The visual perception of artworks
at the National Museum of San Matteo (Pisa, Italy)

Zumtobel Research

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Short summary

This study aimed to investigate how different light sources, their particular settings and the contrast they create between the artworks on display and their backgrounds affect the visual perception of art and space and visitor preference when it comes to lighting arrangements. The study involved a psychophysical experiment that was performed in two exhibition rooms at the National Museum of San Matteo in Pisa (Italy), using two artworks from its permanent collection, namely a panel painting and a marble sculpture. The experiment was carried out by 55 people, who were asked to assess and evaluate different lighting configurations for the two artworks and compare them in terms of contrast, enhancement of the characteristics of the artworks and, finally, personal preference.

The purpose of the study was to find out whether there are correlations between the three aforementioned parameters and, especially, whether contrast and enhancement have a tangible effect on personal preference. The final goal was to identify and define lighting configurations that offer the best impression of the artworks, in terms of both faithfulness to the original message of the artist and enjoyment of the exhibition for visitors to the museum. In addition, the experiment was designed to investigate whether viewers prefer lighting configurations that enhance the artworks or whether personal preference is actually driven by other factors, such as individual feelings and specific messages communicated by the artworks.

The experiment involved various lighting configurations: three traditional configurations, created using spotlights and wallwashers with warm light, and one configuration made by mixing smaller spotlights with different CCTs, which tested the so-called Monza Method. ARCOS LED expert spotlights, ARCOS wallwashers and SUPERSYSTEM II spotlights were installed to realise the multiple lighting configurations, which featured combinations of the various luminaires and different settings, optics and lenses.

The study found that observers generally preferred more neutral configurations, which created an intermediate contrast ratio between the exhibits and their backgrounds. Furthermore, the lighting solutions that were described as relaxing and simple were rated as the most pleasant and interesting, while more uniform scenarios were seen as being boring and not suitable for the enhancement of the artworks.

1. Museum lighting and visual perception

Museums are now regarded as participative institutions and social spaces. They represent a focal point for the cultural urban scenario and a meeting place for society, as people go there to spend their spare time, stroll around and meet friends. The buildings themselves therefore often represent crucial urban landmarks. However, as several statistical reports show, a very small number of individuals actually visit museums because of their passion for art or architecture, as most people are happy to simply go and think about the artworks. There are numerous surveys about the interaction between museum visitors and exhibits. This research has found that the average viewer goes up to an artwork, looks at it for less than two seconds, reads the wall text for another 10 seconds, glances back at the painting and then moves on. For this reason, many museums are developing eye-catching exhibitions that are easier to understand with the specific aim of attracting more visitors and encouraging these people to really focus on and enjoy the displays. The main goal of museums is often therefore to provide an improved visual experience that blends aesthetic stimulation with clear and simple communication of the artistic message.

This objective can be achieved by carefully designing the lighting for the route through the exhibition. Much of the current research about museum lighting focuses on the visual perception and preferences of the visitors, in order to generate lighting solutions that can mould the aesthetic impression of the artworks and create the best possible visual experience for visitors. Architectural and lighting parameters have a significant impact on the visual perception of art exhibitions and can really support the optimal enhancement of individual works. Several different types of luminaires can be used for museum exhibitions – individual or multiple spotlights, light lines or wallwashers – and each one can be combined with different reflectors, lenses, glare rings or accessories to shape and control the light output. Furthermore, the selection and configuration of the appropriate luminaires – as well as a combination of different light sources – represent a crucial step when it comes to designing art exhibitions, because different layouts can generate different lighting effects – firstly for the artworks and secondly for the overall exhibition space. The lighting arrangement creates a defined relationship between the exhibits, the background and the surrounding exhibition space, depending on the purpose of the exhibition and the feelings that it should stimulate. For example, a wide beam or a wallwasher will illuminate the background as well as the work of art, creating a more uniform lighting scenario, while smaller and narrower light beams may focus purely on the surface of the artwork, leaving the background largely in the dark.

In conclusion, the same artwork can be illuminated in many different ways, depending on the dimensions of the light beams and their setting, direction and shape.

Museo del Duomo - Milan, Italy

Städel Museum - Frankfurt, Germany

Alongside these factors, the Correlated Colour Temperature (CCT) of the light sources has an important influence on individual colour perception and the visual impressions of artworks. Warmer light sources were traditionally used for museum lighting, as tungsten sources tended to take preference before the development of solid-state lighting (SSL). LEDs offer many advantages for art exhibitions: higher luminous efficacy, minimal IR and UV radiation (which enables improved conservation of the exhibits) and, crucially, tunability of the spectrum. Thanks to this tunability, it is possible to design the spectrum of the light sources and obtain exactly the required CCT. Many researchers are investigating the effect of CCT on the visual and colour appearance of artworks displayed in museum settings, along with the impact of the illuminance level and the colour rendering, in order to individually realise the best lighting solutions for visitors. Following tests in controlled museum environments, several studies have found that more neutral CCTs (4000 K – 5700 K) represent the most preferable lighting arrangements for the presentation of paintings. Francesco Iannone and Serena Tellini from Consuline Architetti Associati in Milan recently developed an interesting new approach. The so-called Monza Method consists of creating dynamic lighting using LEDs with different CCTs and mixing them on the surface of the artwork, depending on the colours and details of the particular piece. This method is designed to provide a more vibrant three-dimensional visual effect, which in turn can communicate the true meaning of the art more effectively.

In conclusion, light shapes the visitor experience in a museum by actively influencing how people enjoy and understand both the works of art and the core message of the artist. High visual quality, glare control, accurate colour rendition, light chromaticity and the appropriate luminance contrast between the surroundings and the exhibits are all ways of ensuring a proper lighting microclimate for every piece of art, taking into account its specific history, sensitivity and interpretation.

2. The National Museum of San Matteo (Pisa, Italy)

The experiment was conducted at the National Museum of San Matteo in Pisa (Italy). The museum is located in the medieval monastery of San Matteo, which has housed the collections since 1949. The exhibition halls are arranged around the old courtyard of the monastery on the first floor of the building, while the museum entrance museum overlooks the Arno river. The museum contains one of the most important collections of medieval paintings and sculptures in Europe, featuring works by leading Italian artists from between the 11th century and the 13th century.

The layout of the exhibition was renewed during the 1970s, when the collection was organised by period and type of work, giving each room a particular theme. The design of the museum does not make visitors follow a defined path and there is no real chronological order to the exhibits. The original lighting design was realised using halogen spotlights set on tracks fixed to the ceiling. This meant that the exhibition was illuminated with warm light, which was perfect to enhance the colours of the paintings – especially the many gold-ground paintings. A series of LED spotlights were installed more recently in the exhibition hall displaying the various Renaissance paintings.

2.1 Selected artworks

The experiments were carried out on two different artworks (one two-dimensional and one three-dimensional piece): the Sacra Conversazione by Domenico Ghirlandaio and the Madonna del Latte by Nino Pisano and Andrea Pisano. The Sacra Conversazione (1479) is a panel painting on show alongside the Renaissance Paintings ("Low sensitivity" category, Appendix B), while the Madonna del Latte is a marble sculpture decorated with gildings ("Irresponsive" category, Appendix B) displayed amongst sculptures from the Spina Church.

2.2 Experiment setup

The experiment setup was realised using an aluminium structure made of two tripod stands and two horizontal elements. The structure measured 3.2 metres in length and enabled a height of between 1.6 and 3 metres to be individually selected. Various interchangeable luminaire configurations could be mounted on luminaires tracks, which were fitted to the horizontal elements. At the same time, the length of the structure enabled luminaires to be fixed at the extremities of the tracks, creating either lateral lighting or a combination of lateral and frontal illumination.

National Museum of San Matteo (Pisa, Italy)
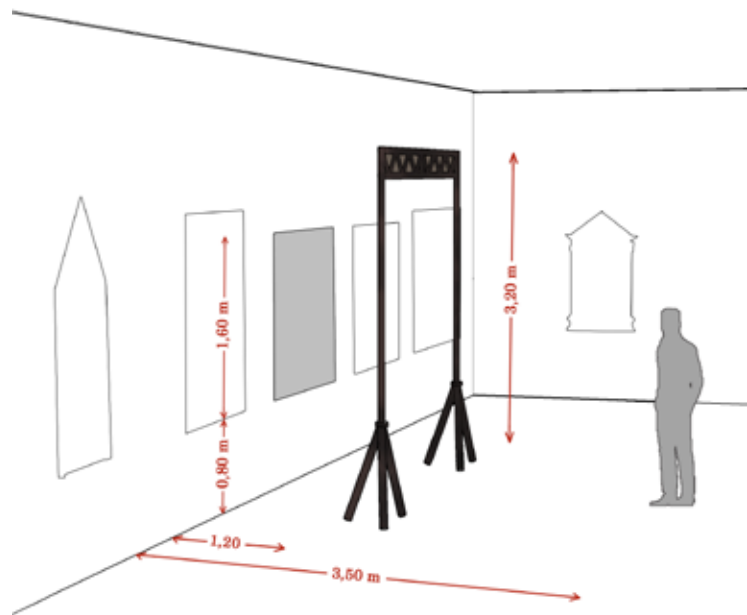Exhibition room 9 - Renaissance Paintings

National Museum of San Matteo (Pisa, Italy)
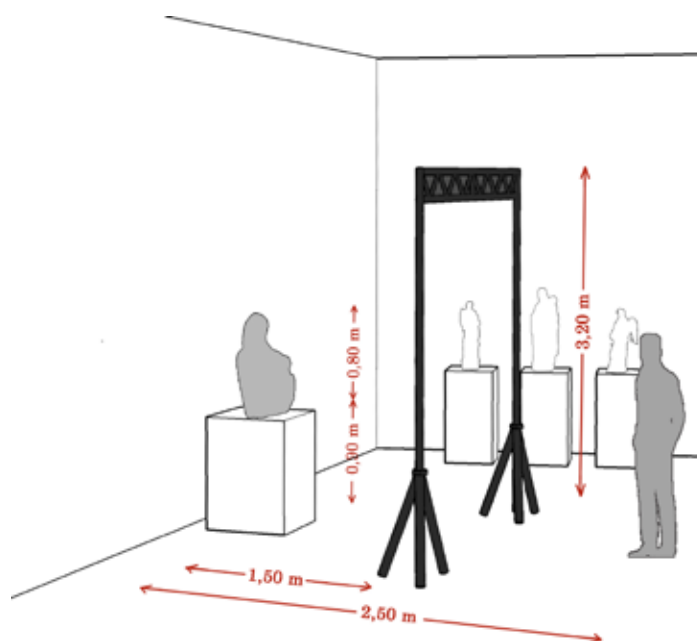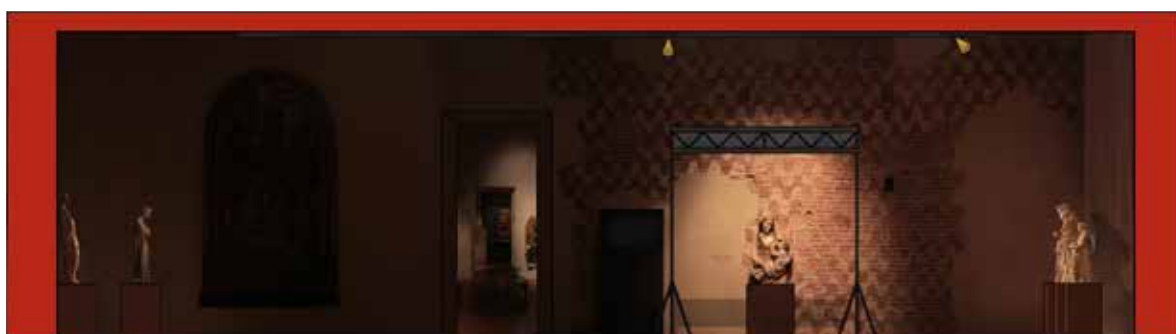Exhibition room 9 - Sacra Conversazione (1479)

National Museum of San Matteo (Pisa, Italy)
Exhibition room 6 - Sculptures from the Spina Church

National Museum of San Matteo (Pisa, Italy)
Exhibition room 6 - Madonna del Latte (1343-1347)

3. Zumtobel luminaires

The lighting solutions used for the experiment were three Zumtobel luminaires designed specifically for museum projects. The three types of luminaires were:

- SUPERSYSTEM II spotlights (Mini, Midi and Maxi);
- ARCOS LED expert spotlights (ARCOS 2 and ARCOS 3);
- ARCOS wallwasher.

Various optics (Superspot, Spot, Flood and Wideflood) and lenses were used for the spotlights
to generate specific lighting effects, beam shapes and dimension for the artworks. All the light sources featured a Colour Rendering Index (Ra) rating higher than 92 and were free form IR and UV radiation, helping to stop colours from fading.

The SUPERSYSTEM II luminaires selected for the experiment had a Correlated Colour Temperature (CCT) of 3000 K and 4000 K, while the ARCOS luminaires had a CCT of 3000 K.

3.1 Measurements

The luminaires used for the experiments were measured with a Konica Minolta Luminance spectrophotometer CL-500A. The spectrum, the CCT, the chromatic coordinates, and the Colour Rendering Index (Ra) were measured for each light source.

Main features of the SUPERSYSTEM II spotlights

	Mini	Midi	Maxi
Size (mm)	26	45	65
Luminous Flux (lm)	350	550	900
RA	>92		
CCT (K)	2700 – 3000 – 4000		
Super Spot - Beam	10°	8°	8°
Spot - Beam	20°	20°	13°-18°
Flood - Beam	32°	34°	29°
Wide Flood - Beam	57°	57°	54°

Main features of the ARCOS luminaires

	2 LED expert	3 LED expert	Wallwasher
Size (mm)	100	120	320
Luminous Flux (lm)	850	2000	1000
RA	98	98	>90
CCT (K)	3000 – 4000		
Super Spot - Beam	8°-10°	8°-10°	-
Spot - Beam	11°-15°	11°-15°	-
Flood - Beam	22°-30°	22°-30°	-
Wide Flood - Beam	32°-40°	32°-40°	-

Measured features of the ARCOS and SUPERSYSTEM II luminaires

	CCT (K)	RA	x	y	u'	v'
SupersystemII Mini 3000 K	3009	92	0,44	0,42	0,25	0,53
SupersystemII Mini 4000 K	3963	91	0,38	0,38	0,22	0,50
SupersystemII Midi 3000 K	2963	93	0,44	0,41	0,25	0,52
ARCOS LED 3 expert 3000 K	3100	97	0,43	0,40	0,25	0,52
ARCOS LED 2 expert 3000 K	3019	95	0,44	0,40	0,25	0,52
ARCOS Wallwasher 3000 K	3174	87	0,42	0,40	0,25	0,52

SUPERSYSTEM II spotlights
(Mini, Midi and Maxi)

ARCOS wallwasher

ARCOS 2/3 LED expert

4. Lighting settings

Two sets of two lighting configurations were designed for each artwork, making a total of four different configurations for both the painting and the sculpture. When it came to the painting, the lighting was optimised to enhance the colours, the details and the figures of the artwork, so configurations with one or multiple light sources were arranged to create different lighting effects on the surface. The sculpture, on the other hand, needed lights and shadows to be created on the artwork itself, helping to make the shapes, volumes and details of the exhibit more visible and more attractive. In both cases, the different configurations were carefully planned to create different contrast ratios between the exhibits and the background, as well as a range of lit effects.

It was agreed that four lighting configurations for each artwork struck the right balance between showing different scenarios and not overwhelming test participants with too many lighting scenes. The various luminaires were tested and Dialux simulations were made to identify the fittings and optics that were suited to the particular works. In contrast, the specific lenses were chosen directly in the experiment room before the start of the tests. The rendering of the marble and its golden decorations made Dialux simulations for the sculpture somewhat difficult to perform, so a number of initial tests were conducted on the statue in the experiment room.

The illuminance and luminance levels of the eight test configurations and the two existing lighting configurations in the museum were measured using a Delta OHM luxmeter and a Hagner S4 luminancemeter. Several measurements points were selected on the artworks and their background. In addition, the presence of UV radiation was checked with another Delta OHM probe.

After measuring the luminance and illuminance level on various points of the artworks and their backgrounds, the average illuminance and luminance values were calculated for the artworks and their backgrounds to help work out the contrast ratios and identify any changes in contrast between the various configurations. Furthermore, the average illuminance values were compared with the limitations of the current legislation, in terms of both maximum illuminance level and the annual luminous exposure allowed for museum lighting. Based on 2018, the National Museum of San Matteo is usually open to the public 306 days per year for 11.5 hours (5 hours on public holidays). This represents a total of 3130 hours per year.

4.1 Lighting settings for the Sacra Conversazione

Configuration 1 – for the Sacra Conversazione was realised using three SUPERSYSTEM II mini spotlights (two with a CCT of 3000 K and one with a CCT of 4000 K). This combination was used to test the Monza Method and create a more vibrant lighting effect on the painting, using sources with a different CCT focused on specific areas of the painting. The two spotlights with a CCT of 3000 K were directed on two areas around the faces of the five figures, while the spotlight with a cooler CCT was directed on the areas with cooler colours, like the blue dress worn by the Madonna. The Superspot optic was specified for the 4000 K spotlights and the Spot optic was used on the two 3000 K spotlights. The measured UV radiation was equal to 0.2×10^{-3} W/m².

Configuration 2 – was achieved with two SUPERSYSTEM II midi spotlights (3000 K), set laterally in relation to the painting. This configuration was more traditional, as the whole painting was uniformly illuminated and there were no accents on specific areas. A Flood optic was used for both luminaires to cover the whole surface of the painting. The measured UV radiation was equal to 0.1×10^{-3} W/m².

Configuration 3 – consisted of an ARCOS 3 LED expert spotlight (3000 K). A Wideflood optic and a diffuser lens were chosen to maximise the beam dimensions and illuminate the whole painting. However, the configuration featured more accent lighting on the Madonna and the child than on the other figures. The measured UV radiation was equal to 0.2×10^{-3} W/m².

Configuration 4 – was made up of an ARCOS 2 LED expert spotlight (3000 K) and an ARCOS wallwasher (3000 K). The wallwasher was set frontally in relation to the painting, while the spotlight, positioned immediately next to the wallwasher, was slightly tilted to highlight the face of the Madonna. In this way, the configuration created uniform lighting for the painting with an accent spot on the faces of the Madonna and the child. A Superspot optic and an opaque lens were chosen for this configuration. The measured UV radiation was equal to 0 W/m².

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Settings of the luminaires on the support structure for the Sacra Conversazione:
Configurations 1 (a), Configuration 2 (b), Configuration 3 (c) and Configuration 4 (d)
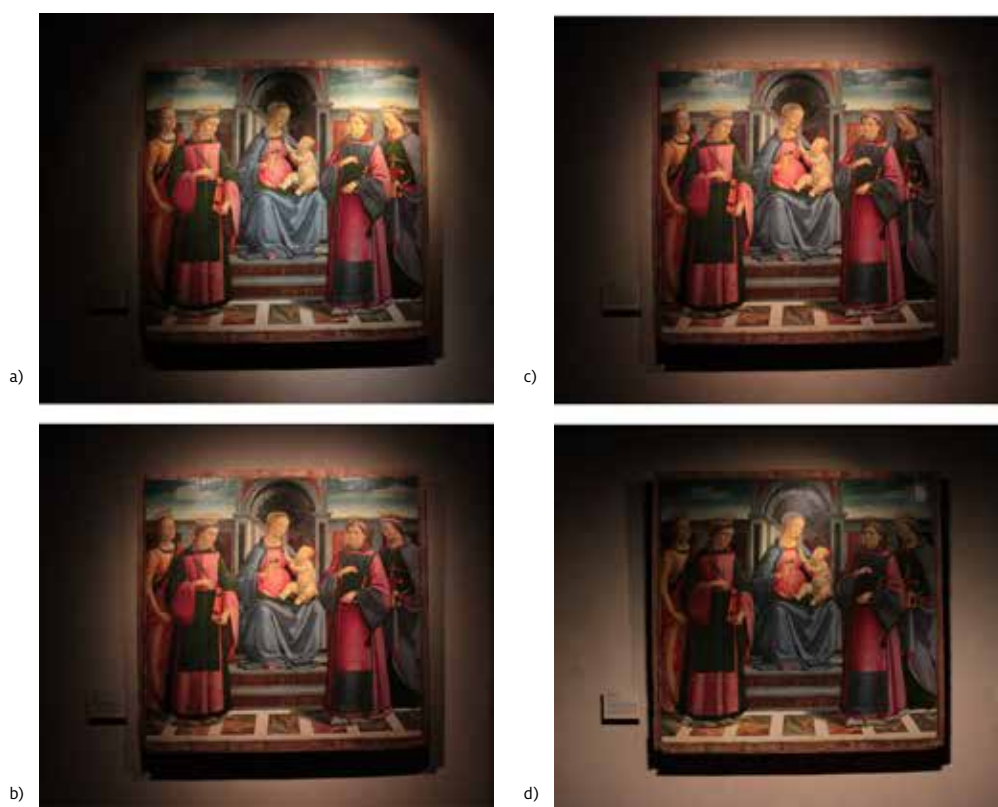
Appearance of the Sacra Conversazione under the four test lighting:
Configuration 1 (a), Configuration 2 (b), Configuration 3 (c) and Configuration 4 (d).

Measurement points selected on the Sacra Conversazione

Illuminance levels (lx) measured on the painting for all four test lighting configurations

Measurement Points	E (lx) - Config. 1	E (lx) - Config. 2	E (lx) - Config. 3	E (lx) - Config. 4
1	90	77	29	27
2	125	182	524	266
3	247	74	57	30
4	120	95	81	75
5	16	25	16	63
6	41	35	42	66
7	7	8	8	22
8	22	23	23	55

Annual luminous exposure calculated for all four test lighting configurations

|	Config. 1	Config. 2	Config. 3	Config. 4
Annual luminous exposure (lx*hours/year)	334.910	253.530	391.250	275.440

4.2 Lighting settings for the Madonna del Latte

Configuration 1 – for the Madonna del Latte was realised using two SUPERSYSTEM II mini spotlights, with a CCT of 3000 K. One of the spotlights was directed towards the face of the Madonna, while the other was pointed towards the body of the child. This first configuration was therefore traditional, designed by directing the two spotlights onto the faces of the two figures. The Superspot optic was used on both spotlights and all of the details of the statue were visible. The measured UV radiation was equal to 0 W/m².

Configuration 2 – was achieved with a single SUPERSYSTEM II midi spotlight (3000 K), mounted laterally to the left of the support structure. This position was chosen to directly illuminate the faces of the Madonna and the child and to create more contrast between light and shadow on the rest of the sculpture. The Spot optic was used and the measured UV radiation was equal to 0 W/m².

Configuration 3 – only required a single frontal ARCOS 3 LED expert spotlight (3000 K), which was directed towards the faces of the Madonna and the child. A Superspot optic was chosen to purely illuminate the statue and to create a sharper contrast between the exhibit and the background. A diffuser lens was included make sure that the light was as diffuse as possible. This configuration created a very dramatic effect, as the background was almost invisible and the marble of the statue was highlighted by contrast. The measured UV radiation was equal to 0 W/m².

Configuration 4 – which only featured the ARCOS Wallwasher, was designed to deliver a more uniform lighting effect on the sculpture and its background. Both of these elements were illuminated equally, generating a simple lighting effect, yet all of the fine details and decorations of the artwork were very much still clearly visible. The wallwasher was positioned frontally in relation to the sculpture.
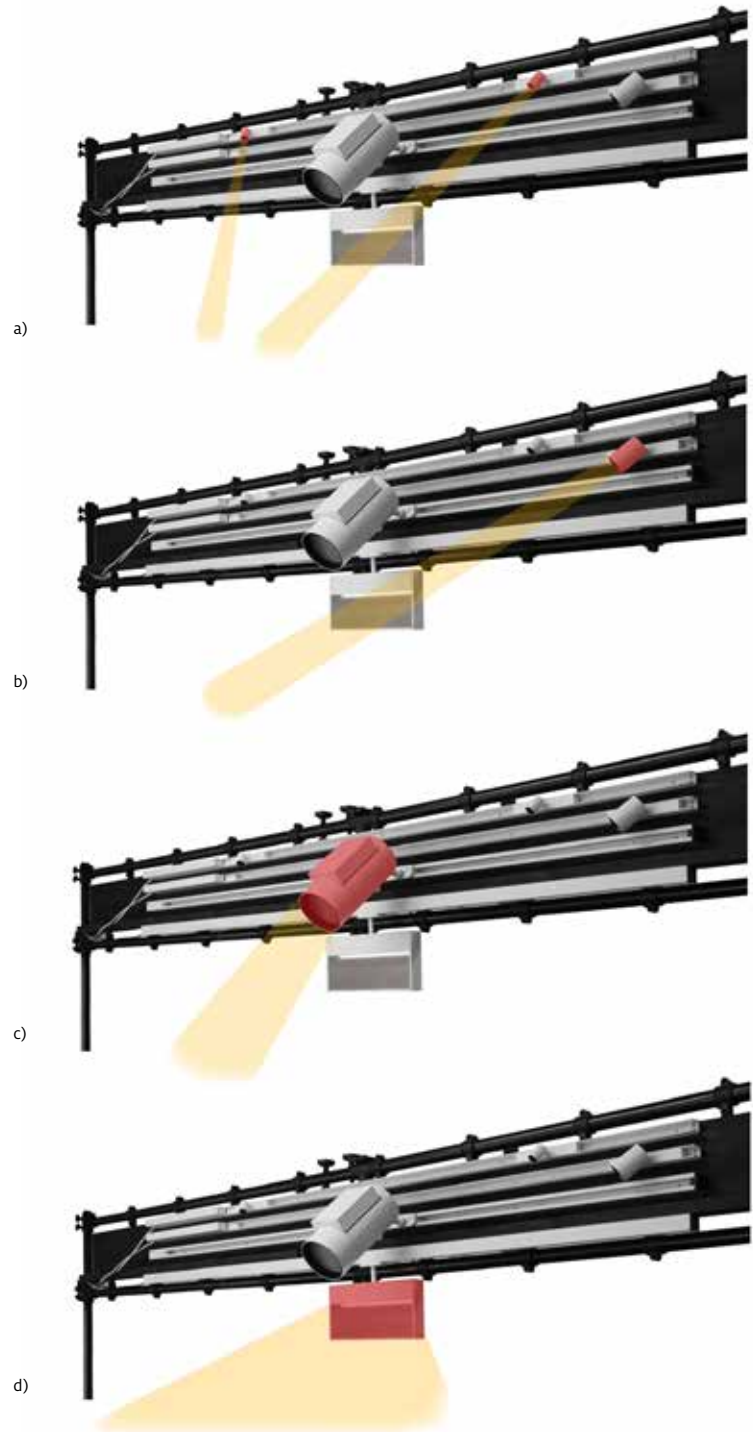
Settings of the luminaires on the support structure for the Madonna del Latte:
Configuration 1 (a), Configuration 2 (b), Configuration 3 (c) and Configuration 4 (d)
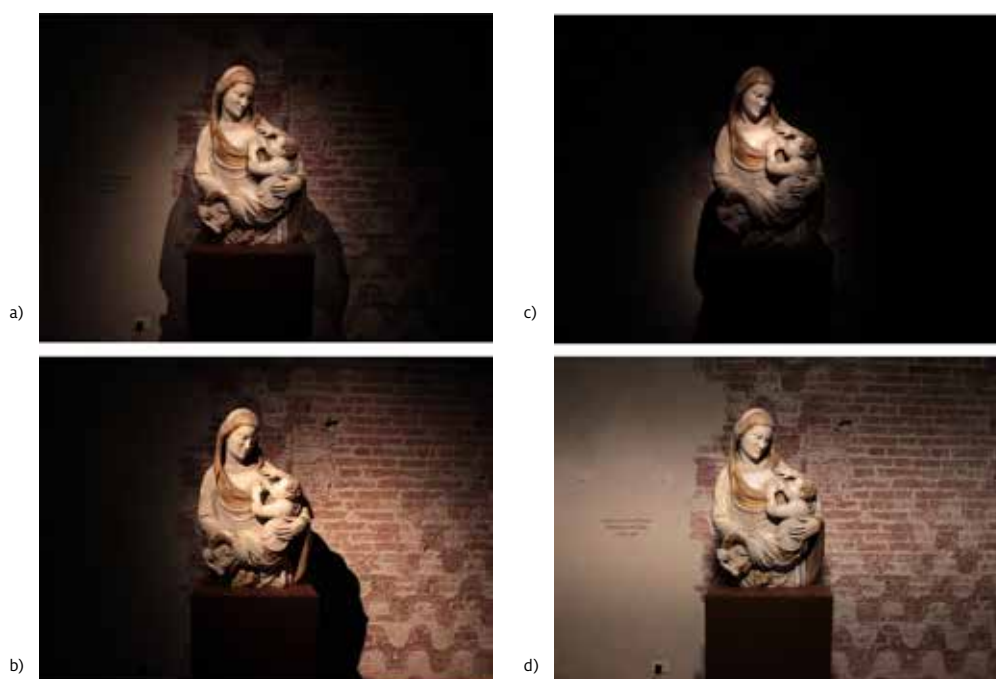
Appearance of the Madonna del Latte under the four test lighting:
Configuration 1 (a), Configuration 2 (b), Configuration 3 (c) and Configuration 4 (d).

Measurement points selected on the Madonna del Latte

Illuminance levels (lx) measured on the painting for all four test lighting configurations

Measurement Points	E (lx) - Config. 1	E (lx) - Config. 2	E (lx) - Config. 3	E (lx) - Config. 4
1	44	134	75	175
2	94	128	54	131
3	65	54	9	60
4	75	94	11	58
5	7	9	0,6	24
6	7	2	0,6	44
7	7	48	0,5	39

Annual luminous exposure calculated for all four test lighting configurations

	Config. 1	Config. 2	Config. 3	Config. 4
Annual Luminous Exposure (lx*hours/year)	219.100	322.390	115.810	331.780

5. Experiment procedure

The experiment was conducted over the course of two days (one for each artwork), with two different groups of observers assessing the lighting configurations. A total of 27 observers carried out Test 1 on the Sacra Conversazione (15 males and 12 females, aged between 21 and 74 years old, with an average age of 30). Seven of these participants had an interest or level of expertise in lighting design, while the other 20 people had no prior experience of lighting design and little knowledge of art. Test 2 with the Madonna del Latte involved 35 observers (18 males and 17 females, aged between 21 and 75 years old, with an average age of 33). From this group, seven people had an interest or level of expertise in lighting design and one person had proficient knowledge of both lighting design and art. The other 27 people had no prior knowledge of lighting design or art.

Participants were asked to fill in a questionnaire that included four questions for each lighting configuration and three general questions, which were to be answered once all the configurations had been seen. The first three questions were evaluated on a scale of 1 to 6 and focused on the following factors:

- **Contrast perception:** How sharp or dim the contrast between the exhibit and the background was perceived (1 = very low contrast; 6 = very high contrast).
- **Enhancement of the artwork:** To what extent the lighting configuration enhanced the characteristics of the artwork – style, colours, details, shapes and volumes (1 = poor enhancement; 6 = very good enhancement).
- **Personal preference:** Whether the individual observer appreciated each configuration or not (1 = low appreciation; 6 = high appreciation).

Finally, participants had to choose adjectives from a list that described the lighting configurations and reflected the feelings evoked by the installations. The various adjectives were divided into four groups:

- Positive: pleasant, compelling, interesting and suitable;
- Negative: unpleasant, boring, unsuitable and dull;
- Neutral-Relaxing: uniform, relaxing, simple;
- Neutral-Vibrant: complex, dynaimc, dramatic.

The observers were advised not to check the answers given to the previous configurations (to avoid direct comparisons) and were prevented from checking the evaluation of each configuration before filling in the last three questions. In addition, the order of the displayed lighting configurations was chosen randomly to help avoid any bias in the evaluations.

6. Test results

The tests were analysed by calculating the average results and analysing the individual answers from to identify particular trends. The findings for the average observer were defined by working out the geometric mean for each evaluated parameter – contrast perception, enhancement of the artwork and preference – and the standard error for each of the lighting configurations. The geometric mean was selected because it is less affected by extreme values and possible data fluctuations. The trends for the three parameters across the four configurations were plotted together to understand whether there were significant differences between the results for the four lighting configurations. Analysis of the adjectives chosen by the observers simply involved checking the frequency of the answers.

Once the geometric mean values for each lighting configuration had been calculated, the data was statistically analysed with an rmANOVA test (analysis of variance with repeated measurements). The findings were then divided into two groups: the naive observers and the expert observers. The aim of this analysis was to determine whether there are similarities between the evaluations of the two groups or any specific trends.

6.1 Sacra Conversazione

The results for the average observer revealed that the evaluations of contrast were all set between 3 and 4. This shows that, on average, no substantial differences in contrast between the painting and its background were perceived across the four lighting configurations. Configurations 1 and 3 appeared to be the solutions with the highest contrast, while configurations 2 and 4 had the lowest contrast. These last two installations were in fact the two configurations with a more uniform effect on the painting and a lower contrast ratio between the painting illuminance and the background illuminance, while configurations 1 and 3 created more accent spots on the actual painting. When it comes enhancement of the artwork, it is clear that configuration 1 was rated as the best solution to highlight the specific characteristics of the painting. The ratings for the other lighting configurations then gradually decreased until configuration 4, which was seen as the least suitable to enhance the painting. The evaluation of preference followed a similar pattern as enhancement, but with a marked decrease for the third configuration, which seemed to be the least appreciated of the four lighting configurations. On the other hand, configurations 1 and 2 were jointly the most appreciated, with the charts showing no major difference in terms of evaluation.

The observers used a total of 251 adjectives to describe the configurations, with a mean of 9 adjectives per person (2-3 adjectives per configuration). Positive and neutral-relaxing adjectives were mostly used for configurations 1 and 2, even though some observers also found them to be vibrant. Very few participants found them to be unsuitable or unpleasant. Configurations 3 and 4, on the other hand, prompted a wider variety of adjectives, although positive adjectives still tended to be more prevalent than negative ones. However, configurations 3 and 4 were overall rated as more vibrant and less relaxing than configurations 1 and 2 and therefore not as pleasant and not as appropriate for the illumination of the painting. Configuration 1 was mostly described as "relaxing" and configuration 2 was found to be "uniform", "simple" and "appropriate". Configurations 3 and 4 had no real specific descriptions.
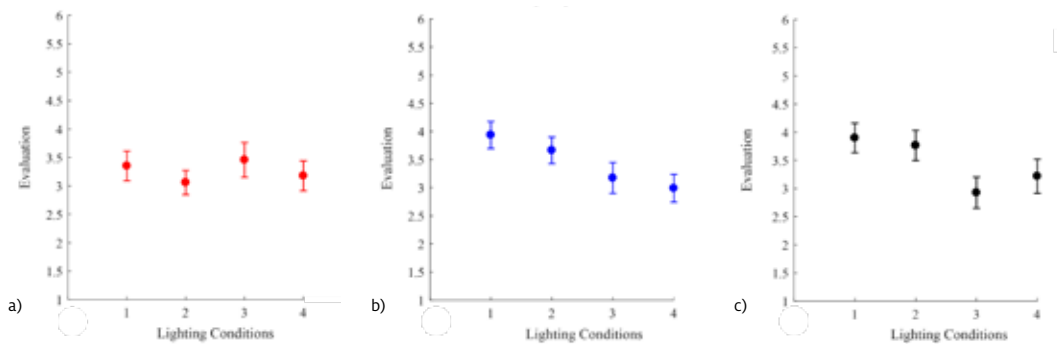
Sacra Conversazione - Plotted results for the three parameters:
Contrast perception (a), Enhancement of the artwork (b) and Preference (c).

Sacra Conversazione - Average results

		Config. 1	Config. 2	Config. 3	Config. 4
Contrast perception	Geometric Mean	3.35	3.06	3.46	3.18
	Standard Error	0.26	0.21	0.31	0.26
	Median	3	3	4	3
Enhancement of the artwork	Geometric Mean	3.94	3.66	3.17	2.99
	Standard Error	0.26	0.27	0.28	0.30
	Median	4	4	4	3
Preference	Geometric Mean	3.90	3.76	2.93	3.22
	Standard Error	0.26	0.27	0.28	0.30
	Median	4	4	3	3

Sacra Conversazione - Frequency of the various adjectives used to describe the four lighting configurations

Config. 1			
Pleasant	7	Unpleasant	-
Suitable	8	Unsuitable	1
Interesting	8	Boring	1
Compelling	5	Dull	6
Uniform	5	Dynamic	5
Relaxing	9	Dramatic	1
Simple	5	Complex	3

Config. 2			
Pleasant	8	Unpleasant	-
Suitable	12	Unsuitable	2
Interesting	3	Boring	2
Compelling	3	Dull	5
Uniform	12	Dynamic	3
Relaxing	7	Dramatic	2
Simple	10	Complex	-

Config. 3			
Pleasant	5	Unpleasant	4
Suitable	4	Unsuitable	5
Interesting	4	Boring	1
Compelling	7	Dull	5
Uniform	1	Dynamic	6
Relaxing	3	Dramatic	4
Simple	5	Complex	2

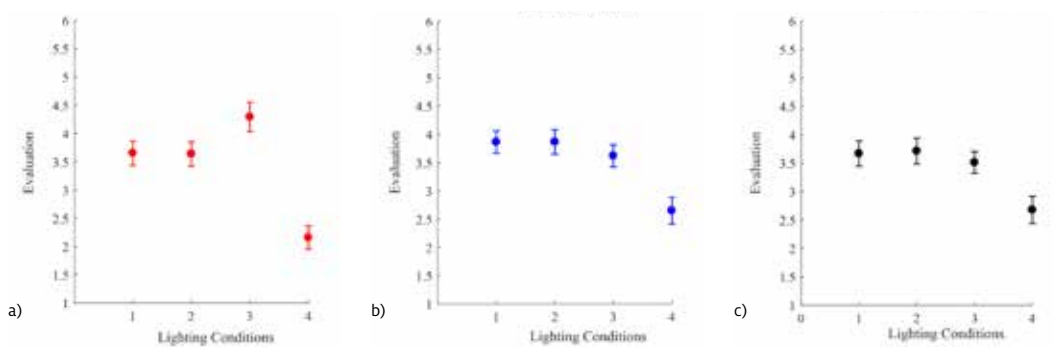| Config. 4			
Pleasant	5	Unpleasant	2
Suitable	4	Unsuitable	8
Interesting	7	Boring	2
Compelling	6	Dull	6
Uniform	2	Dynamic	5
Relaxing	3	Dramatic	4
Simple	5	Complex	3
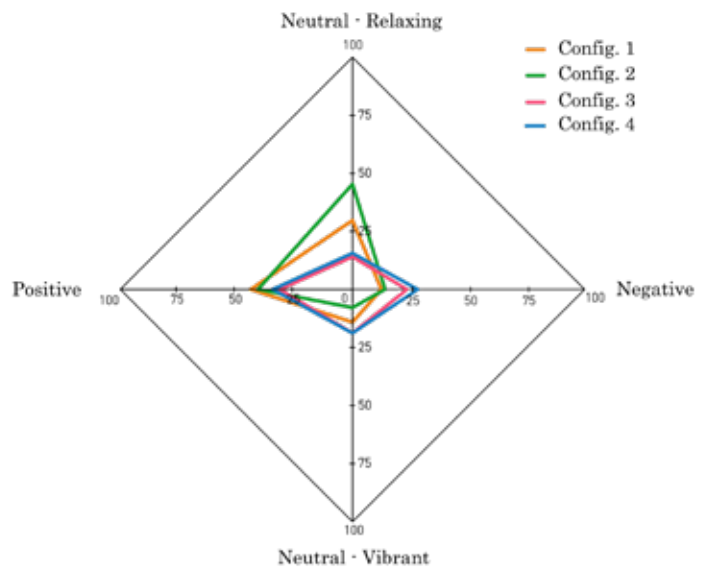
Sacra Conversazione - Radar graphs showing the frequency of use of the four groups of adjectives used to describe the four test lighting configurations

6.2 Madonna del Latte

The results for the average observer showed that the issue of contrast was evaluated differently across the four lighting configurations. The sculpture enabled the creation of four very distinct lighting scenarios and thereby generated four different contrast ratio values. However, configurations 1 and 2 were perceived equally in terms of contrast, configuration 3 was seen as having the highest contrast level and configuration 4 recorded the lowest perceived contrast level. It can therefore be concluded that the evaluations agree with the measured levels of illuminance on the sculpture and its background. In terms of enhancement of the artwork, while there were no significant differences between the evaluations of configurations 1, 2 and 3, there was a sharp drop for configuration 4. The results for preference were very similar to those for enhancement. This means that configurations 1,2 and 3 were almost equally appreciated and that configuration 4 was the least appreciated.

The observers used a total of 342 adjectives to describe the configurations, with a mean of 10 adjectives per person (2 - 3 adjectives per configuration). It should be noted that the adjectives chosen for configuration 1 were mostly positive and neutral-relaxing. At the same time, configurations 2 and 3 were associated with both neutral-relaxing and neutral-vibrant adjectives, rather than positive ones. Only a few people described these three configurations as unsuitable or unpleasant. Negative and neutral-relaxing adjectives were mostly used for configuration 4. Configuration 1 was described as being especially "relaxing" and "simple", configuration 2 was felt to be "interesting" and "pleasant" and configuration 3 was perceived as being "dramatic", "relaxing" and "interesting". In stark contrast, configuration 4 was described as being "dull", "boring" and "uniform".

Madonna del Latte - Plotted results for the three parameters:
Contrast perception (a), Enhancement of the artwork (b) and Preference (c).

Madonna del Latte - Average results

		Config. 1	Config. 2	Config. 3	Config. 4
Contrast	Geometric Mean	3.65	3.64	4.30	2.16
perception	Standard Error	0.21	0.21	0.26	0.21
	Median	4	4	5	2
Enhancement	Geometric Mean	3.86	3.87	3.62	2.65
of the artwork	Standard Error	0.20	0.22	0.20	0.24
	Median	4	4	4	3
Preference	Geometric Mean	3.67	3.71	3.51	2.68
	Standard Error	0.22	0.23	0.19	0
	Median	4	4	3	3

Madonna del Latte - Frequency of the various adjectives used to describe the four test lighting configurations

Config. 1					Config. 2			
Pleasant	13	Unpleasant	1		Pleasant	11	Unpleasant	1
Suitable	11	Unsuitable	1		Suitable	8	Unsuitable	1
Interesting	9	Boring	5		Interesting	12	Boring	2
Compelling	2	Dull	3		Compelling	9	Dull	4
Uniform	5	Dynamic	3		Uniform	6	Dynamic	9
Relaxing	13	Dramatic	3		Relaxing	5	Dramatic	7
Simple	10	Complex	3		Simple	7	Complex	3

Config. 3					Config. 4			
Pleasant	6	Unpleasant	1		Pleasant	6	Unpleasant	1
Suitable	5	Unsuitable	4		Suitable	4	Unsuitable	8
Interesting	10	Boring	4		Interesting	4	Boring	12
Compelling	6	Dull	4		Compelling	3	Dull	19
Uniform	1	Dynamic	3		Uniform	16	Dynamic	3
Relaxing	10	Dramatic	14		Relaxing	4	Dramatic	-
Simple	6	Complex	8		Simple	13	Complex	-
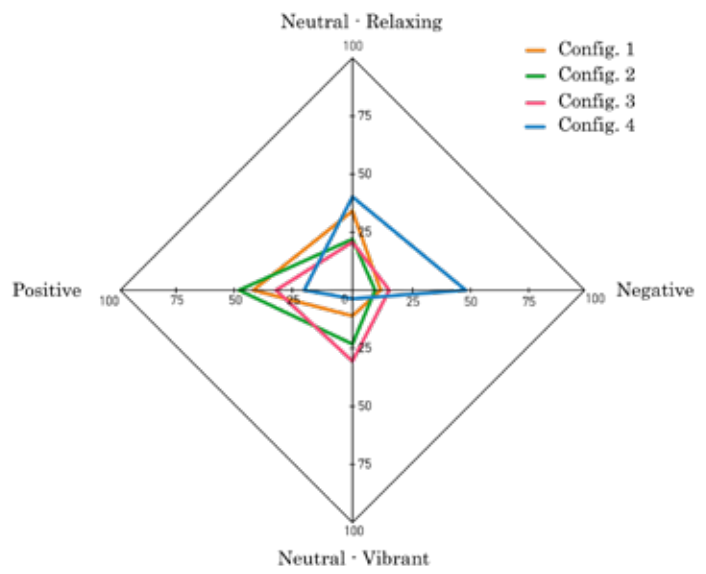
Sacra Conversazione - Radar graphs showing the frequency of use of the four groups of adjectives used to describe the four test lighting configurations

7. Statistical analysis

Possible correlations and interactions between the three parameters – contrast, enhancement and preference – were analysed with an rmANOVA test, which assesses levels of variance with repeated measures (as the evaluations for the various configurations were not independent from each other). This test was performed with SPSS software and the "multivariate test" results were then evaluated. In addition, a test of within-subject effects was carried out to check the significance of differences between the evaluations of the four lighting configurations for each parameter. The significance level considered was p = 0,05. The data for each parameter was studied individually to check for significant statistical differences between the evaluations of the four test lighting configurations. Finally, the whole data set was analysed to identify correlations or interactions between the three parameters.

7.1 Sacra Conversazione

The interactions between the criteria for the Sacra Conversazione were evaluated once the rmANOVA test had been performed on the data for the individual parameters. The test on the contrast data showed no statistical significance (p = 0,54) and no significant differences between the evaluations of the four lighting configurations. We can therefore conclude that the contrast between the painting and its background was not a statistically significant factor.

The test on the enhancement of the artwork data showed a statistical significance (p = 0,02) and, crucially, significant differences between the evaluations of configurations 2 and 3 (p = 0,04) and configurations 3 and 4 (p = 0,03). As a result, it can be concluded that the first two configurations were equally suitable for the illumination of the painting.

The test on the preference data did not show a statistical significance (p = 0,11) – even though a significant difference was found between the evaluations of configurations 2 and 3 (p = 0,012). The evaluations of configurations 1 and 2 were therefore significantly higher than the evaluations of configurations 3 and 4, which in turn means that they can be regarded as the best lighting arrangements for the painting. However, it is not possible to indicate which single configuration was the best, as their ratings were not significantly different.

Lastly, although the existence of potential correlations between the three parameters was carefully analysed, the actual tests did not reveal any significant correlations (p = 0,18).

7.2 Madonna del Latte

The same tests were performed on the data for each parameter of the experiments carried out on the Madonna del Latte. In this case, the test on the contrast data showed statistical significance (p=0,001), which confirms that contrast had a significant effect on the perception of the participants. Significant differences were also found between configurations 2, 3 and 4, but no significant differences were detected between configurations 1 and 2. Most observers reported that these two installations appeared to generate the same level of contrast between the sculpture and the background.

The tests on the enhancement of the artwork data also showed statistical significance (p=0,02) and significant differences between the evaluations of configurations 3 and 4 (p=0,03). It can therefore be inferred that the first three configurations were judged to be equally suitable for the illumination of the painting, whereas configuration 4 was seen to be the least suitable.

Although the tests on preference did not reveal any statistical significance (p=0,09), a significant difference was detected between the evaluations of configurations 3 and 4 (p=0,02). This means that the evaluations of configurations 1, 2 and 3 were statistically higher than the evaluations of configuration 4, which was quite clearly the least appreciated configuration. However, it is not possible to ascertain which installation (from configurations 1,2 and 3) was actually the best, as the individual evaluations were not significantly different.

Possible correlations between the three parameters were also investigated, but the tests did not show any significant correlations (p=0,07).

Results of the rmANOVA for the two artworks

	Sacra Conversazione			Madonnada del Latte		
	Val	F	p-value	Val	F	p-value
Contrast perception	0.09	0.75	0.54	0.54	12.67	0.00
Enhancement of the artwork	0.32	3.75	0.02	0.26	3.78	0.02
Personal Preference	0.22	2.28	0.11	0.19	2.42	0.09
Interaction	0.32	1.68	0.18	0.31	2.19	0.07

8. Conclusions

The psychophysical tests performed on the two objects highlighted some interesting correlations between contrast perception, enhancement of the artworks and overall personal preference.

8.1 Contrast

The complete data set shows that when observers concentrated on the contrast between the exhibit and its background, they generally preferred higher contrast ratios for both the painting and the sculpture. In fact, if we analyse the choice of adjectives, it is possible to notice that the observers considered these two lighting configurations (configuration 3 for both tests) to be more "interesting", "stimulating" and also "dramatic". From the results for the average observer, it is clear that the contrast ratio was mostly correctly perceived by the participants, as conclusions about higher or lower contrast ratios tally with the illuminance levels measured on the artworks and their background. However, the contrast ratios for the painting were closer to each other, so the average evaluations are very similar (with ratings of between 3 and 4). There were however slight peaks for the solutions with higher contrasts (configurations 1 and 3). On the other hand, there was more difference in terms of contrast between the lighting configurations for the sculpture, which in turn means that the evaluations are more widely dispersed. This is probably because it was easier for the observers to assess the level of contrast across the four lighting configurations.

In conclusion, the lighting configurations perceived as being the ones with higher levels of contrast were also seen to be the best in terms of contrast and also the most appealing, especially for the sculpture. The lighting configurations that were believed to have lower contrast ratios were also correctly perceived, as they had the most uniform effect between the lighting on the artwork and the lighting on the background (configuration 4 for both tests). However, they were also the least appreciated for both objects, especially in the case of the sculpture. Analysis shows that the issue of contrast was not statistically significant for Test 1 (with the painting), but that it was a statistically significant factor for the sculpture (Test 2).

8.2 Enhancement of the artworks

When it comes to the enhancement of the artwork, the data analysis clearly shows that configuration 1 was considered the best solution for the painting, while configurations 1,2 and 3 were seen to be equally suitable for the sculpture. It is therefore not possible to identify the single best lighting configuration for the sculpture (unlike for the painting) – despite the fact that the lighting effects and contrast ratios of the three configurations were all very different. However, the installations with the lower contrasts (configuration 4 for both tests) were generally found to be the least suitable for the enhancement of the two artworks. The observers used adjectives such as "dull", "boring" and "simple" to describe configuration 4 and some of the people found these solutions to be inappropriate for the works. Statistical analysis on the enhancement data demonstrated the statistical significance of this parameter for the tests on both the painting and sculpture, along with a number of statistically significant differences. This confirms the assumptions made from the analysis of the graphs for the average observer.

8.3 Personal preference

Although the preference data proves that configurations 1 and 2 were generally the most appreciated for both tests, no statistically significant difference between the evaluations of these two lighting configurations could be detected for either artwork. Indeed, the answers given to the final "best lighting configuration" question for both tests show that there was no marked difference between the four lighting configurations. Despite what the average observer graphs appear to show and the types of adjectives used, the two versions of configuration 4 do not actually have such a poor rating. Moreover, while configuration 4 received the lowest rating for the Madonna del Latte, it was tied with configuration 2 for the Sacra Conversazione. Configuration 1 was less frequently selected as the best lighting installation.

In conclusion, there are no specific trends when it comes to preference and no significant outcomes that can be drawn from the numerical data. The statistical analysis revealed no statistical significance between the evaluations of preference and no correlations or interactions between the three parameters – especially in terms of enhancement and preference. This is despite the fact that the best overall lighting configurations were also the ones deemed to be the most appropriate for the artworks.

8.4 Preference towards neutrality

The first conclusion that can be drawn from both tests concerns the relationship between contrast and preference. The lighting configurations with higher contrast ratios were not the overall favourite installations, even though they were chosen as the best when the question focused on the contrast between the artwork and the background. As a result, contrast does not appear to have had a major impact on the overall preference for the lighting – taking into account both the exhibition space and the specific artwork. Indeed, evaluations of preference seem to be more closely related to the enhancement factor. The adjectives used for the preferred lighting configurations (mostly configurations 1 and 2) were "relaxing", "pleasant", "simple" and "interesting". Although the observers found the higher contrasts more appealing and stimulating, this indicates that they actually preferred more uniform and relaxing lighting scenarios, which were perceived as being simple and yet still interesting.

The final preference therefore tended to involve lighting configurations with intermediate levels of contrast between the exhibits and the background. According to participants, these solutions enabled the correct presentation of both the painting and the sculpture. These installations, which were seen to be relaxing, simple and yet interesting, can be contrasted with the "dull" and "boring" uniform configurations. When assessing the enhancement of the artwork, the highest contrast ratios were not rated as the best.

The impression given by the test results (driven by previous considerations, although not confirmed by the statistical analysis) is that while the participants were more attracted to dramatic and high-contrast lighting configurations (which were described as eye-catching and more appealing), when also factoring in the correct presentation of the artwork, observers ultimately preferred more relaxing and simpler lighting configurations. However, preference is driven by multiple factors, most of which are related to the subjective and emotional feelings stimulated by the artwork under certain lighting conditions. As a consequence, they are naturally extremely difficult to standardise.

In conclusion, the tests proved that most participants appreciated lighting configurations with intermediate levels of contrast between the exhibits and their backgrounds. This means that they preferred more relaxing and uniform scenarios to the installations characterised by increased levels of contrast and dramatic effect. These latter configurations were perceived as being appealing, but also less appropriate for the authentic appearance of the artworks. The preference evaluations therefore appear to be a kind of compromise between subjective attraction and objective opinions about the most effective presentation of the artworks.

Appendix A

Take deLIGHT in Colors

Analysis of color appearance of paintings under various lighting settings

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Introduction

This study aimed to analyze some of the parameters affecting the color perception of paintings displayed in museum settings and to establish, through a survey, whether there are preference patterns for the observers. Parameters related to color, such as the Correlated Color Temperature (CCT) and the Color Rendering of the light sources, as well as the characteristics of the exhibition space – the background and the surround – have a great impact on our perception of the artworks and can affect the visual experience of museum visitors. Therefore, these parameters must be carefully designed in order to obtain the intended visual impressions of the artworks and a good visual experience for the viewers.

Investigated parameters

With the aim of understanding what lighting arrangements the viewers prefer, this study investigated three parameters:
- the lightness of the background.
- the color content of the paintings;
- the CCT of a LED spotlight used as accent lighting on the paintings;

The LED spotlight had three tunable channels (Red, Green and Blue) and one fixed channel (3200 K). The three tunable channels were optimized in order to obtain five specific CCTs: 3000 K, 3500 K, 4000 K, 5000 K and 6000 K. This optimization was performed while keeping the average illuminance value constant across the various CCTs, equal to 160 lx.
The color content of the paintings was investigated using five different paintings, selected from the artworks of the artist Leonid Afremov: four paintings with a predominant color (red, green, blue and yellow) and one painting without a predominant color (all colors).
The lightness of the background was realized using curtains of different colors: white, grey and black.

Experiment Setup

The setup aimed to replicate a simple museum room in the laboratory. The setup was made of one frontal wall, where the paintings were hung, and two tilted walls, which created the broadest possible field of view and the feeling of immersion. The observing position was set in front of the paintings, 1.40 m away from the wall.

The lighting of the setup consisted of Accent Lighting, realized with the LED spotlight directed into the paintings, and Ambient Lighting, realized with fluorescent lamps (5900 K). The Ambient Lighting was positioned above the position of the observers, in order to provide only horizontal illuminance and not affect the lighting on the paintings.

Experiment Procedure

The three backgrounds, the five paintings and the five CCTs were combined into 75 different arrangements. The various arrangements were presented to a group of 25 observers (14 males and 11 females, average age 29 years), who were asked to assess six quality factors related to the color appearance of the paintings and their level of appreciation on a bi-polar 11-point scale:

- Overall Appreciation (high/low) of the configuration;
- Background Appreciation (high/low);
- the perceived Warmth (cold/warm) of the colors of the paintings;
- the perceived Brightness (dark/bright) of the colors of the paintings;
- the perceived Vividness (dull/vivid) of the colors of the paintings;
- the perceived Colors Attractiveness (high/low) of the paintings.

Each observer assessed a total of 90 arrangements: the 75 different arrangements and 15 additional repeated configurations (selected randomly) to assess observer consistency. The test was divided into three sections, one for each background: once the background was set, they had to assess each painting at a time under the five different lighting configurations.

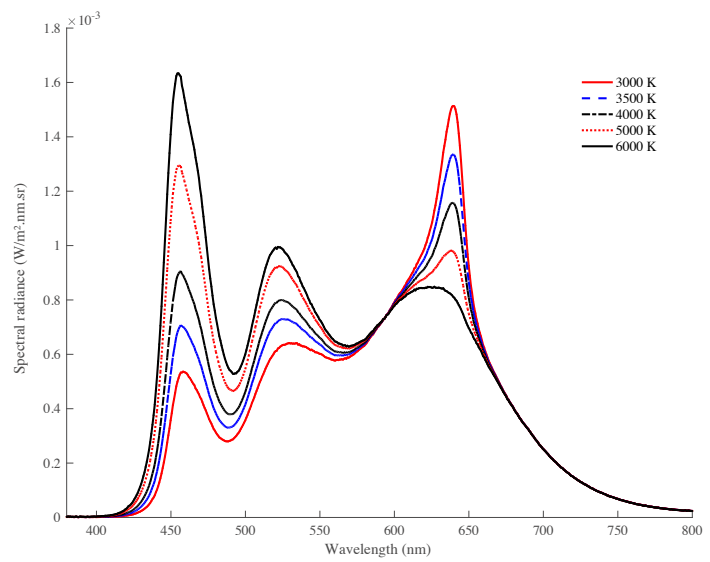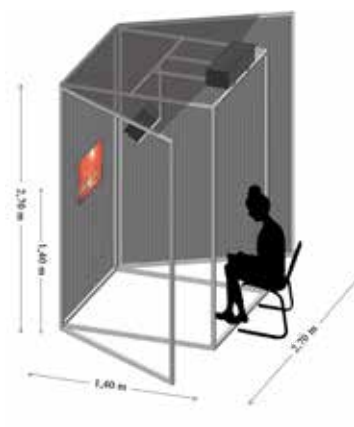a)   b)   c)

The lightness of the background: (a) white, (b) grey and (c) black.

a)   b)   c)   d)   e)

Leonid Afremov's paintings: (a) "When dreams come true", (b) "Mistery of the night", (c) "Smmer Forest", (d) "Pink fog" and (e) "Happy couple".

Optimized spectra of the LED spotlight for the various CCTs.

Sketch and picture of the Experiment Setup.

a)

b)

c)

Pictures of the three of the selected paintings displayed on the three backgrounds under three of the lighting configurations: (a) 3000 K, (b) 4000 K and (c) 6000 K.

Discussion of results

The results of psychophyscal experiments are analyzed by calculating the data for the Average Observer. The geometric mean and its standard error of the 25 evaluations for each quality factor and each arrangement were calculated and plotted as a function of the CCT, in order to identify possible trends.
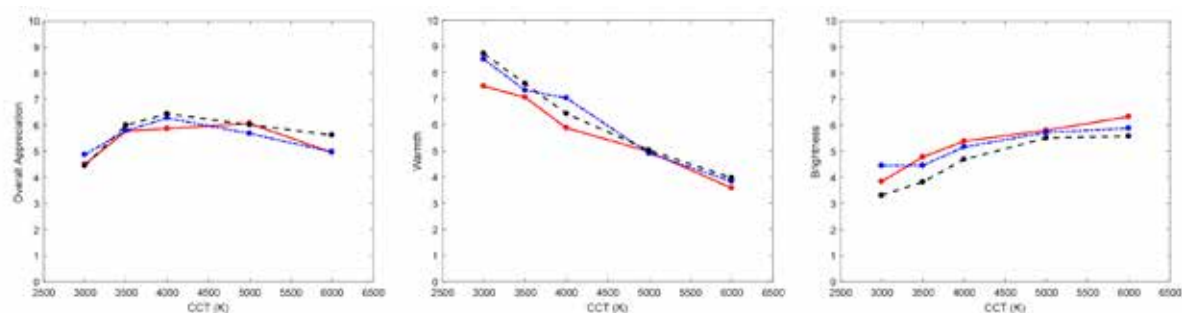
Example of graphic analysis for the Red Painting - "Pink Fog"

The impact of the CCT

The CCT of the spotlight turned out to be the only parameter affecting the observers' evaluations. From the collected data, it is clear that the warmest (3000 K) and the coolest (6000 K) configurations were the least appreciated. Neutral configurations (4000-5000 K), instead, were the most appreciated for all arrangements, regardless of the color of the paintings and the background lightness.

The impact of the background

The data for the various backgrounds are not remarkably different from each other. Therefore, when evaluating the parameters, it is possible to say that the change of the background lightness did not have a considerable impact on the observers' assessments. However, from the "Background Appreciation" data, it is possible to notice a slight preference for the black background, which recurs for all paintings.

The impact of the paintings' color content

The two previous trends recur for all paintings, regardless of the predominant hue. Hence, it is possible to conclude that the predominant hue of the paintings has no impact on the preferred arrangements for the lighting.

Conclusions

In this experiment it was possible to notice a preference towards neutrality. Cooler and warmer CCTs were the least appreciated by the viewers, regardless of the background color and the colors of the paintings, while more neutral configurations were perceived as more pleasant.

These results, together with the results driven from the study conducted at the National Museum of San Matteo, suggest that people prefer neutral lighting arrangements, neither too cold or too warm, which create a level of contrast with the background/surround that is neither too high or too low.

Therefore, these two studies indicate that the best visual experience for museum visitors can be obtained with lighting configurations that create a more neutral appearance of the colors of the artworks and a simpler and more relaxing overall lighting scenario.

Appendix B

Commission Internationale
de l'Eclairage CIE 157:2004

Control of Damage to Museum objects by optical radiation

Recommendations for museum lighting

The objects in a museum's collection can be classified into two main conservation categories: materials of mineral or inorganic origin – stone, metals and glass – and organic materials, including materials of vegetable origin – paper, papyrus, wood, natural textiles, many pigments and dyes, etc. – and materials of animal origin – bone, ivory, skins, etc., as well as some pigments and dyes. In general, inorganic materials show little or no responsivity to light, while organic materials are moderately or highly responsive. In particular, pigments are a special concern for conservators because the first visible sign of damage due to exposure is often the deterioration of pigments, which vary widely in response to exposure.

CIE 157:2004 suggest four main categories of materials and relative maximum illuminance levels and exposure times. The CIE 157/2004 proposed a model, called Model of Berlin, which defines the damage suffered by an object exposed to light through the DM factor, as a function of the spectral irradiance of the impinging light, the relative spectral sensibility of each material and the exposure time. The artworks' spectral reflectance is an important parameter to evaluate the conservation status in cultural heritage, especially for paintings. Knowing the spectral responsivity of materials can allow designers to carefully calibrate the level of lighting on the object, in order to create the proper environmental conditions for its conservation.

Whatever the sensitivity category of an artwork, the aim is to achieve the designer's objectives for the display with the minimum exposure of the objects. The first aspect to examine is the duration of exposure. Switching controls should be arranged so that the display lighting is only in use when required. Once the necessary duration of light exposure has been determined, the next step is to minimise the level of irradiance and, most importantly, to make sure that objects are protected from non-visible radiant flux, namely UV and IR.

Four categories of sensitivities of materials

Material Category	Description	Examples
Irresponsive	The object is composed entirely of materials that are permanent, in that they have no light	Most metals, stone, most glass, genuine ceramic,enamel, most minerals.
Low responsitivity	The object includes durable materials that are slightly light responsive	Oil and tempera painting, fresco, undyed leather and wood, horn, bone, ivory, lacquer, some plastics.
Medium responsitivity	The object includes fugitive materials that are moderately light responsive	Costumes, watercolors, pastels, tapestries, prints and drawings, manuscripts, miniatures and most natural history objects.

Limitations of illuminance and exposure time for the four categories of sensitivities of materials

Material Category	Illuminance level (lx)	Exposure time (hours/year)
Irresponsive	No limit	No limit
Low responsitivity	200	600.000
Medium responsitivity	50	150.000
High responsitivity	50	15.000