Testing the colour harmony for painting exhibition

Sabrina Lachheb, Philippe Colantoni; C2RMF; Paris, France
Éric Dinet; Laboratoire Hubert Curien; Saint-Étienne, France

Abstract

A set of colours aesthetically pleasant are described as harmonious in the language of human visual perception. As this notion encloses a subjective part, a psychophysical experiment was carried out to estimate the perception of colour harmony for combinations of paintings with the uniform colour of walls on which they are hung.

The experiment, that involved 38 observers, was based on accurate colours built upon a specific colour flow. Participants were asked to judge the colour harmony of combinations of a sample of 7 selected paintings with backgrounds uniformly coloured in 3 different ranges of colours – achromatic colours, tones derived from the global average colour of the considered painting and tones derived from the complementary of the global average colour of the considered painting.

Results demonstrate that the best colour harmony is obtained when the average colour of paintings is used to colour their background. The experiment presented in this paper clearly shows that the white colour usually used for walls in museums does not optimize the colour harmony.

1. Introduction

Colour harmony has largely focused the attention of many researchers and artists. Different approaches have been proposed to precise and to conceptualize the notion of colour harmony [1]. One of the most famous approaches is certainly the theory developed by Itten [2]. Itten produced a colour wheel to illustrate that the classification of colours, i.e. the relative location of hues on a circle, definitely affects the colour harmony [3-4]. It has also been shown that the mix of colours and, more specifically, the substitution of a colour by another one can significantly impact the perception of a scene and the induced sensations [5].

A simple and objective definition of colour harmony has been introduced by Judd and Wyszecki. They wrote: “when two or more colours seen in neighbouring areas produce a pleasing effect, they are said to produce a colour harmony” [6]. The words “pleasing effect” are very efficient to characterize the colour harmony during psychophysical experiments because they are unambiguous and easily understood by observers [7]. Then we adopted these words for defining colour harmony in the study presented in this paper.

Our work aims at investigating the colour harmony assessed by observers when presenting different fine art paintings on uniformly coloured walls. A psychophysical experiment was carried out to collect data in order to clarify how the colour of the wall on which hangs a painting may modify the general perception of the artwork.

Itten argued that colour combinations are harmonious when corresponding colours form a regular polygon on the wheel he defined or when colours are complementary pairs i.e. they are placed opposite each other [1-2]. Considering this well-established point of view, we chose to focus our study on the assessment of colour harmony for 3 different types of colour pairs. These 3 types of pairs were generated by combinations of selected paintings with walls (backgrounds) uniformly coloured in 3 different ranges of colours – achromatic colours, tones derived from the global average colour of the painting and tones derived from the complementary of the global average colour of the painting.

All the colour management algorithms associated to the psychophysical experiment described in this paper are firstly presented. These custom algorithms provide accurate colour data and produce calibrated stimuli. The stimuli were displayed through a video projector and they simulated the combinations paintings / walls. The construction of the 3 different types of colour pairs as well as the experimental procedure are explained in a following section. Finally, before concluding, results are presented and discussed.

2. Colour flow

In order to build an accurate colour data set for the psychophysical experiment, we used a specific colour flow based on: a set of multispectral images, a dedicated colour management process and chromatic paths defined in the colour gamut of the display device used (here a video projector).

2.1. Multispectral images

The multispectral images of paintings used in the experiment presented in this paper were digitized during the CRISATEL European project [8]. The multispectral system of the CRISATEL European project consisted of a line-scan digital camera with a spatial resolution of 12000 pixels and 12-bit output and 13 interferences filters. The multispectral digitalization was carried out over the range 400-1000 nm.

Such multispectral images allow the reconstruction of colour images according to a given illuminant represented by its spectral power distribution (see Figure 1). This means that the colour reconstruction stage does not require any approximation scheme based on both a chromatic adaptation process and doubtful calibrated images acquired with colour sensors that have not been characterized. For each multispectral image, the CIEXYZ colours are reconstructed with the following standard relation:

$$\begin{cases} X = \sum_{\lambda=400}^{\lambda=760} x(\lambda)R(\lambda)L(\lambda) \\ Y = \sum_{\lambda=400}^{\lambda=760} y(\lambda)R(\lambda)L(\lambda) \\ Z = \sum_{\lambda=400}^{\lambda=760} z(\lambda)R(\lambda)L(\lambda) \end{cases} \quad (1)$$

where $R(\lambda)$ is the reflectance spectrum and $L(\lambda)$ is the light spectrum (the illuminant).

2.2. Colour management

The colour management process that follows the colour reconstruction stage has been developed for painting visualization [9]. As shown by the general flowchart presented in Figure 2, the colour management process includes a forward and a backward model. Such a process will be used to compute the chromatic paths necessary to calculate the different backgrounds required by the experiment.

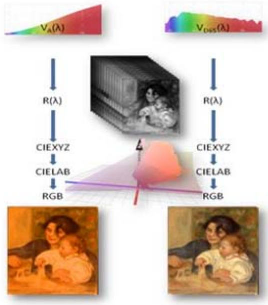

***Figure 1.** Colour workflow, from a multispectral image to a reconstructed colour image*

Traditionally a forward model (or a characterization model) is based on an interpolation or an approximation method. We empirically found that polyharmonic splines, a subset of Radial Basis Function (RBF), were the best approach for our visualization purpose. The backward model could use the same interpolation algorithms but we introduced a new and more accurate method [10]. This new method is a hybrid scheme consisting in a tetrahedral interpolation associated with an over-sampling of the RGB cube. The initial tetrahedral structure is built using a uniform over-sampling of the RGB cube ($n \times n \times n$ samples). The over-sampling is based on the forward model to compute the corresponding structure in the CIELAB colour space. Once this structure has been computed, for an unknown C_{Lab} colour, an associated C_{RGB} colour can be calculated in two steps:

1. the tetrahedron which encloses the point C_{Lab} to be interpolated should be found (the scattered point set is tetrahedrized);
2. an interpolation scheme is used within each tetrahedron.

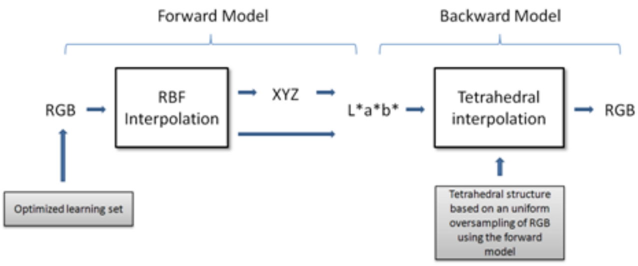

***Figure 2.** Overview of the colour characterization model of the display*

A tetrahedral interpolation method was chosen because of its geometrical features. This method is associated with our gamut clipping algorithm and with the computation of chromatic paths.

As previously stated, in order to increase the reliability of the model, we introduced a new approach to determine the learning data set for the polyharmonic spline interpolation (e.g. the set of colour patches measured on the screen). We found that our interpolation model was most efficient when the learning data set used for the initialization was regularly distributed in our destination CIELAB colour space. It is based on a regular 3D sampling of CIELAB colour space combined with a forward - backward refinement process after the selection of each patch. The algorithm allows the extraction of the optimal set of RGB colours to measure.

Such an approach requires an incremental selection of the RGB patches that will be integrated into the learning database. This patch selection is managed by a custom software tool which is able to drive a colorimeter. The software measures a set of 100 random test patches that are equiprobably distributed in the RGB colour space and that are used to quantify the accuracy of the model.

2.3. Background selection using chromatic paths

The experiment requires coherent colorimetric data according to the display conditions. A video projector is used to generate the colour pairs formed by a reconstructed image of a painting displayed on a uniform background. Then the white of the video projector is chosen as the reference point for all colour reconstruction stages. The video projector becomes a light source for the virtual paintings derived from the available multispectral images.

Each of the 3 types of backgrounds used during the experiment is built upon an appropriate chromatic linear path defined in the CIELAB colour space. The linear paths required by the computation of the different backgrounds correspond to:

- an achromatic path based on the L-axis,
- an average colour path based on an isoluminant line segment passing through the average colour of the displayed image and bounded by the L-axis and the border of the gamut of the video projector (see Figure 3),
- a complementary colour path based on an isoluminant line segment passing through the complementary of the average colour of the displayed image (computed in the CIELHC colour space) and bounded by the L-axis and the border of the gamut of the video projector.

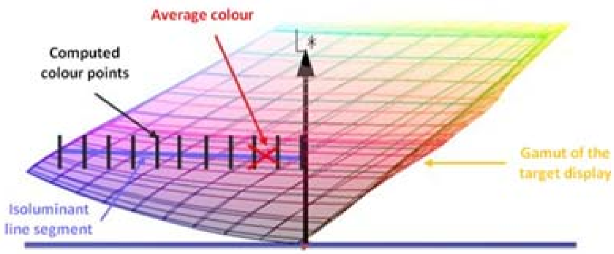

***Figure 3.** Computation of the different background colours based on a chromatic path derived from the average colour of the displayed image*

The desired number of backgrounds specifies the spacing of each point on the corresponding chromatic path (see Figure 3). As all chromatic paths are held in the gamut of the target display, there is no colour clipping problem.

3. Experiment

The experiment consisted in asking observers to evaluate the colour harmony of the combination art paintings / walls (backgrounds). As explained further, the combination art paintings / walls was simulated by displaying segmented colour images on different backgrounds through a video projector.

3.1. Method

In order to have a high degree of relevance, the experiment was conducted with 38 participants aged from 18 to 59. All participants had a normal or corrected-to-normal vision. Each observer was involved twice in the experiment with at least a delay of 1 day between two sessions. The procedure of both sessions was identical.

A Sony VPL-VW100P LCD video projector set to a resolution of 1920 × 1080 pixels was used. The video projector has been characterized with an EyeOne Pro spectrocolorimeter placed at the observer location. It has been empirically determined that a learning set based on a 216 colour patches (corresponding to a 6 × 6 × 6 sampling of the RGB cube) was a good trade-off for the characterization process. A smaller data set provides a degraded accuracy when a bigger does not improve the accuracy because of the measurement problems due to the temporal stability of the video projector. Then, on the basis of 100 random test patches, errors between the forward model and the associated measures provide the following results for the video projector:

- Average error ΔE1976 = 2.32
- Standard deviation ΔE1976 = 1.66
- Maximal error ΔE1976 = 8.45

These colorimetric errors are within the acceptable range for visualization purposes [11-12].

3.2. Stimuli

Figure 4 represents the thumbnails of the 7 paintings selected for the experiment. Paintings have been chosen in order to have different colour palettes and different styles from Fra Giovanni da Fiesole (Italian Renaissance), Giannicola di Paolo (Italian High Renaissance), Jan van Kessel (Baroque), Renoir (Impressionism) to Van Gogh (Post-impressionism).

Participants were presented with displayed stimuli made of a segmented colour image centred on a uniform background simulating the wall on which a painting could be hung (see Figures 6-8). All displayed stimuli were managed according to the colour flow introduced in section 2.

Colour RGB images of the 7 selected paintings were firstly computed from the available multispectral data. These images were then coarsely segmented as shown in Figure 5. Such a segmentation process was managed by averaging colour information on a mosaic of hexagonal patches [13-14]. All patches have the same size and they realize a pavement of the original image. The size of patches is adjusted according to the visual angle sustained by the fovea. It determines the number of patches captured by the human eye when observing the working image at a given distance.

Figure 5. *Coarse segmentation (right) of a colour image computed from multispectral data (left)*

The first advantage of our approach is that it is not driven by the choice of a segmentation algorithm and by the setting of associated parameters. There is a single control parameter derived from the number of patches that the subject should see in his foveal visual field at a given distance of observation. In the context of the experiment presented in this paper, participants were located at a distance of 2.5 meters from the projected image. Each stimulus covered the whole visual field of observers when fixating its centre and each hexagonal patch had a size corresponding to a visual angle of 2° i.e. the visual field of the fovea.

The second advantage of our approach is that the shape of objects is masked after segmentation. Then, we can assume that only colour information of paintings focused the attention of participants during the psychophysical experiment. The study of colour harmony was not biased or corrupted by salient objects or spatial structures.

To study the colour harmony of the combination art paintings / walls, 3 different types of backgrounds were used (see section 2.3). The 3 following parameters were modulated:

a. Luminance levels

For achromatic backgrounds that are the same for all paintings, 10 luminance levels were selected in the CIELAB colour space. As shown in Figure 6, the luminance was changed with a regular step from black (luminance = 0) to white (luminance = 100).

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Figure 4. *Thumbnail of the 7 paintings used for the psychophysical experiment. Image 1: The bedroom (1888) by Vincent Van Gogh. Image 2: Portrait of a young man and a young woman (1876) by Pierre-Auguste Renoir. Image 3: Naked woman in a landscape (1883) by Pierre-Auguste Renoir. Image 4: Gabrielle and Jean (1875) by Pierre-Auguste Renoir. Image 5: The Baptem of Christ by Gionnicola di Paolo. Image 6: A singerie: monkey barbers serving cats by Jan van Kessel. Image 7: Conversion of Saint-Augustine (1436), Fra Giovanni da Fiesole*

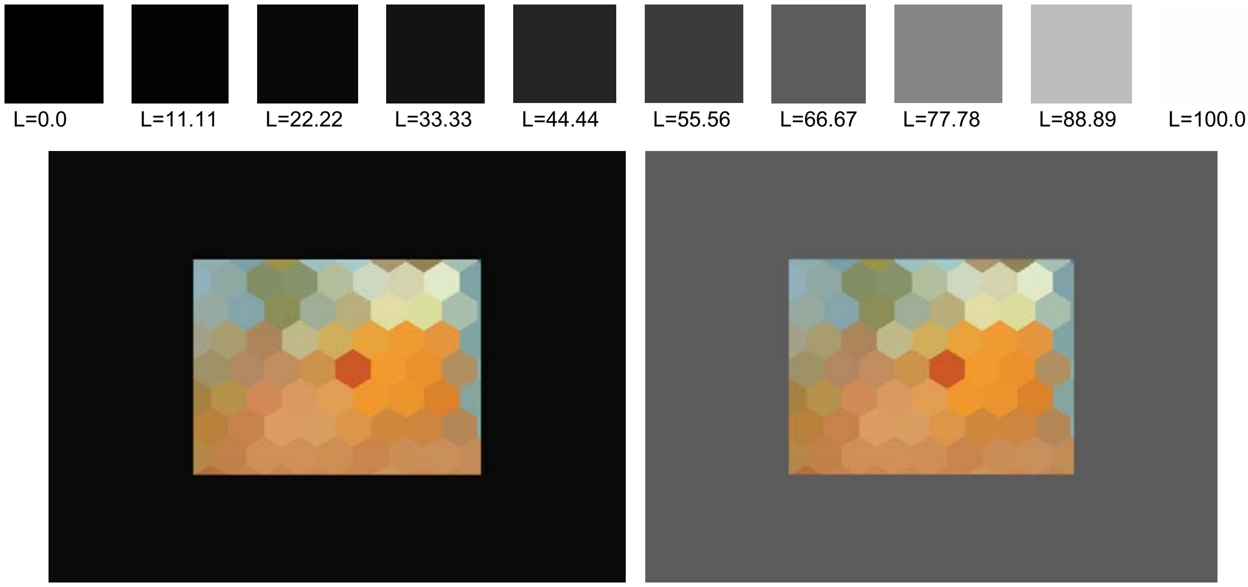

Figure 6. *Top: Levels of luminance used for achromatic backgrounds. Bottom: Example of a segmented colour image displayed on two different achromatic backgrounds*

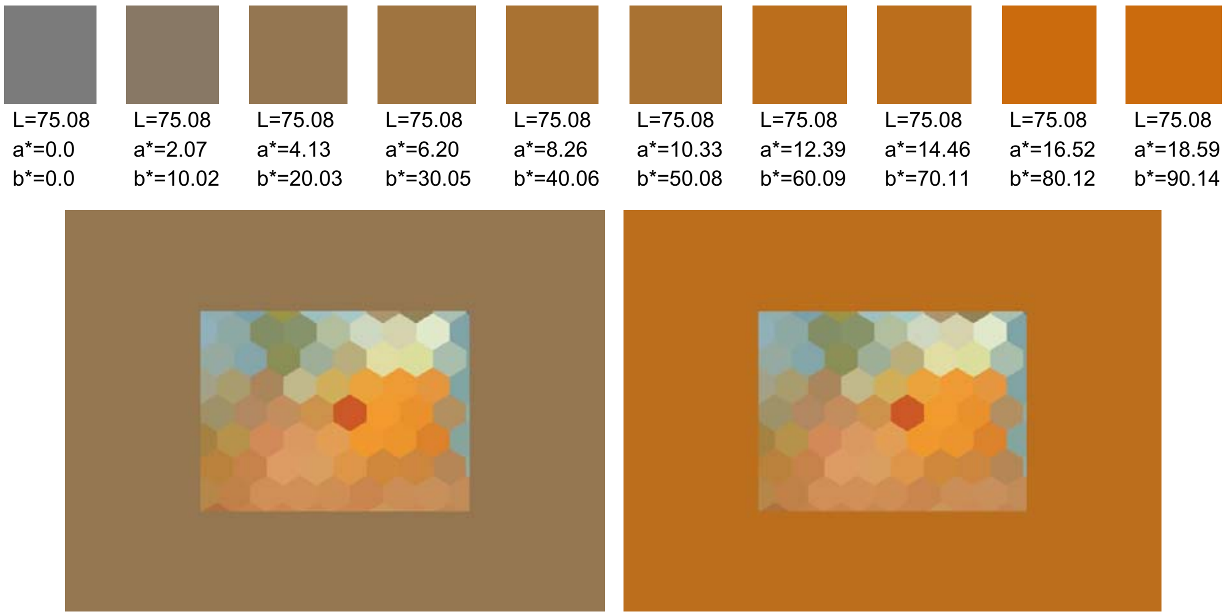

Figure 7. *Top: Colours derived from the global average colour of the segmented image shown in Figure 5. Bottom: The segmented image displayed on two different backgrounds.*

b. Average colours

For this type of chromatic backgrounds, the global average colour of the segmented image that has to be displayed was firstly calculated. This means that these backgrounds depend on the colour content of the considered image.

As explained in section 2.3, an isoluminant line segment can be defined in the CIELAB colour space. Such a line segment allows determining 10 distinct points regularly spaced. The chromatic coordinates of these points provide the colours of the different backgrounds.

c. Complementary colours

For this type of chromatic backgrounds, the global average colour of the segmented image that has to be displayed was converted into its complementary through the CIELHC colour space. This means that these backgrounds depend on the colour content of the considered image.

As explained in section 2.3, an isoluminant line segment can be defined in the CIELAB colour space. Such a line segment allows determining 10 distinct points regularly spaced. The chromatic coordinates of these points provide the colours of the different backgrounds.

3.3. Procedure

Each participant was asked to assess 210 different stimuli: 7 paintings × 3 types of backgrounds × 10 backgrounds. The stimuli were randomly presented to observers and between each stimulus a grey screen was displayed during 2 s [15].

The observers had to answer to two questions as fast and accurately as possible. First, they were asked to estimate the colourfulness through a scale from 1 (poor) to 7 (rich). Then, they were asked to judge colour harmony. Participants had the choice between 3 distinct answers: “Colours are harmonious”, “Colours are not harmonious” and “Hard to say”.

The colourfulness was defined to the observers as the opposite of a black and white picture [4]. All subjects were also instructed that colours are said harmonious when producing a pleasing visual effect [6-7].

The first question was used as a distractor to let observers mainly focus on something different from colour harmony. By this way, participants could more spontaneously answer to the second question which is the centre of the present study.

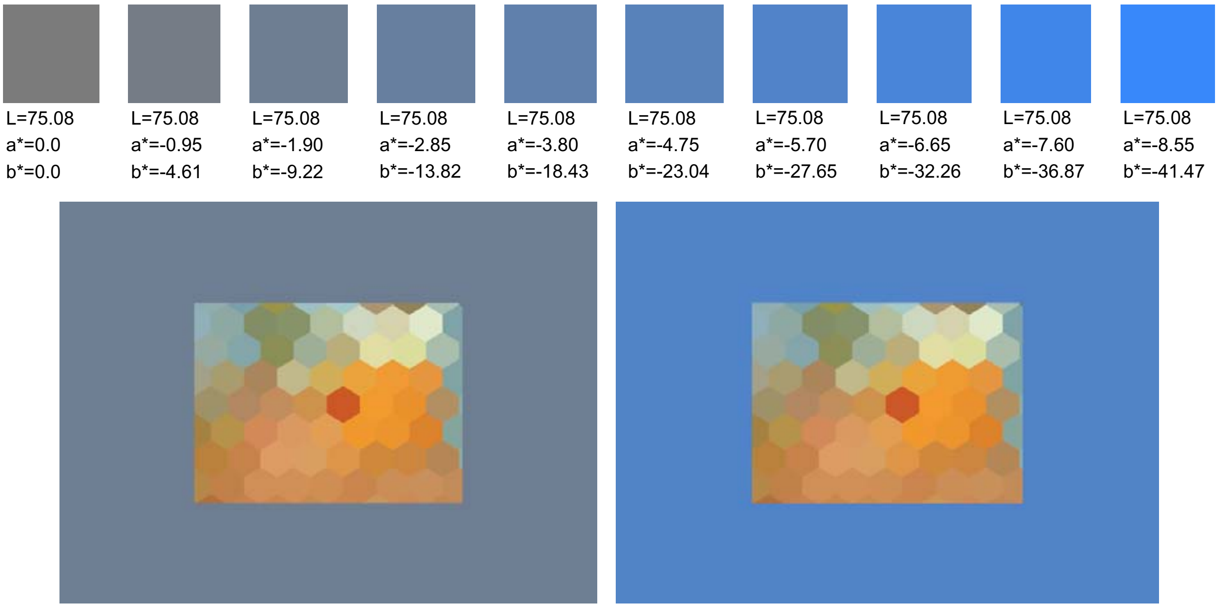

Figure 8. *Colours derived from the complementary of the global average colour of the segmented image shown in Figure 5. Bottom: The segmented image displayed on two different backgrounds*

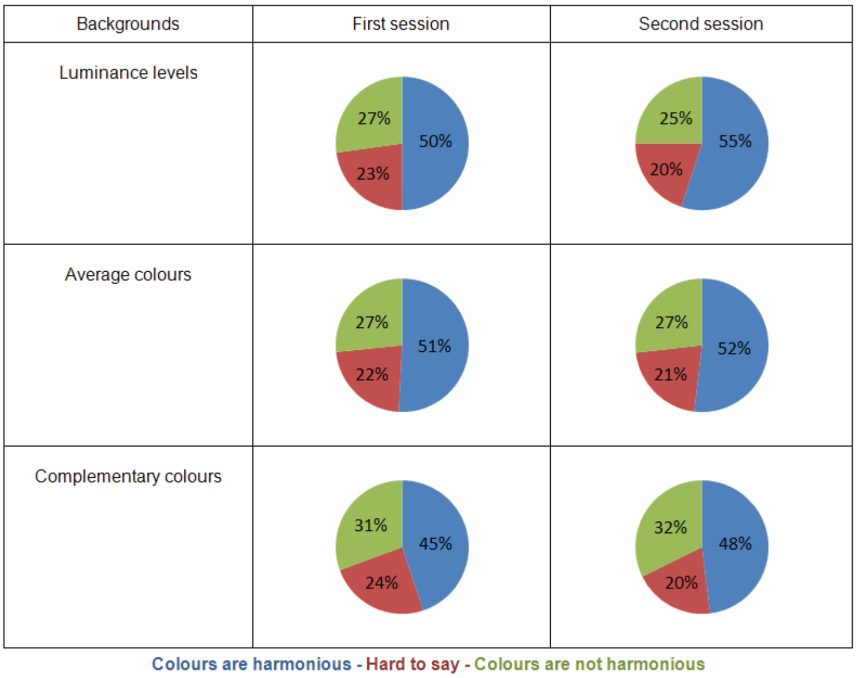

Figure 9. *Percentages obtained during both sessions of the experiment for the 3 possible judgements concerning colour harmony between the displayed image and its background.*

4. Experiment

The global number of answers “Colours are harmonious”, “Colours are not harmonious” and “Hard to say” is almost the same between both sessions of the experiment. As shown by Figure 9, such a stability holds for the 3 different types of backgrounds. There is a clear correlation between the results recorded during the two distinct sessions. We can also notice that the global number of answers “Hard to say” always decreased between the first and the second session respectively. It suggests that observers were more confident during the second session. The presence of an alternative choice which was neither “Colours are harmonious” nor “Colours are not harmonious” could explain the stability of the results between both sessions [16].

The global number of answers “Hard to say” is roughly the same for the 3 different backgrounds used during the experiment. Whatever the colorimetric nature of the background, the difficulty in judging the colour harmony was the same for the participants.

There are no significant differences between the judgements recorded for achromatic backgrounds and backgrounds based on the average colour of the displayed images. The rate of answers “Colours are not harmonious” increased for the backgrounds based on the complementary colours. Observers tended to judge that displaying a colour image on such a background produces more often an unpleasant visual effect than using a uniform achromatic background or a uniform chromatic background based on the global average colour.

Table 1 presents the differences between the answers “Colours are harmonious” and “Colours are not harmonious” recorded with the 38 participants during both sessions of the experiment. Results of Table 1 are obtained for the 10 backgrounds determined from the average colour path. For each image (i.e. for each line of the table), the blue boxes point out the 2 backgrounds with the colour coordinates corresponding to the 2 points located on both sides of the average colour on the chromatic path (see Figure 3).

According to the recorded values, we can clearly notice that, apart for Image 2, observers judged that the best colour harmony is obtained when the colour of the backgrounds is very close to the global average colour of the displayed image. The particularity of Image 2 may be explained by the characteristics of its chromatic content. This painting is based on two dominant colours that are more or less complementary, a dark purple and a dark green. Then, the corresponding global average colour for this image is nearly achromatic and such a feature could divide the opinion of observers concerning the background that generates the stimulus with the best colour harmony. This hypothesis will be studied and clarified in a future work.

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Table 1: Differences between answers “Colours are harmonious” and “Colours are not harmonious” for the 10 backgrounds derived from the chromatic path based on the average colour of the displayed image. Blue boxes correspond to the 2 backgrounds having the closest colours to the average one

Images	First session										Second session									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	11	8	10	19	11	16	9	6	10	10	14	9	14	20	17	6	4	-1	1	2
2	18	7	12	15	17	12	14	7	12	15	17	4	15	17	18	14	5	5	4	14
3	13	21	23	18	20	16	15	15	8	2	13	18	20	20	20	11	6	-3	-11	-5
4	7	14	18	18	22	16	11	14	11	2	13	12	18	22	16	16	5	3	-1	1
5	6	7	4	15	18	12	14	14	11	14	13	13	14	19	21	22	18	18	14	10
6	-5	-4	7	7	5	2	4	5	1	-6	10	6	11	8	8	4	9	4	-1	-1
7	-2	-5	0	3	5	4	0	-2	-4	-7	3	5	12	9	10	10	7	5	-2	-4

Table 2: Differences between answers “Colours are harmonious” and “Colours are not harmonious” for the 10 backgrounds derived from the chromatic path based on the complementary colour of the displayed image

Images	First Session										Second Session									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	15	9	14	19	16	11	16	14	4	6	19	14	16	15	9	6	1	1	-5	-6
2	14	17	12	10	4	1	-4	-6	-10	-10	20	17	6	-2	-3	-3	-9	-18	-17	-18
3	20	19	20	15	19	17	11	11	2	2	23	24	25	19	19	4	8	3	-7	-10
4	20	10	12	11	8	4	-1	1	2	-3	18	23	21	16	8	2	-3	-7	-8	-7
5	10	11	6	10	8	5	3	3	4	7	14	19	23	18	15	14	9	6	4	2
6	0	3	4	5	-2	1	-6	-10	-5	-4	11	14	10	5	6	4	2	-2	-8	-9
7	-5	3	5	0	-1	-5	-1	-3	-7	-12	10	17	12	12	11	0	2	0	-7	-9

Table 3: Comparison of the differences between answers “Colours are harmonious” and “Colours are not harmonious” for white backgrounds and for backgrounds based on average colours

Images	Backgrounds	
	White	Average colour
1	4	20
2	3	15
3	9	20
4	8	22
5	15	22
6	-7	8
7	7	10

Table 2 presents the differences between the answers "Colours are harmonious" and "Colours are not harmonious" recorded for the 10 backgrounds determined from the complementary colour path. Results are very different from those obtained with backgrounds based on average colours. For complementary colours, participants judged that the best harmony arises for the darkest backgrounds. It suggests that images displayed on the complementary of their global average colour produce an unpleasant visual effect for observers. Such an unpleasant visual effect is decreased when darkening the background i.e. when colour fades. But Table 2 clearly shows that fading the complementary colour by decreasing its saturation does not improve the colour harmony. This result also holds for backgrounds having the global average colour of the displayed image.

The differences between answers "Colours are harmonious" and "Colours are not harmonious" for white backgrounds and for backgrounds based on average colours are reported in Table 3. The values in column "Average colour" correspond to the data recorded during the second session of the experiment for backgrounds that have the colour given by the point lying on the chromatic path and located between the average colour and the L-axis of the CIELAB colour space (see Figure 3). Such a choice of data is driven by two criteria: during the second session, observers are more self-confident and respond more spontaneously than during the first session, and the background have the most desaturated colour closest to the average colour point of the chromatic path.

Table 3 demonstrates that the optimal colour harmony is produced when using average colours and not when using a white colour for backgrounds. To optimize the visual sensation of observers and to enhance the perception of colours, it is better to adapt the colour of the background according to the chromatic content of images to display. A white background is not a standard and always the most appropriate choice in terms of colour harmony.

5. Conclusion

The purpose of this paper was to study the colour harmony of the combination art paintings / walls. As it is extremely difficult to conduct psychovisual experiments with a lot of observers by using real fine art paintings and different coloured walls, we chose to work by simulation. Then, each combination painting / wall was approached by displaying a colour image on a uniform coloured background through a calibrated video projector. Colour images represented 7 paintings covering different palettes and artistic styles. They were all digitized with a multispectral device that was perfectly characterized and calibrated. A dedicated colour management algorithm was used to eliminate all the problems introduced by gamut limitations and by the white point reference. Finally, as the study concerned colour harmony, all images were coarsely segmented in order to mask spatial structures and to exhibit only colour information.

Participants were asked to judge the colour harmony of different combinations between wall (backgrounds) and paintings (segmented images). Achromatic and chromatic backgrounds were tested.

Our study showed that backgrounds having a colour corresponding to the global complementary colour of the displayed image never generate pleasant visual sensations. Experiments clearly demonstrated that white backgrounds do not lead to the best colour harmony. To optimize the colour harmony it is more relevant to choose the colour of the background according to the global average colour of the segmented image.

Regarding to the results of the study presented in this paper, we can argue that white walls are not the best supports for fine art paintings in terms of colour harmony. If the colour of the wall on which the painting will be presented is adapted to the chromatic content of the artwork, the colour harmony will be optimized. Our study shows that the colour of walls in museums play an important role. A fine art painting hung on walls of different colours triggers different visual perceptions.

For this work, we deliberately used different styles of paintings to cover a large range of stimuli. In an upcoming survey, we will address the same problem of colour harmony with paintings from one artist.

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Author Biography

Sabrina Lachheb received her Master degree with honours in Science, Technology, Vision and Signal in 2009 from University Jean Monnet, Saint-Etienne, France. She spent nine months working for the C2RMF as an internship. She recently joined the specialized Master Degree in International and Industrial Project Management and she is currently studying in the French National Graduated Management and Engineering School (Ecole Nationale Supérieure des Mines).