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DOCUMENTATION

Non-invasive imaging systems as tools for evaluating treatments: The case of *Bathers* by Henri Matisse

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Abstract
Conservation treatments for unvarnished modern paintings can prove challenging, since they are especially susceptible to physicochemical changes caused by environmental soiling deposition, pollutants, humidity and temperature. This study aims to contribute to enhancing the role of technical imaging in the decision-making process for conservation treatments, in particular to evaluate the use of a novel cleaning method – nanogels – on Henri Matisse's *Bathers* (1907), an unvarnished and sketch-like painting. A combination of imaging systems, including technical multispectral imaging, X-ray and microphotography, was used to assess the cleaning process used. The two key results obtained by this case study are (i) the efficiency of Nanorestore Gel Peggy 6 in the removal of soiling on unvarnished sketch-like oil paintings and (ii) the role of multispectral imaging in assessing their cleaning.

INTRODUCTION

Conservation treatments for unvarnished modern paintings can prove challenging, since they are especially susceptible to physicochemical changes caused by environmental soiling deposition, pollutants, humidity and temperature. Conservation treatments carry considerable risk for key aspects such as surface integrity, as interactions with the painted surface can involve unacceptable pigment pickup, paint, swelling, uneven soiling removal and gloss change (Daudin-Schotte et al. 2013, Tempest et al. 2013, Ormsby et al. 2019). Over the past decade, research efforts have contributed to the evaluation of new cleaning methods more suitable for unvarnished and water-sensitive artworks, producing novel lower-risk systems for removal of soiling (Green 1990, Khandekar 2000, Veríssimo Mendes et al. 2014, Cárdaba and Solbes 2021). This paper aims to contribute to the literature available by examining a case study: the characterisation of Henri Matisse's *Bathers* (1907) and the search for a suitable cleaning treatment. The case study is presented in iterative stages, which directly reflect the conservation treatment decision-making process, alongside a detailed account of the treatment carried out.

Bathers: Description of condition

Bathers by Henri Matisse (1869–1954) is an important painting that offers a new perspective on Matisse's working methods during a period when he was experimenting with new techniques and modes of expression. The subject itself, two bathing figures in a sketch-like landscape depicted by loosely applied, vibrant brushstrokes, exemplifies an important dimension in Matisse's experiments that has hitherto remained unrepresented in the Statens Museum for Kunst (Figure 1a).

It is painted on a machine-made, finely woven canvas that is still on its original stretcher. Based on X-ray, it can be assumed that the artist applied the ground layer with a knife or spatula. The painting is intentionally unvarnished, and it exhibits a sketch-like technique over a visible ground. The entire surface had a light brown-yellowish tone, more evident in the areas where the ground is exposed. In addition, the painting had undergone treatment in the past which left stains in the matte paint layer from previous consolidation.

The paint was applied in different ways. In some areas, highly diluted oil paints were used, giving a matte and meagre paint layer that lacks body and

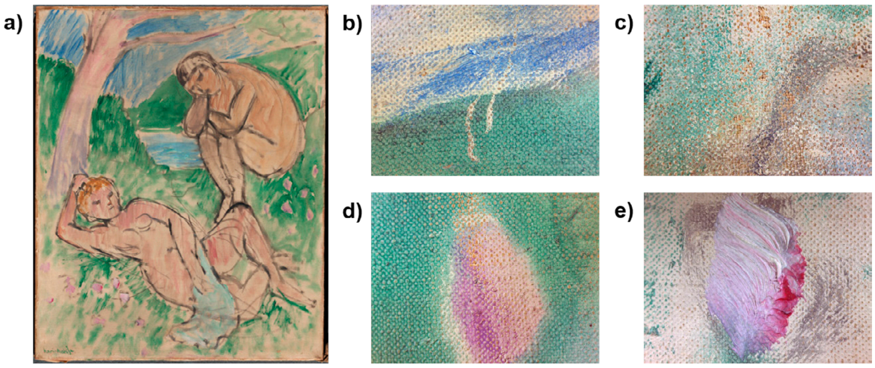

Figure 1. (a) Visible light image of Henri Matisse's *Bathers*, 1907, oil on canvas, 73 × 59 cm, Statens Museum for Kunst (SMK Photo/Loa Ludvigsen); (b–e) details of damages and losses on the surface of *Bathers* (SMK Photo/Pauline Lehman Banke). © Succession H. Matisse/VISDA 2022

brilliance. In others, the colours were applied in thicker and more intense paint layers in clearly visible zigzag brushstrokes and glossy impasto.

The surface dirt had uniformly dampened the colours, and numerous subtle features on the paint surface, such as gloss variance and brushstrokes, had become obscured. In addition, the microscopic examination of the painting revealed that the canvas structure is visible through tiny losses and microcracks in the thinly applied priming layer (Figure 1b, 1c). This gives the painting a rough and eroded surface and high sensitivity to moisture.

Previous attempts at surface cleaning had been unsuccessful due to the inherent complexity of the painting. Cleaning methods based on the use of sponges and the gentle rolling motion of cotton swabs were discarded, since they can cause unacceptable abrasion.

The ultraviolet (UV)-induced visible luminescence images obtained from the multispectral imaging analysis showed a yellowish layer on the painting surface. In contrast, a lack of luminescence was observed at the edges of the painting covered by the frame. This can be associated with the presence of a soiled layer. This layer was also visible in the UV reflectance image, where the painting seems to be covered.

The primary objectives of the conservation treatment were to evenly remove the soiled layer responsible for the yellowing while maintaining the overall tonal balance of the painting and minimising any risks associated with the use of cleaning systems. Additionally, the conservation treatment included the correction of the prior treatment that was causing deformations to the canvas and original covering material. Consolidation and retouching of minor paint losses, unstable ground and paint along the cracks in the impasto paint strokes was also required in order to prevent further loss during transport.

METHODS OF STUDY

Instrumentation

Digital microscopy

High-resolution digital microscopy was performed on the painting surface prior to, during and after the cleaning with a Leica M50 microscope with

0.6 × 10 magnification. Images were processed with a Leica IC80 HD camera and LAS EZ software. The cleaning process was also monitored with a digital microscope.

Imaging techniques

The Phase One Rainbow system[1] was used with Rainbow MSI software. This software is produced by Phase One according to Charisma guidelines (Dyer et al. 2013, Keller et al. 2020). The camera used was a Phase One iXG 100MP Wide Spectrum with a CMOS sensor (resolution of 11608 × 8708) and Schneider-Kreuznach RS 72 mm lens. Filters were placed in front of the camera in a filter wheel (Baader UV/IR Cut L-filter for UV-induced visible luminescence images and UG11 filters for reflected UV images; a Schott BG39 filter for visible light; and a Heliopan 830 nm filter for IR). The attached lighting system consisted of a set of Dedo LEDs: UV Dedolights (DLED4-UV365) with additional UG11 filters, visible light (DLED7-D) with a BG39 filter and IR (DLED4-IR860). The system was operated using Phase One Rainbow MSI software.

Infrared reflectography (IRR) was carried out using an Apollo camera (Opus Instruments) with a bandwidth region of 1100–1700 nm and fitted with an 1250–1510 nm bandpass filter. The illumination sources were two Hedler halogen spots placed at an angle of 25° to the paintings.

X-ray reflectivity (XRR) was performed with a Yxlon SMART EVO 160D directional X-ray system with 1.0 mm focal spot, 20–160 kV, 0.5–7.0 mA tube range, an additional 3 mm $AlMg_3$ filter and a Dürr HD-CR 35NDT CR digital scanner using 30 × 40 cm HD imaging plates from Dürr NDT. The distance between the tube and paintings was 110 cm.

Cleaning system optimisation and evaluation methodology

Due to the characteristics of the surface of the painting (described above) and after an extensive literature review, it was judged that the Nanorestore aqueous-based gels series would fulfil the requirements established for a successful cleaning strategy (Angelova et al. 2013, Baglioni et al. 2014, Cárdaba et al. 2019, Mastrangelo et al. 2019, Bartoletti et al. 2020a and b, Porsmo et al. 2021). Nanorestore Gel Peggy was developed by the Centre for Colloid and Surface Science (CSGI, Florence, Italy) under the NANORESTORE project for the cleaning of contemporary works of art (Baglioni et al. 2014). It has been used successfully to clean unvarnished and water-sensitive paint surfaces (Bartoletti et al. 2020a and b, Porsmo et al. 2021). These gels are opalescent, physical hydrogels based on polymeric networks of poly(vinyl alcohol) (PVA) and can be tailored with cleaning solutions. Nanorestore Gel Peggy 6 is made from PVA alone and is more flexible than Nanorestore Gel Peggy 5, with the potential for enhanced conformation to moderately textured surfaces, which makes it adequate for cleaning an oil painting with an impasto and sketch-like surface (Figure 1).

Nanorestore Gel Peggy 6 is a rigid gel that is easy to apply and remove from the paint surface. The gels are dispatched in ready-to-use sheets (approx. 10 cm × 15 cm × 2 mm) immersed in a small volume of demineralised water. They must be rinsed by immersion in deionised water for 24 hours before use.

Previous tests have shown that deionised water is insufficient for the removal of the deposited soiling layer. The nanogels were tested using chelating agents to explore tailored solutions. Table 1 shows the cleaning solution options tested with both a cotton swab and nanogels. The selection was based on the supporting literature showing that higher pH solutions generally resulted in enhanced soiling removal. Lowering the pH below 6.5 reduces the risk of pigment removal from oil paintings (Osmond and Carter 2013, Dillon et al. 2014, Soldano and van der Berg 2014, Gillman et al. 2019). A two-phase approach was designed in order to find the optimal loading solution and cleaning strategy for *Bathers*. The tested areas and the gels were examined under the microscope to assess any impact on the paint surface. During the optimisation and evaluation process, a star diagram was used to represent the results obtained for the gel combined with the studied solutions, where the criteria had been adjusted from previous research (Bartoletti et al. 2020a, Porsmo et al. 2021) to reflect the specific requirements of this case study. For each parameter of interest, the cleaning systems were rated on a scale of 1 (inadequate/poor) to 5 (most appropriate), where the larger stars represent more promising systems. They were rated based on soiling removal efficiency, cleaning evenness, pigment pickup, colour and gloss appearance (including lack of blanching), and lack of noted residues.

Table 1. Cleaning solution options tested on a mock-up during the first phase. The solutions tested on *Bathers* during the second phase are indicated with an asterisk

Cleaning solutions tested on mock-up				
No.	**Chelating agents**	**Concentration**	**pH**	**Clearance**
0	Deionised water (DI)	-	x	Deionised water
Citric acid/NaOH (CA/NaOH)				
1		0.5% w/v CA/NaOH	6.5	
2*		1% w/v CA/NaOH	6.0	
Triammonium citrate (TAC)				
3		0.5% TAC in DI water	7.1	
4*		0.75% TAC in DI water	7.2	
5		1% TAC in DI water	7.2	

In the first phase, a mock-up was made to mimic approximately the soiling adhesion using a commercially primed canvas and an artificial soil mixture based on a system used by Ormsby et al. (2010). The artificial soil was applied in multiple (wet) brush applications. The mock-up was divided into three sections: control (unsoiled and unaged), soiled and soiled and artificially aged (for 96 hours). The tested areas and the gels were examined under the microscope to assess any effect on the surface, soiling removal and swelling due to exposure time with the cleaning method. Figure 2 shows the star diagram results for the test carried out on the mock-up with Nanorestore Gel Peggy 6 loaded with the different solutions.

In the second phase of the optimisation and evaluation process, only the solutions that received the highest rating (5) were tested. During the optimisation phase, two cleaning systems – cotton swab and nanogels – were used in order to adjust the exposure time of the gels in contact with the painting surface. The nanogels were cut to cover a testing area of approximately 1 × 1.5 cm^2.

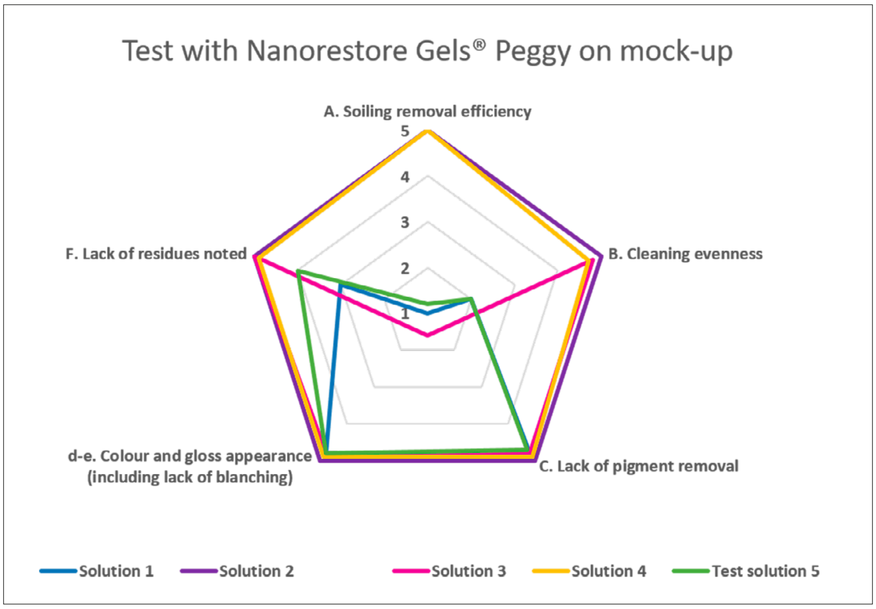

Figure 2. Results of the star diagrams for the test carried out on the mock-up with Nanorestore Gel Peggy 6 loaded with the five solutions

RESULTS AND DISCUSSION

As mentioned above, microscopic examination of the canvas revealed that the weave structure was visible through the thinly applied priming layer; moreover, due to countless micro-losses, the painting was extremely water-sensitive and in a poor state of conservation. An aqueous-based rigid gel was considered to reduce the risks associated with mechanical action, solvent penetration, pigment pickup and tideline formation.

Previous discrete swab tests confirmed that the use of mechanical action-based cleaning methods was too invasive for the removal of the deposited yellowing soiling after long exposure (i.e. around 10 double rolls), as the dirt layer remained unaffected. This meant that both exposure and pressure must be increased to remove the deposited soil-containing layer. These tests confirmed that the priming and oil paint remained unaffected by the deionised water. After an extensive literature review and characterisation of the painting surface in terms of technique, it was considered that Nanorestore Gel Peggy 6 fulfilled the requirements established for a successful cleaning strategy.

Five loading solutions for Nanorestore Gel Peggy 6 were tested in a mock-up during the first phase, consisting of the cleaning solutions with the highest rating (4–5 for all criteria included on the star diagram). The nanogels were loaded with two solutions: 0.75% triammonium citrate at pH 7.2 and 1.0% citric acid/NaOH at pH 6.0. Both solutions exhibited good cleaning efficiency in the mock-up with regard to evenness of soiling removal and lack of pigment pickup when tested with a cotton swab on *Bathers*. Nevertheless, the 1.0% citric acid/NaOH (pH 6.0) scored higher in terms of soiling removal.

Final protocol for *Bathers*

After the preliminary tests on *Bathers* were evaluated, the cleaning procedure was optimised and finalised as follows:

1. The Nanorestore Gel Peggy 6 gels were primarily used in the manufacturer's standard sizes (approx. 10 cm × 15 cm × 2 mm); however, some smaller pieces were required due to the size of the painting. In the cases where smaller nanogels were required, the gels were cut to the desired size after being loaded. To avoid any overlap, the gel was applied through a cut-out Mylar template designed to align with the painting composition or desired figure, in order to protect the previously cleaned surrounding area.
2. Using gloves, the already rinsed (in deionised water) gels were loaded into the desirable solutions overnight (Figure 3a).
3. Before application and using gloves, each gel was pressed firmly between a double layer of Whatman filter paper to reduce excess liquid and surface moisture exposure. At this stage, the gel was very slightly moist to the touch (and very sticky).
4. The gel was then gently placed onto the painting surface and left there for one minute (as determined by the mock-up trials) under a sheet of Melinex. The gels were gently pressed using light finger and palm pressure to ensure that there were no bubbles and the contact between the gel and the painted surface was homogeneous (Figure 3b).
5. After the timed exposure, the gel was gently rolled off the painting surface and placed aside on Whatman filter paper for re-application using the other (clean) side.
6. Immediately after application, a clearance step was performed with Nanorestore Gel Peggy 6 uploaded with deionised water and applied for the same exposure time.
7. After removal, the surface was left to air dry for at least 24 hours before proceeding with the cleaning of the next section.
8. Each gel was used once on both sides and placed into a bath of deionised water, which was changed various times. Even though the manufacturer mentions that the gels can be used up to 4–5 times on each side, they were only used once during the cleaning of *Bathers*.

Figure 3c shows an image of *Bathers* with the surface partially cleaned. The difference between the two areas is the yellowish tone on the uncleaned part. In general, the cleaned section has enhanced colour saturation and brightness and greater contrast. In total 30 gels were used to complete the cleaning treatment.

EVALUATION OF THE CLEANING PROCESS USING A MULTI-IMAGING APPROACH

The complexity of the sketch-like painting technique used by Matisse made 'tracking' of the cleaning progress complicated. A set of technical images using a multispectral imaging system were collected before, during and after the treatment to evaluate the cleaning process and to map and avoid over-cleaned areas, as well as uncleaned areas. The use of multi-imaging systems has proved to be a successful tool for assessment and monitoring of conservation treatments on paintings (Fischer and Kakoulli

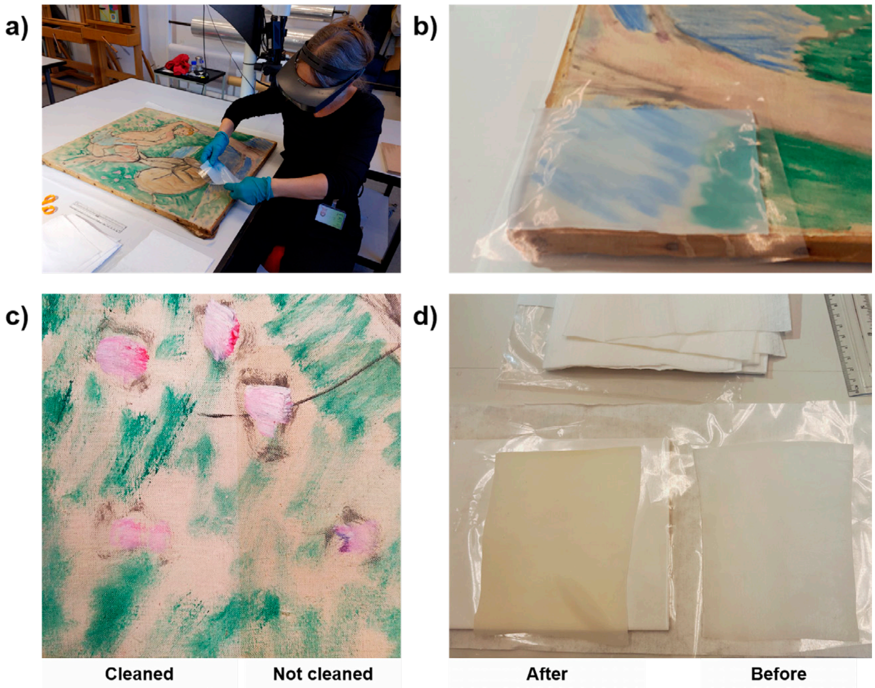

Figure 3. Details of the cleaning procedure and results for the paint layer: (a) application of the Nanorestore Gel Peggy 6; (b) Nanorestore Gel Peggy 6 placed onto the painting surface; (c) the exposed paint layer after the cleaning and clearance procedures; (d) aspect of Nanorestore Gel Peggy 6 after one use and without use. SMK Photo/Annette S. Ortiz Miranda, © Succession H. Matisse/VISDA 2022

2006, Chillè et al. 2020, Brunetti et al. 2022). A set of images including, but not limited to, visible reflected images (VIS-R-VIS), UV-induced visible luminescence (VIS-L-UV) and UV reflected images (UV-R-UV) was included in this study.

Some of the most sensitive pigments identified in the painting were cobalt blue and red lake (cochineal) (Haddad et al. 2022). The VIS-L-UV images were particularly useful to monitor possible changes suffered in the areas coloured with these pigments, since they have a very intense luminescence response. In addition, a yellow-brownish response in VIS-L-UV images was due to the soil deposited on the surface. Therefore, imaging was used as a complementary technique to identify possible traces of this deposit when visual examination under the microscope was not sufficient due to the characteristics of the painting.

As mentioned above, *Bathers* proved to be a complicated painting in many aspects, in particular the artist's priming of the canvas (with a knife or spatula) together with his sketch-like technique. This provided the painting with features that could be easily misread during a cleaning treatment, such as the lines associated with the application of the ground that were only visible by X-ray, the features of the canvas and the loose brushwork. The use of X-ray and UV-R-UV images proved to be invaluable for monitoring gel-based cleaning treatments of unvarnished sketch-like oil paintings (see the yellow lines in Figure 4). Another benefit of using this complementary approach for a conservation cleaning process was the possibility to monitor and track small, uncleaned details (see the red triangle in Figure 4).

Figure 5 shows a combination of VIS-R-VIS, UV-R-UV and VIS-R-VIS images used towards the end to assess the cleaning process by distinguishing

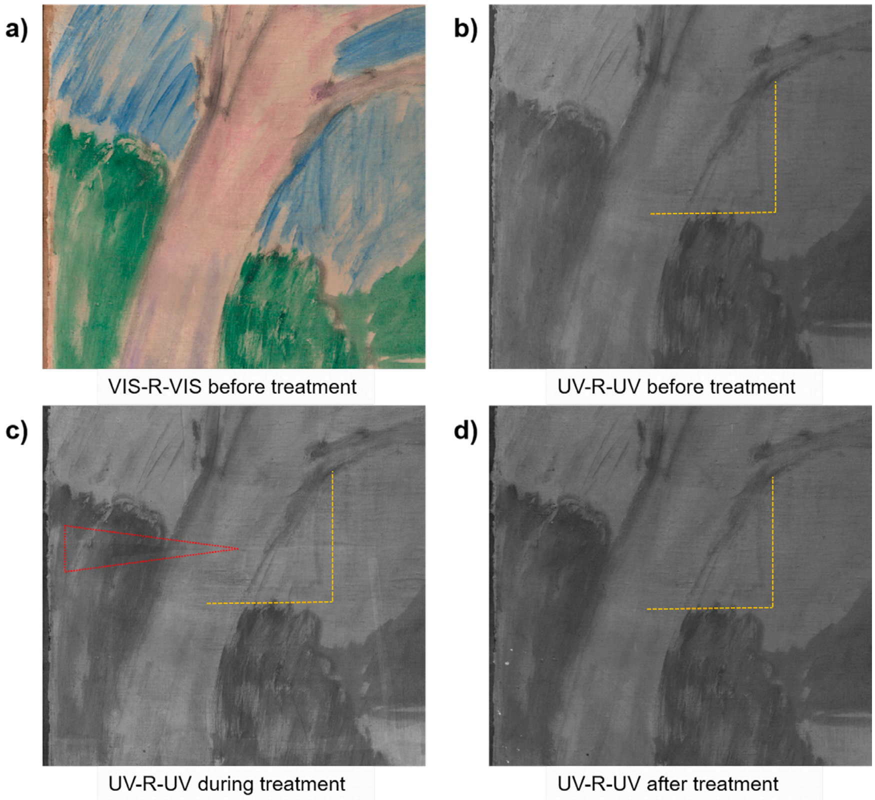

Figure 4. Visible light image detail from *Bathers*: (a) ultraviolet reflectance ultraviolet (UV-R-UV) images (b) before, (c) during and (d) after the cleaning treatment with Nanorestore Gel Peggy 6. Painting features indicated with a yellow box and uncleaned details indicated with a red triangle. SMK Photo/Loa Ludvigsen, © Succession H. Matisse/VISDA 2022

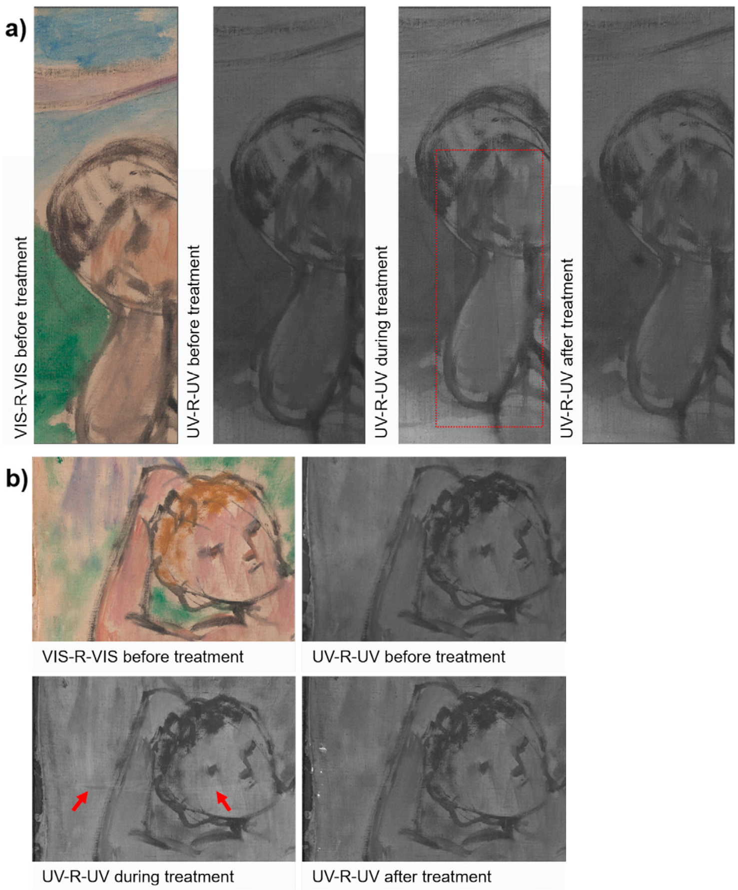

Figure 5. Detail from (a) the male figure and (b) the female figure in *Bathers*. Visible light image and ultraviolet reflectance ultraviolet (UV-R-UV) images from before, during and after the cleaning treatment with Nanorestore Gel Peggy 6. Monitoring of uncleaned details highlighted in red. SMK Photo/Loa Ludvigsen, © Succession H. Matisse/VISDA 2022

features associated with the cleaning process (indicated in red) from those related to the artist's technique. The use of a multispectral imaging system proved to be a powerful means of avoiding over-cleaning. By looking at the images, it was possible to identify and cover the cleaned areas with Melinex while applying nanogel to the areas of interest.

CONCLUSION

This study presents a practice-based multidisciplinary approach to the cleaning of Henri Matisse's iconic sketch-like painting *Bathers* (1907). The two key advantages of this case study were the efficiency of (i) Nanorestore Gel Peggy 6 for removal of the soiling from unvarnished sketch-like oil paintings and (ii) the use of multispectral imaging to assess the cleaning of complex/challenging modern paintings.

Nanorestore Gel Peggy 6 proved to be suitable for the cleaning of abrasion- and water-sensitive painted surfaces with imbedded soiling. However, a slight deformation due to moisture was observed which can be controlled by removing as much of the excess cleaning solution or water as possible and leaving the painting to dry between cleaning steps.

The cleaning of modern unvarnished sketch-like oil paintings can cause substantial and irreversible changes to the surface appearance, and it is critical for conservators and conservation scientists to be able to monitor these changes. The multidisciplinary approach used here was complementary and important in assessing the cleaning treatment used on *Bathers*. UV-R-UV images were found to be a useful complementary monitoring technique for mapping uncleaned details and avoiding over-cleaned areas when visual examination under the microscope was insufficient.

NOTE

[1] Phase One Rainbow Multispectral Imaging Solution for automated multiband and narrowband imaging: https://digitization.phaseone.com/products/complete-solutions/multispectral-imaging/ (accessed on 15 November 2022).

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