge of the painting (Figure 7a). Nevertheless, it is highly likely that the vertical dimension is smaller than the horizontal one. The attribution of the underlying portrait is still under discussion. The use of a probable horizontal format in 1913 is disconcerting. Indeed, except during his nude period in 1917/1919, all Modigliani's paintings are executed in a vertical format.

4 | CONCLUSIONS

The analyses of the two Modigliani paintings *Jean-Baptiste Alexandre au crucifix* and *Paul Alexandre devant un vitrage*, dated, respectively, from 1909 to 1913, give new insights on his studio practice at the beginning of his artistic life.

Regarding his artist's process, our analyses revealed some pentimenti, as well as previous composition(s). For this item, the use of complementary two-dimensional imaging techniques proves to be a successful strategy. Indeed, depending on the spectral range different features are emphasized. Notably it unveils hidden compositions that were not always visible using X-ray radiography. It demonstrates the power of the new imaging techniques that are the MA-XRF and the SWIR reflectance hyperspectral analysis of paintings. In the near future, it would be interesting to consider the analysis of vast corpus of paintings made by artists for whom the re-use of canvas is known.

The analyses of all paintings of the corpus enabled us to characterize Modigliani's color palette on each painting and his artistic gesture with a characteristic brush-stroke. As a next step, all results need to be compared to highlight the evolution of his technique and studio practice over his short artistic life.

ACKNOWLEDGEMENT

The authors gratefully acknowledge Gérald Parisse and Jean-Louis Bellec for the technical imaging of all paintings, as well as Aurélie Tournié, Anne Michelin and

Christine Andraud for the acquisition of the SWIR reflectance hyperspectral data sets. All our thanks to the eleven museums that are involved in the research project, for letting us study the Modigliani's works of art from their collections. The Musée des Beaux-Arts de Rouen and in particular Sylvain Amic is acknowledged for allowing us to discuss here the analytical results obtained on their two Modigliani's paintings.

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ENDNOTE

¹ The project is co-lead by the LaM (Lille Métropole Musée d'art moderne, d'art contemporain et d'art brut) museum and the Centre de Recherche et de Restauration des Musées de France (C2RMF), with the close collaboration of the CNRS through the UMR 8247 involving the C2RMF and Chimie ParisTech and the USR 3290 Miniaturisation pour la Synthèse, l'Analyse et la Protéomique (MSAP) at Lille University. The eleven museums involved in the project are: the LaM (Lille métropole musée d'art moderne, d'art contemporain et d'art brut, Villeneuve d'Ascq), the Musée de l'Orangerie (Paris), the Musée national d'art moderne – Centre Pompidou (Paris), the Musée national d'art moderne de la Ville de Paris, the Musée des beaux-arts de Rouen, the Musée des beaux-arts de Nancy, the Musée Picasso, the Musée d'art moderne de Troyes, the Musée de Grenoble, the Musée d'art et d'histoire du judaïsme (Paris), the Musée des beaux-arts de Lyon.

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How to cite this article: Genty-Vincent A, Laval E, Senot M-A, Menu M. Modigliani's studio practice revealed by MA-XRF and non-invasive spectral imaging techniques. *X-Ray Spectrom.* 2020; 1–9. <https://doi.org/10.1002/xrs.3211>