INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE
ISSN: 2067-533X Volume 13, Special Issue 1, December 2022: 1623-1634 www.ijcs.ro

MICROFADE LIGHTFASTNESS TESTING ON THE SCREAM VERSIONS IN THE MUNCH MUSEUM COLLECTION

Emma CHAN[1,*], Marthe AAMBØ[2], Tomasz ŁOJEWSKI[3], Inger GRIMSTAD[1], Magdalena UFNALEWSKA-GODZIMIRSKA[1], Irina Crina Anca SANDU[1]

[1] The Munch Museum – Oslo, Norway
[2] National Museum of Denmark – Copenhagen, Denmark
[3] AGH University of Science and Technology – Kraków, Poland

Abstract
A microfading tester (MFT; also refers to microfading testing) was used to examine the light sensitivity of the colors on the eight different versions of The Scream in the MUNCH collection. The results would help in assessing how to meet the educational and exhibition mandates to always having one version of The Scream on display, while at the same time protecting the different version from overexposure. Earlier analytical studies on the museum's painted version, MM.M.00514, published in 2020, identified environmentally induced process of fading involved in the deterioration of the cadmium-sulfide-based yellow paint. However, colorimetric tests on color changes from a given cumulative light exposure had not been undertaken on either colorants or substrate in the various versions. Among the different areas investigated with the MFT, the most sensitive color was a dark red hue found in the sky region on the oil and tempera version (MM.M.00514 (1910?)) as well as on the hand-colored lithographic print (MM.G.00193-03 (1898)), where earlier analyses pointed out the presence of Vermillion. The overarching goal of the present research was, therefore, to optimize the lighting conditions based on the results of the MFT. A balanced rotatable display in exhibition context was introduced in the exhibition according to the different version's sensitivity. As a result, the museum can display artworks safely up to the permissible light exposure in an essential in-house exhibition while simultaneously learning more about their light-related degradation rate.

***Keywords**: Microfading tester; Lightfastness; Museum display; the Scream, Edvard Munch*

Introduction

With the opening of the new Munch Museum (MUNCH) in Bjørvika, Oslo in 2021, the Exhibition and Collection department started developing a comprehensive new plan for the presentation of Munch's artworks. The objective was to fill the exhibition spaces/rooms with more art objects from the museum's own collection. During the planning process, a "Scream room" was presented and the main question was "Can we have a semi-permanent exhibition with one Scream on view at all times?" This question served as the foundation for using the microfading tester, performed on the world-famous motif at the MUNCH in 2019 [1].

Accurate estimates of cumulative light exposure before visible color change were required to assess and limit light-induced damage to the museum artworks on display, especially for *The Scream* versions, which are all on cellulose-based substrates; hence, it was critical to obtain an informed decision about the allowance of light exposure for the exhibition.

The MUNCH has used a set of "rules of thumb" for limiting light exposure on cellulose-based artworks for almost three decades. However, it was required to investigate how much

* Author for correspondence: emma.chan@munchmuseet.no

display light exposure had an impact on the artworks in order to meet new exhibition requirements and the ability to complete new and presumably more challenging display requirements.

The Scream

The MUNCH has eight versions of *The Scream* in its collection. Munch made four, fully colored versions (Fig. 1): in tempera and oil (A), tempera and crayon (B), one pastel drawing (C) and one in crayon (D). Two of these remained in his own possession and are now in the museum's collection: tempera and oil on cardboard (1910?) and crayon on cardboard (1893). The other two are housed by the National Museum in Oslo – a tempera and crayon on unprimed cardboard (1893), and in a private collection – a pastel on unprimed cardboard (1895). Munch also produced monochromatic lithographs of the motif; we estimate around 30 impressions in total, six of these, including one hand-colored, are a part of the museum's collection (Fig. 2).

Fig. 1. Four colored versions of *the Scream*. From left to right:
a. MUNCH, MM.M.00514/Woll 896 (1910?); b. MUNCH, MM.M.00122b/Woll 332 (1893);
c. National Museum, Oslo, NG.M.00939 (1893); d. Version from a private collection (1895)

Fig. 2. a. First row: MM.G.00193-01/Woll G 38 (1895) monochromatic lithograph on wove paper, adhered on secondary cardboard; MM.G.00193-02/Woll 38 (1895); MM.G.00193-03/Woll G 38 (1895) monochromatic lithograph with handcoloring in watercolor; b. Second row: MM.G.00193-04/Woll 38 (1895); MM.G.00193-05/Woll G 38 (1895); RES.B.00143/Woll 38 (1895)

Primary causes of deterioration and previous studies

A significant issue that fines art museums all around the world are currently facing must be addressed by extensive research, such as in the area of: deterioration of priceless impressionist and early modernist masterpieces due to exposure to light for more than a century, which has led to the physical and chemical breakdown and discoloration of the early synthetic pigments in these works.

Light affects the surface appearance of art objects at both material and aesthetic levels. Some coloring materials (pigments, dyes) are weakened by light; some of them may darken, but most of them fade. These color damages are wavelength dependent and involve photochemical processes of the sensitive materials [2]. Understanding how light affects colors and how it affects an artwork's overall appearance will challenge our acceptance of the change in hue and how we, as professionals in the field of conservation and science, and the wider public, will further perceive the artwork. Moreover, the question from a preventive conservation point of view is how to slow down the rate of photochemical degradation.

The Scream has long been the topic of professional debate, both as a concept and as an artwork [3]. What can be perceived as poor artistic technique and material selection, mean faster chemical changes due to natural ageing of these materials as well as changes caused by environmental parameters (temperature, relative humidity, pollution and light exposure). Also known as factors of deterioration of an art object. Lighting is crucial in a museum environment since it is one of many unfavorable factors that can induce long-term, cumulative photodegradation processes. Limiting illumination levels and exposure time is advised in order to properly care for the artworks, allowing for both conservation and display conditions, to fulfill the goals of both preservation and access to the artwork. The color of cellulose-based materials can change significantly when exposed to light due to photodegradation, including yellowing, bleaching, fading, and/or losing their inherent strength. With that background knowledge, a thorough study involving color change and light sensitivity for each of the individual version of *The Scream* has not previously been conducted but is much desirable. Only the tempera and oil version have been previously measured. As a result, we have assumed that the materials in *The Scream* have a high sensitivity to light and have used the minimum of recommended light levels for sensitive materials (with UV filtration).

Colorimetric analysis

Jotun, a Norwegian chemicals company manufacturing decorative paints, conducted in collaboration with MUNCH, colorimetric measurements on the tempera and oil version twice (Fig. 1. version a), in 2008 and 2013. The focus was on the damages inflicted by the 2004 theft, especially in relation to the large moisture stain in the lower left corner. The colorimetric studies then were conducted to see whether the tideline in the cardboard, would gradually fade or change over time. In the five years between 2008 and 2013, the colorimetric analysis concluded that there had been little change in the color and hue at the measured areas [4]. These results are however not considered reliable as the reproducibility of the specific measurement conditions is under question. MFT however, does not necessitate the same degree of consistency and new results can be obtained. It also made it easier in understanding the lightfastness of other areas of the painted surface and of the cardboard.

Mobile Laboratory, MOLAB

In more recent years, MUNCH, in collaboration with international research teams, has particularly researched the degradation of cadmium yellow color layers, which has added new knowledge regarding the fading phenomenon. This phenomenon was first studied in 2013 [5-7] and expanded to other collaborations such as the access to MOLAB infrastructure in 2017 [7, 8] (Fig. 3).

These collaborative studies made on the collective works of *The Scream* aimed to determine the chemical composition of materials by non-destructive analytical techniques. The analysis of the cadmium yellow brushstrokes in the sky and central figure and their causes of fading to off-white gave a new understanding of the color changes of the painted and oil version. This research concluded that moisture is the main cause of the decaying cadmium sulfide pigment; therefore, control of the relative humidity in exhibition setups was recommended.

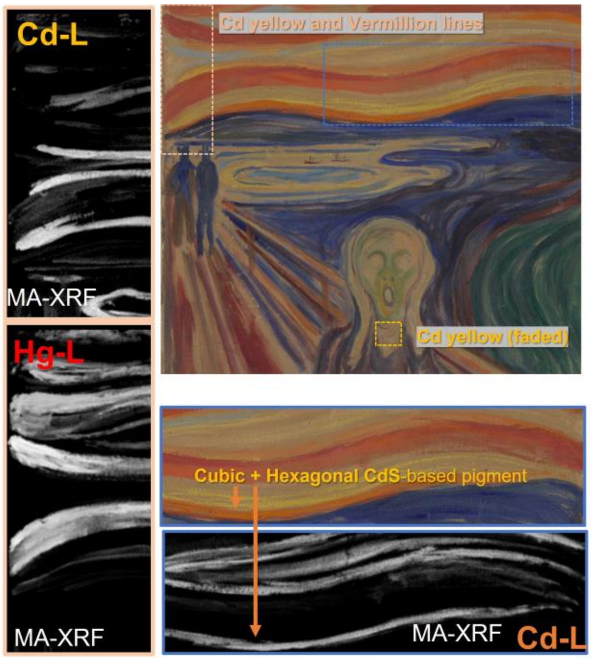

Fig. 3. Image of the Scream (1910?) with areas of fading of Cd yellow (CdS) and identification of other pigments (HgS – Vermillion) using MA-XRF mapping

Microfading tester, MFT

The microfading tester (MFT), developed by *Paul M. Whitmore et al.* [9] was first used in the field of heritage conservation in the middle of the 1990s. While the original MFT setup with a Xenon-arc lamp, newer MFT designs allow a more diverse use of light source and a more user-friendly approach. In recent years, the Polish company Instutyt Fotonowy has produced an automated MFT that was used for the accelerated light ageing in this project. The instrument is equipped with a spectrometer which measures spectra of the light reflected from the measurement point, a testing spot with a radius no greater than 0.5mm. The light source is a high-power white LED, without UV or heat generation, with high CRI and is compatible with the light source chosen in the exhibition (Fig. 4). The light dosage delivers an intensity of 5.00 Mlux or 3.04mW in the spectral range 420-730nm. Colorimetric data for MFT measurements were obtained from reflectance values collected every two seconds of the test, color changes are presented using CIELAB color space and the difference between the original colors for a specified spot to the color resulting from the accelerated light ageing are expressed in ΔE* units.

CIELAB Color space

The CIELAB color space expresses color as three numerical values: L* for lightness, a* for green-red components, and b* for blue-yellow components. The lightness value, L*, respresent the darkest black at L* = 0 and the brightest white at L* = 100. The a* axis represents green in the negative direction and red in the positive direction, and the b* axis represents blue in the negative direction and yellow in the positive direction. The L*a*b* values for two given colors can be measured as the color difference, or ΔE. The calculation of these differences was first introduced in 1976 (ΔE^*_{ab}) and has since then been refined by CIE to new equations in 1994 (ΔE^*_{94}) and 2000 (ΔE^*_{00}). These new ΔE* equations corrects the perceptual nonuniformity, and the ΔE^*_{00} equation is preferred over the ΔE^*_{ab} as it takes the human eye's perceptual sensitivity at different colors into account. Noteworthy is that the human eye's capacity for color perception in small spaces is far lower than that in bigger areas, any color change on the measured spot will be almost impossible to detect by the naked eye. To uphold the preservation target of 1 JNF, ΔE^*_{00} of ~1.5 was set [10].

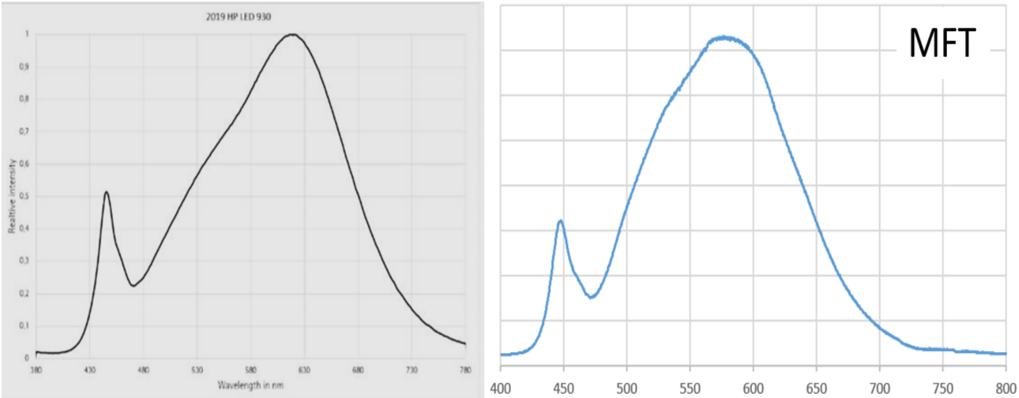

Fig. 4. Spectral power distribution of the lightning source of MUNCH (left) with the light source in the microfading tester (right). Photo @ Tomasz Łowjewski

Blue wool standards

The Blue Wool (BW) Scale is a European standard (ISO 105-B08) [11] used in the textile industry as a standard reference of lightfastness and the criterion is applicable when evaluating the results from the MFT tests. The ISO lightfastness categories can be used to anticipate light damage to colorants and materials of an object. If the tested material present in an object is rated in the BW category of 1, 2 and 3, they are considered highly light sensitive. These three categories are used as an internal standard for comparison to the tested materials. Further, the preservation target was set to 1 Just Noticeable Fading (JNF) obtained in 100 years. A yearly exhibition duration is recommended for each category based on the approximate number of luxhours believed to cause fade of a material.

Prior to the MFT tests at MUNCH, artworks on cellulose-based substrates were treated as having the same lightfastness, a BW2 category. This corresponds to 1.2 Mlxh per century or 12,000 lux-hours annual dosage. Based on the calculation, a single work can be exhibited for 42-hour exposure week with an intensity of 75lux [12]. This “rule of thumb” was applied to the whole paper collection, with few exceptions (such as highly fugitive material and/or ink). As a result, certain artworks would be overexposed, while others too constrained in reference to the preservation aim.

Table 1. Estimated light doses (UV filtered) of high sensitivity items, resulting in 1 JNF in a 100 years perspective for BW1, 2, and 3. Reference of S. Michalski, 1987 [2]

Blue Wool (BW) Standard	Light dose (Mlx-hrs) to cause a JNF of the Blue Wool Standards
BW1	0.3
BW2	1
BW3	3

MFT analysis

Materials

For the eight versions of *The Scream* presented, a total of 45 points of interest were selected, including colorants and substrates (Fig. 5 and Table 2). The results of the MFT measurements reveal the most sensitive colorant or material on the tested artworks and it was used to assign the whole artwork to the nearest Blue Wool category, or Blue Wool Equivalence (BWE).

Table 2. List of *The Scream* versions in the MFT testing, presented by registration number, medium & material and number of testing points

Registration no.	Medium & Material	Number of testing points
MM.M.00514/Woll M 896	Tempera and oil on unprimed cardboard	18
MM.M.00122b/Woll M 332	Colored crayon on unprimed cardboard	6
MM.G.00193-01/Woll G 38	Lithographic printing ink on wove paper, adhered on a secondary cardboard	3
MM.G.00193-02/Woll G 38	Lithographic printing ink on wove paper	2
MM.G.00193-03/Woll G 38	Lithographic printing ink on wove paper with handcoloring in watercolor	10
MM.G.00193-04/Woll G 38	Lithographic printing ink on wove paper	2
MM.G.00193-05/Woll G 38	Lithographic printing ink on wove paper	2
RES.B.00143/Woll G 38	Lithographic printing ink on wove paper	2

Results of MFT testing

As described earlier, MFT results are presented utilizing colorimetric data, collected in real-time, and the color change values, or ΔE*, are presented with the CIELAB color space. For a single point measured on the artwork, the measurement time was 6 minutes (360 seconds), with spectral data collected every other second, in 5.00Mlux of illumination with an LED light source. The measurements were stopped after 6 minutes of testing (corresponding to 0.50Mlux). The progression of the curve is of interest when trying to understand the results. By only viewing the arbitrary endpoint is sometimes not enough for a more precise interpretation of the color changes. The measurement time was selected to give a consistent outcome for all the areas tested, regardless of how the curve advances. The JNF criterion is therefore different for small points as for larger areas or color [13]. Nevertheless, when a material shows indication of being extremely light-sensitive during the MFT test, stopping the test before any noticeable damage is always preferable.

MM.M.00514/Woll M 896

18 points were measured on the oil and tempera version (version a, figure 1) (1910?) shown figure 5.

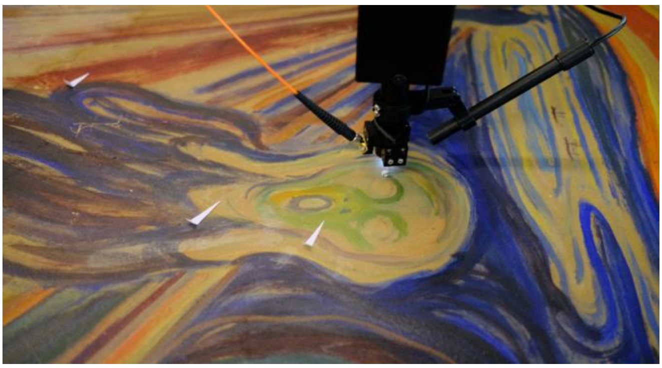

Fig. 5. Detail of MFT measurements on *The Scream*, MM.M.00514/Woll 896 (1910?) (Version a, Fig. 1)

The most reactive color seen in the test was the red colorant in the sky, RedDarkSky1 (identified as containing Vermillion red and gypsum) [14, 15]. The tests show that this color will darken with exposure [16] (Table 3).

For this artwork, most of the colors will darken (negative ΔL* values, indicates darkening). Only the cardboard, especially the scratch and undamaged area tested, will lighten in color. The spots Tideline1, Yellowcadmiumsky, and Bluemattefigure all exhibit no alteration in lightness, hence the 0 ΔL* values. Due to unwanted movement of the microfading tester during testing, the curvature of GreenLightScreamFace has a bump in its reading at approximately the 4-minute mark (Fig. 6).

Table 3. Results of measured color changes for MM.M.00514/Woll M 896 in realtion with BW1-3

Name/Measuring point	ΔL*	Δa*	Δb*	ΔE_{00}*
BlueWoolStandard1	2.6	-0.9	8.2	3
BlueWoolStandard2	1	2.2	4.1	1.9
BlueWoolStandard3	0.6	0.5	1.5	0.8
MMM514: BlueGlossyFigureLeft	-0.2	0.2	-0.6	0.4
MMM514: BlueLightSky	-0.1	0	-0.5	0.5
MMM514: BlueMattFigureLeft	0	0	-0.6	0.3
MMM514: CardboardScratch	0.3	-0.6	-1	0.7
MMM514: CardboardUndamaged	0.2	-0.2	-0.2	0.3
MMM514: GreenDarkArea	-0.1	0.2	-0.1	0.2
MMM514: GreenDarkScreamFace	-0.2	0	-0.4	0.3
MMM514: GreenLightScreamFace	-0.4	0	-1	0.6
MMM514: OrangeRailBottomRight	-0.1	0	-0.4	0.3
MMM514: OrangeRailTop	-0.3	-0.4	-0.7	0.5
MMM514: OrangeSky1	-0.5	-1	-0.7	0.7
MMM514: PurpleBoatLeft	-0.2	0	-0.3	0.2
MMM514: RedDarkBridge1	-0.1	-0.4	-0.5	0.4
MMM514: RedDarkSky1	-0.9	-2.2	-1.3	1.4
MMM514: RedMidSky1	-0.5	-0.6	-0.8	0.6
MMM514: TideLine1	0	-0.1	-0.5	0.3
MMM514: YelloCrayonSky	-0.1	-0.1	-0.2	0.2
MMM514: YellowCadmiumSky	0	-0.2	-0.5	0.3

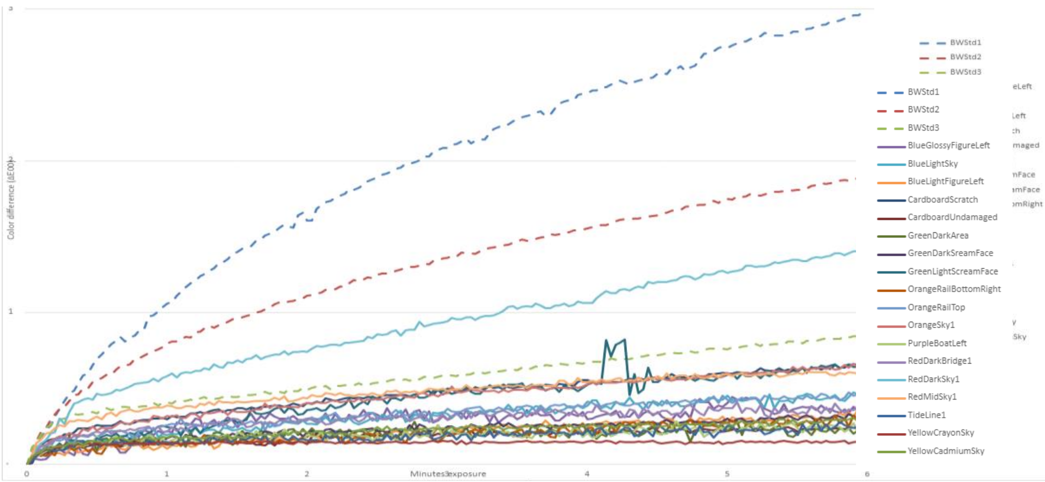

Fig. 6. MFT results of MM.M.00514/Woll M 896. Delta E 2000 graph of 18 testing points in relation with 3 BW-standards.

MM.M.00122b/Woll M 332

Six points were tested on the crayon drawing (version a, Fig.1). It showed little color change during the test. BlueLightSky was the most sensitive point tested, identified as Ultramarin [7, 18], as seen in figure 7 and Table 4.

MM.G.00193-03/Woll G 38

This is the only lithographic print of them all that is hand-colored with gouache and watercolor (Fig. 2, first row). It tested to be the lightest sensitive of all the *Scream* versions. The most light-sensitive areas are the red colorants in the sky, RedBright and RedDark (identified as Vermillion and gypsum and/or Vermillion and lead white [14]). The curves show the reaction is unlikely to cease for a good while and a very reactant colorant. This artwork was given a BW category 1.

All the other monochromatic lithographic prints were more resistant to light exposure and are categorized as BW3 with only the paper substrate of a BW3 equivalence and therefore slightly lighter sensitive than the printing ink (Table 6 and Fig. 9.) A recurrent outcome for the lithographs; is that the primary and secondary paper support have a light sensitivity between BW2 and BW3 which is less sensitive than what was initially predicted.

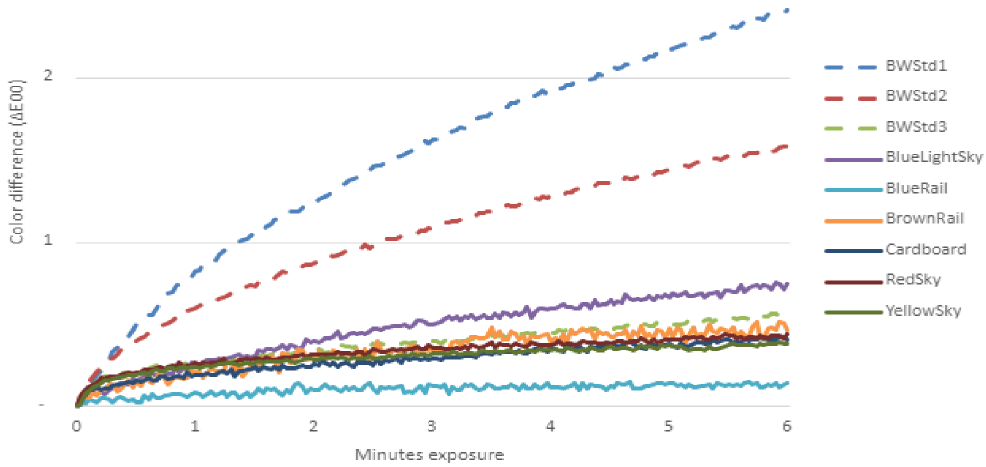

Fig. 7. MFT results of MM.M.00122b/Woll M 332. Delta E2000 graph of six testing points in relation with 3 BW-standards

Table 4. Results of measured color changes for MM.M.00122b/Woll M 332 in relation with BW1-3

Name/Measuring point	ΔL*	Δa*	Δb*	ΔE_{00}*
BlueWoolStandard1	2.6	-0.9	8.2	3
BlueWoolStandard2	1	2.2	4.1	1.9
BlueWoolStandard3	0.6	0.5	1.5	0.8
MMM122B: BlueLightSky	0	-0.2	-0.7	0.7
MMM122B: BlueRail	-0.1	-0.1	-0.2	0.1
MMM122B: BrownRail	-0.1	0	-0.5	0.5
MMM122B: Cardboard	0.1	-0.3	-0.6	0.4
MMM122B: RedSky	-0.1	-0.6	-0.6	0.4
MMM122B: YellowSky	-0.2	-0.3	-0.8	0.4

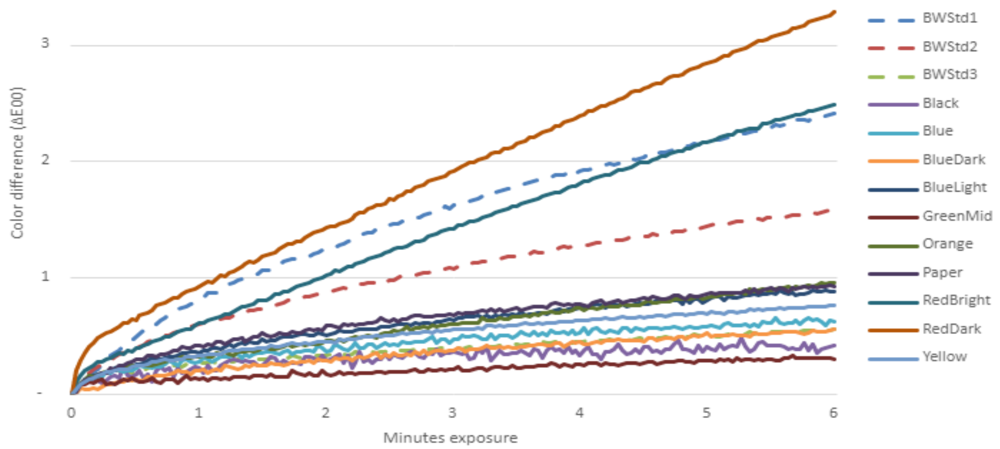

Fig. 8. MFT results of MM.G.00193-03/Woll G 38. Delta E2000 graph of 10 testing points in relation with 3 BW-standards

Table 5. Results of measured color changes for MM.G.00193-03/Woll G 38 in relation with BW1-3.

Name/Measuring point	ΔL*	Δa*	Δb*	ΔE_{00}*
BlueWoolStandard1	2.6	-0.9	8.2	3
BlueWoolStandard2	1	2.2	4.1	1.9
BlueWoolStandard3	0.6	0.5	1.5	0.8
MMG1933: Black	0	0	-0.4	0.4
MMG1933: Blue	0	0	-0.7	0.6
MMG1933: BlueDark	0.3	-0.2	-0.8	0.6
MMG1933: BlueLight	-0.1	-0.1	-1.2	0.9
MMG1933: GreenMid	0.2	0.2	-0.2	0.3
MMG1933: Orange	-0.6	-1.2	-1.5	1
MMG1933: Paper	-0.2	-0.1	-1.3	1
MMG1933: RedBright	-1.9	-4.6	-3.5	2.5
MMG1933: RedDark	-2.5	-6.2	-4.5	3.3
MMG1933: Yellow	-0.4	-0.4	-1.7	0.8

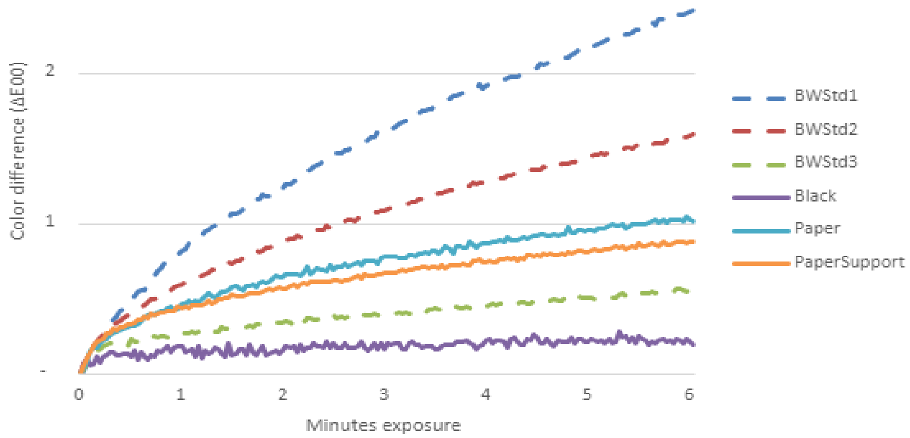

Fig. 9. MFT results of MM.G.00193-01/Woll G 38. Delta E2000 graph of three testing points in relation with 3 BW-standards

Table 6. Overview of *the Scream* results in Blue Wool Equivalence (BWE) and allocated light dosage

Registration no.	BWE	Total light dose allocated (lux-hours annually)
MM.M.00514 / Woll M 896	2/3	18.000
MM.M.00122b / Woll M 332	3	30.000
MM.G.00193-01 / Woll G 38	3	30.000
MM.G.00193-02 / Woll G 38	3	30.000
MM.G.00193-03 / Woll G 38	1	3.000
MM.G.00193-04 / Woll G 38	3	30.000
MM.G.00193-05 / Woll G 38	3	30.000
RES.B.00143 / Woll G 38	3	30.000

The results of the MFT tests serve as a key determinant of whether color changes will take place under given scenarios with light exposure. The cardboards and paper substrates, which have been the longstanding main concern for light exposure, unexpectedly, proved to be more stable (BWE 2-3) than anticipated, see table 6. However, the effect of light on the deterioration of paper should not be underestimated and the amount of visible light should still be controlled. The already faded cadmium yellow does not appear to change much more with further exposure. With exposure, the vermillion red will darken [1, 15].

The Scream rooms

Most of the curves were easily appointed with a BWE category; however, the tempera and oil version (version a, Fig. 1) had a curve between BW2/BW3. Given that the allocated lux-hours between BW2 and BW3 are not standardised, the allocated annual dosage of this version was instead set by an interdisciplinary workgroup for an annual light exposure of 18.000 lux-hours in order to facilitate the rotational schedule. The hand-colored lithographic print (Fig. 2, first row) is taken completely out of the loop due to its results allowing 3.000 lux-hours which would not facilitate the rotational schedule. The remaining versions, crayon and black/white lithographic prints are in the BW3 category and can be allowed 30.000 lux-hours annually. The museum put the MFT findings into practice in *The Scream* room, which is a part of the semi-permanent exhibition *Infinite.* It has four walls and three showcases with automatic doors housing three installations of *The Scream*. The key rule that was set in terms of practical implementation was taking into account light exposure during hours of operation of a total of 25 lux/hour; that during the course of a day, one lithograph, the crayon drawing, and the oil and tempera version are on view for one hour at a time. The lithographs can be shown the most and as much as up to 7 hours a day as they also are shifted after 5 months* (*allowed time limit of the prints on display are continously altered with new and updated opening hours). The drawing is exhibited 3 hours per day and the tempera and oil version only 2 hours per day. Outside of these hours, the artworks are in complete darkness.

Fig. 10. *The Scream* rooms. Picture showing all three show cases open. Photo @ MUNCH

Discussion of MFT results

With this research, the various versions could be assessed and presented in a predetermined order according to a rotational schedule. Light-induced damage was identified and the preservation aim was upheld by understanding how lightfast all the 8 versions of *The Scream* are. The information obtained from the MFT testing, helped in establishing *The Scream* room's requirements. With customized showcases, it is possible to cautiously, but better, facilitate appropriate light conditions for the exhibition display based on the artworks different degree of light sensitivity. *The Scream* room allows the artworks to be integrated into the exhibition as a whole, as part of a kaleidoscope that maintains its integrity without compromising its condition and by defining the contextualization of the versions. With it, we also maintain the values and principles in conservation goals and purposes, which is presented on the fourth wall inside the room. Hourly rotation according to the results, allows a creative and suitable exhibition for three *Scream* versions available throughout a day, while providing more confidence in exposure time and dosage and in-house dissemination. The BW-scales are a simple approach to show how much color change is brought on by exposure, but it is never easy to evaluate a truly correct color change. However, in the majority of cases, the general correlation between the colorant's sensitivity and the BW standard's scale will be sufficient to allow for a well-informed decision.

Additionally, MFT can be included in the museum’s guidelines and the way data is validated. That entails updating the current light policy, putting it into practice for collection management, and integrating it into the database of the museum. It establishes rules for its acceptance of exhibition display and awareness of any future damages. With MFT as a screening tool, the light sensitivity levels of the collection can be updated for subsequent uses of it without having to rely on estimates. Through more research on the degradation and deterioration processes, MFT measurements will aid in both display and preservation. It also simplifies other arrangements and loan agreements for these high-demand works of art.

Conclusions

Whether MUNCH will continue displays of permanent or semi/permanent exhibitions or not, we are at present better equipped, and in an ingenious way, to administer our own collections. The MFT analysis, and rotational display of the Screams, has provided valuable insight, knowledge, and facilitating the inclusion of these coveted artworks by presenting them in a new way and allowing for longterm display. This new approach has resolved what seemed an impossible task and enabled new ways of bringing a collection to life, allowing visitors to make new discoveries.

In conclusion, this research provides museum proffesionals, and art enthusiasts, with knowledge on the light sensitivity in general, and vital to one of Edvard Munch's most well-known work of art. Following the MFT analysis and the presentation of its results, the entire organization in the MUNCH has become more aware of the negative effects of exhibition light. Based on the facts in the analysis, it has also proven easier to reach a common understanding at all levels for the necessity to limit light exposure to our most vunerable works of art.

Acknowledgments

The authors would like to thank Mathis Junker Gran, project manager for the exhibition *Infinite* at MUNCH and Manthey Kula Architects that helped to make *the Scream* room possible.

References

[1] T. Łojewski, *Report on Lightfastness Tests Performed for Objects from the Munch Museet on September 16-21, 2019*, **Internal Report**, The Munch Museum, 2019.

[2] S.W. Michalski, *Damage to Museum Objects by Visible Radiation (Light) and Ultraviolet Radiation (UV)*, **Lighting in Museums, Galleries and Historic Houses**, Museums Association, UKIC, and Group of Designers and Interpreters for Museums, London, 1987, pp. 3-16.

[3] U. Plahter, B. Topolova-Casadiego, *The Scream by Edvard Munch: painting techniques and coloring materials*, **Studying Old Masters Paintings**, (Red. M. Spring), The National Gallery Technical Bulletin, 2008, pp. 244–252.

[4] L. Christiansen, B. Holtan, *Colorimetric Measurements on Scream in 2008 and 2013*, **Internal Report**, Jotun, 2014.

[5] J. Mass, B. Buckley, D. Carson, J. Church, M. Cotte, J. Delaney, I. Grimstad, C. Hirschmugl, A. Mehta, R. Opila, C. Patterson, *Cadmium yellow degradation mechanism in Henri Matisse`s Le Bonheur de Vivre (1905–6) compared to the Munch Museum The Scream (1910) using chemical speciation as function of depth*, **Proceedings from the Munch150 Conference,** Munchmuseet og Universitetet i Oslo, 2013.

[6] J. Mass, E. Uffelman, B. Buckley, I. Grimstad, A. Vila, J. Wadum, V. Andrews, L. Burns, S. Florescu, A. Hull, *Portable X-ray Fluorescence and Infrared Fluorescence Imaging Studies of Cadmium Yellow Alteration in Paintings by Edvard Munch and Henri Matisse in Oslo, Copenhagen, and San Francisco*, **The Noninvasive Analysis of Painted Surfaces Scientific Impact and Conservation Practice,** (Editors: A. Nevin and T. Doherty), Smithsonian Contributions to Museum Conservation, no 5, Smithsonian Institution Scholarly Press, 2016, pp.53-65.

[7] L. Monico, L. Cartechini, F. Rosi, A. Chieli, C. Grazia, S. De Meyer, G. Nuyts, F. Vanmeert, K. Janseens, M. Cotte, W. De Nolf, G. Falkenberg, I.C.A. Sandu, E. S. Tveit, J. Mass, R. Pereia De Freitas, A. Romani, C. Milani, *Probing the chemistry of CdS paints in The Scream by in situ noninvasive spectroscopies and synchrotron radiation x-ray techniques*, **Science Advances**, **6**(20), 2020, Article Number: eaay3514. DOI: 10.1126/sciadv.aay3514.

[8] L. Cartechini, I.C.A. Sandu, F. Rosi, C. Grazia, L. Monico, A. Romani, R. Pereira De Freitas, M. Godzimirska, E. Chan, G. Landro, E. S. Tveit, P. Pettersen, C. Miliani, *The "Scream" by Edvard Munch (1910?): Non-invasive integrated spectroscopic investigations of the painting materials*, **MA-XRF Scanning in Conservation and Archeology**, Catania, October 15-16, 2019 (poster).

[9] P.M. Whitmore, X. Pan, C. Bailie, *Predicting the Fading of Objects: Identification of Fugitive Colorants through Direct Nondestructive Lightfastness Measurements*, **Journal of the American Institute for Conservation**, **38**(3), pp. 395-409 (Autumn - Winter, 1999).

[10] B. Ford, J. Druzik, *Microfading: The State of the Art for Natural History Collections*, **Collection Forum, 27**(1-2), 2013, pp. 54-71

[11] *** *,** *Textiles — Tests for colour fastness — Part B08: Quality control of blue wool reference materials 1 to 7,* **International Standard ISO 105-B08: 1995,** 1995.

[12] K.M. Colby, *A Suggested Exhibition/Exposure Policy for Work of Art on Paper*, **Journal of the International Institute for Conservation – Canadian Group**, **17**, 1992, pp. 3-11. www.lightresource.com/policy1.html.

[13] E. Chan, M. Aambø, M. Godzimirska, I. Grimstad, T. Lojewski, I.C.A. Sandu, *Light-induced color changes on "The Scream" versions in the Munch Museum collection*, **First MUNCH2022 International Conference, Book of Abstracts,** 21st-23rd March 2022 (oral communication), 2022.

[14] B. Singer, T. Aslaksby, B. Topalova-Casadiego, E. Storevik Tveit, *Investigation of Materials Used by Edvard Munch*, **Studies in Conservation, 55,** 2010, pp.274-292.

[15] U. Plahter, L.E. Plahter, *Munch's paintings: scientific research both recent and in retrospect*, **Public Paintings by Edvard Munch and His Contemporaries - Change and Conservation Challenges**, Archeype Publications, 2015, pp. 3-35.

[16] R.L. Feller, *Studies on the darkening of Vermillion by Light***, Report and Studies in the History of Art**, Vol.1, National Gallery of Art, Washington, 1967, pp. 99-111.

[17] I.C.A. Sandu, T. Ford, C. Miliani, K. Janssens, G. Van Der Snickt, J. Striova, M. Raffaelli, R. Fontana, L. Cartechini, F. Rosi, A. Romani, L. Monico, C. Grazia, R. Pereira De Freitas, A. Tournie, C. Andraud, V. Detalle, E. Bourguignon, K. Laclavetine, F. Mirambet, S. George, J.-Y Hardeberg, M. Ufnalewska-Godzimirska, G. Landro, E. Storevik Tveit, P. Pettersen, *The "Scream" by Edvard Munch - same motif, different colours, different techniques and approaches – a novel non-invasive comparative study of two of its versions,* **CHEM-CH Conference**, 3rd-7th July 2018, Bucharest (oral presentation).

[18] B.D.A. Levin, K.X. Nguyen, M.E. Holtz, M.B. Wiggins, M.G. Thomas, E.S. Tveit, J.L. Mass, R. Opila, T. Beebe, D.A. Muller, *Detection of CdS Nanoparticles and Implications for Cadmium Yellow Paint Degradation in Edvard Munch's* The Scream *(c. 1910, Munch Museum)*, **Microscopy and Microanalysis**, **23**(S1), 2017, pp. 1910–1911, DOI: 10.1017/S1431927617010212.

Received: August 19, 2022
Accepted: December 17, 2022