Supporting history of art with colorimetry: The paintings of Amadeo de Souza-Cardoso

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Abstract
Colour is a key element in paintings but its quantitative analysis is seldom used as an interpretative element in the context of the history of art. Here, we show how this can be accomplished by measuring and analyzing the colours of the paintings of the influential Portuguese painter Amadeo de Souza-Cardoso (1887-1918). His last paintings have been classified by art historians as the most successful and are considered a chromatically homogeneous nucleus in his career. However, there are no quantitative data supporting these considerations. To access this we compared 24 of his paintings (1911-17) using hyperspectral imaging data. From estimates of the number of colours that can be perceived in each painting we show that in the later works Amadeo has expanded the range of colours by including more hues and more levels of lightness. Moreover, the paintings dated from 1917 have similar chromatic distributions in colour space. This colorimetric analysis revealed to be an important tool that provides quantitative support to the hypothesis formulated by art historians.

KEYWORDS
colorimetry, discernible colours, history of art, paintings, spectral imaging

1 INTRODUCTION

The chromatic diversity in paintings is a very important property that traditionally is evaluated qualitatively by visual observation. Spectrophotometers are commonly used to perform a quantitative colorimetric analysis on artworks, but they are, generally, limited to small sampling areas, providing local and very limited colorimetric information. Modern multi and hyperspectral imaging techniques allow improvements on the quality and on the spatial resolution of traditional colorimetric analysis. Using spectral imaging instead of spectral sampling it is possible to estimate the colorimetric values of each pixel of a painting and therefore represent accurately color information of the entire painting in different color spaces. Hyperspectral imaging data are widely used in cultural heritage, e.g., to map pigments and dyes in paintings and in manuscripts, to simulate cleaning processes in paintings, to study visual effects of illumination and to explore aesthetic aspects of visual perception of paintings. Some studies already reported tools to visualize the distribution of paintings’ colorimetric data acquired by multi and hyperspectral devices but, have seldom been used as tool to support research in history of art.

Here, we describe a methodology that can be used to analyze and compare the chromatic properties of different paintings. The analytical parameters may be used to compare
paintings belonging to the same artists, helping art historian investigations by highlighting discontinuity points in an artist career. Or, on the other hand, to compare works from different artists belonging to the same group or school, highlighting similarities and influences between artists. We tested the methodology on a set of paintings by the Portuguese painter Amadeo de Souza-Cardoso (1887–1918). Amadeo’s paintings were shown at important exhibitions such as the Salons de Paris (1911–1912), the Armory Show (1913) and, recently, at the Grand Palais in Paris (April–July 2016). He was educated in Portugal but between 1906 and 1914 lived in Paris, where he developed a creative dialog with the artists of the avant-gardes. This dialog was partially interrupted in 1914 due to the beginning of the First World War and his consequent return to Portugal, where he died prematurely a few years later.

Art historians consider colour as one of the most important features in Amadeo’s works, and they identify in his last works (1917) a homogeneous nucleus in which he developed a personal stylistic method. Although he maintained the use of high quality artists’ oil paints, in a set of 6 paintings he experimented different textures by adding sand or starch, and included collages of daily-life materials as matches, hair clips and mirrors. How his use of colour accompanied this experimentation of materials and techniques? What new insights could colorimetric and comparative analyses bring?

To answer these questions and to provide further tools to assist art historians’ studies, the chromatic properties of his

FIGURE 1 Colour thumbnails of the 24 paintings of Amadeo de Souza-Cardoso analyzed in this work (Photographic Archive CAM-FCG). The paintings are from the collection of the CAM-FCG in Lisbon. The code used to identify the paintings (P#) refer to the numeration used in 20
works where characterized, quantified and compared with
data obtained from hyperspectral imaging techniques. The
analysis was based on 24 selected paintings representative of
different periods of Amadeo’s career (Figure 1) and focused
on comparing the colours of the last paintings (P196-P201)
with those of the previous ones (P29-P172).

2 | MATERIALS AND METHOD

Figure 1 shows images of the 24 paintings analyzed.20 In the
period 1916–1917 Amadeo painted at least 6 paintings (P196-P201 in Figure 1), three of which with the same
dimensions (93x76 cm).18 In these works he included uncon-
tventional materials such as spheres of silica, sand, mirrors,
hair clips and matches.21 These paintings are considered as
an homogenous nucleus and the most representative of his
career.18–20 They have a characteristic colour palette22 and a
common language, where each element of the composition
has multiple meanings.16 These considerations are, however,
of a qualitative nature and have limited quantitative support.
The painting materials and techniques used by Amadeo in
these paintings are described in detail elsewhere.21,23

The spectral digitalization of the paintings was carried out
from 400 to 720 nm in 10 nm intervals. Detailed description of
the system and acquisition methodologies is given by Pinto et
al.24 Spectral imaging data were calibrated using the spectrum
of the light reflected from a gray reference surface placed in
the scene and covered with a matt gray emulsion paint with
the spectral reflectance of Munsell N7. The estimate of the
spectral reflectance of each pixel of the image was obtained
after corrections for dark noise, spatial nonuniformities, and
stray light and has an accuracy of about 2%.14

The analysis of the chromatic properties of the paintings
was carried out in the CIELAB colour space. The spectral radi-
ance from each pixel was estimated assuming the CIE standard
illuminant D65. The corresponding colour was computed by
converting the radiance into tristimulus values assuming the
CIE 1931 standard colorimetric observer and converting it into
the CIELAB colour space25 were each point represents a col-
our. As illustration, Figure 2 shows the representation in CIE-
LAB space of the colours of two of the paintings analyzed. All
images were acquired without intruding the painting.

3 | RESULTS

3.1 | Gamut analysis

To compare the colour distributions of the paintings in the
CIE ($a^*$, $b^*$) plane an ellipse was fitted to the data of each

![Figure 2](image-url)
painting (Figure 2C). Figure 3A shows the centers of these ellipses, representing the average colour of each painting. All paintings are distributed in the upper quadrants of the colour space ($b^* > 0$). A shift from green-yellow to orange-red occurred during the period analyzed. The paintings dated 1913-14 show a high yellow component. Figure 3B shows the angles of the longer axis of the ellipses with respect to the positive CIELAB $a^*$ axis. These angles give the orientation of the colour gamut of each painting. There is no clear relationship between the angles and the date of the paintings, except for the paintings dated 1917 which show similar angular values. The axis ratios of the ellipses of each painting are presented in Figure 3C. They also show similar values for the later paintings. Figure 3D shows that in the last six paintings (dated 1917) Amadeo used a wider average gamut of colours comparing with the previous paintings.

### 3.2 Number of discernible colours

The number of discernible colours (NDC) for each painting was estimated by segmenting the corresponding CIELAB colour volume into unitary volumes and by counting the number of unitary cubes containing at least the colour of one pixel. This methodology produces a reasonable estimate of the number of colours that can be perceived in the paintings.\(^{26,27}\) Figure 3E shows the NDC for each painting. The paintings dated 1911-16 do not show any regular pattern, whereas the paintings P172 (1916) and P196-P201 (1917) show similar NDC with a mean value of 113,600, which is higher than for most paintings before. The average values for the 4 periods are: 74462, 66068, 75396 and 111245 respectively.

### 3.3 Distribution of the number of discernible colours

The NDC contained in consecutive 20 cylindrical shells of increasing radius $r$ and thickness of 5 CIELAB units was estimated (Figure 4A, left). This analysis gives information about how the number of colours varies with chromatic saturation. In a similar way, the NDC contained in 20 circular annuli with the same radius and thickness as the shells was also estimated (Figure 4A, right). This analysis gives information about how the number of hues varies with saturation as the analysis discards lightness values.

Figure 4B shows the estimated NDC contained in the 20 cylindrical shells. It is clear that Amadeo’s paintings from 1917 used a higher NDC comparatively to the previous paintings. Note that the distribution and the position of the maximum of the NDC in both groups of
paintings are very close. The maximum of the NDC is in the region $15 < r < 25$, characterized by unsaturated colours. Figure 4C represents the estimated NDC contained in 20 circular annuli instead of cylinders and shows that Amadeo’s last paintings increased the range of saturated hues in comparison with previous paintings, as the curve correspondent to the later period paintings is higher for large values of $r$. Nevertheless, in the case of using circular annulus, as for the cylindrical analysis, the distribution and the position of the maximum of the NDC in both groups of paintings are very similar.

The ratio between the NDC computed in the cylindrical shells and in the circular annulus represents the average number of colours used by the artist for each hue and gives information concerning the use of the lightness in each part of the colour space. Figure 4D shows that Amadeo used the lightness to increase the number of colours in the unsaturated region of the colour space $15 < r < 25$ but not for the saturated colours. Despite that the analysis of the average distribution of the lightness Figure 3F shows that Amadeo’s paintings have a lightness value uniformly distributed around the mean value $L^* = 50(\pm 15)$.

### CONCLUSIONS

The mean colour in the early Amadeo’s paintings shifted from green-yellow tones to orange-reddish tones in the later works. No common clusters or trends were identified in the paintings dated 1911–1916. This result may support the hypothesis that considers the paintings of his early phase as the result of a convergence of different artistic influences.\(^{17}\)

The analysis of the gamut orientation and NDC show that the paintings dated 1917 are extraordinarily close, supporting art historian’s hypothesis that interprets these artworks as a homogeneous nucleus inside the Amadeo’s career. In particular, it was found that in these paintings Amadeo increased the NDC. The analysis of the distribution of NDC showed that this effect is partly due to an increase of the saturated hues, but above all to an increase in the number of the lightness levels in the unsaturated colours.

These colorimetric comparisons, only made possible by the nondestructive or nonintrusive imaging technique which is the hyperspectral imaging technique, have proven to be an important tool that provides a fast comparative and global analysis providing a basis for quantitative support to
hypothesis formulated by art historians. Moreover, this analysis highlights new data which may suggest further direction of investigation concerning the technique used by the artist and the relation between his artworks or limits to the use of the paintings he used and the techniques he implied to increase the chromatic content of his paintings.

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