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On the most representative colors of the national flag of Spain

Sobre los colores más representativos de la bandera de España

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ABSTRACT:

We report the results of a visual experiment where 53 adult observers with normal color vision, born and living regularly in Spain, were asked to obtain the colors of the flag of Spain they considered most representative. Observers used a laptop screen and software developed by us with six sliders that allowed independent changes of lightness, chroma and hue for the red and yellow stripes of the Spanish flag. We found no statistically significant differences between the colors reported by civil/military (p=0.150) or male/female (p=0.432) observers. Each observer performed two trials, on consecutive days, with average intra-observer variability being 14 and 17 CIELAB units for red and yellow, respectively. Inter-observer variability, or mean color difference with respect to the mean, was 13 and 17 CIELAB units for the red and yellow, respectively. Chroma differences were the main components in intra- and inter-observer variability. CIELAB ellipsoids were reported, including 95% of the red and yellow stimuli selected by observers. In addition to individual colors, observers in our experiment also paid attention to red-yellow contrast. Color differences between legal values and average visual values in our experiment were 24 and 20 CIELAB units for red and yellow, respectively. The methodology described in this paper may be useful for future quantitative color specifications of other flags as well.

Key words: Vexillology, colorimetry, Spanish flag, color difference, CIELAB.

RESUMEN:

Presentamos los resultados de un experimento visual en el que 53 observadores adultos con visión normal del color, nacidos y residentes habituales en España obtuvieron los colores de la bandera de España que consideran más representativa. Los observadores usaron una pantalla de ordenador portátil y software desarrollado por nosotros con seis deslizadores que permiten cambios independientes de claridad, croma y tono para las franjas rojas y amarilla de la bandera de España. No se detectaron diferencias estadísticamente significativas entre los colores elegidos por observadores civiles/militares (p=0.150) ni hombres/mujeres (p=0.432). Cada observador realizó dos elecciones, en días consecutivos, siendo la variabilidad intra-observador promedio de 14 y 17 unidades CIELAB para los colores rojo y amarillo, respectivamente. La variabilidad inter-observador promedio, o diferencia de color media respecto al color promedio, fue de 13 y 17 unidades CIELAB para los colores rojo y amarillo, respectivamente. Las diferencias intra-observador e inter-observador se deben principalmente al atributo croma. Damos los elipsoides CIELAB que incluyen el 95% de los estímulos rojos y amarillos elegidos por los observadores. Detectamos que los observadores prestaron atención al contraste rojo-amarillo además de a los colores individuales. Las diferencias de color entre los valores legalmente establecidos y los valores promedio obtenidos en nuestro experimento visual fueron de 24 y 20 unidades CIELAB para los colores rojo y amarillo, respectivamente. La metodología

del presente trabajo puede ser útil para futuras especificaciones colorimétricas cuantitativas de los colores de otras banderas.

Palabras clave: Vexilología, colorimetría, bandera España, diferencia de color, CIELAB.

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1. Introduction

Flags are symbols of great social and emotional significance, in which shapes and colors often play a key role [1,2]. The colors of national flags can have complex meanings linked to a country's history, identity or values [3-5]. Unfortunately, however, within the science dedicated to the study of flags —known as vexillology— little attention has been paid to the quantitative specification of color. Most regulations concerning flags ignore the recommendations of the International Commission on Illumination (CIE) for color specification [6], which could be summarized as the use of the CIELUV and CIELAB color spaces. For example, in current legislation on the flags of Spain's autonomous communities and cities [7] or on the flags of the 27 member states of the European Union [8], color specifications are based on a wide variety of systems not recommended by the CIE —Pantone in particular—, which makes accurate color communication very difficult and hinders standardization.

The current flag of Spain is the one adopted by King Charles III in 1785 [9], with colors regulated by Royal Decree 441/1981 [10], which specifies the x, y, Y and CIELAB coordinates of the colors red and yellow under CIE illuminant C and CIE 1931 standard observer, with a tolerance of 5 CIELAB units. Reference [10] states that colorimetric specifications of the Spanish flag were established by the Military Standardization Service in collaboration with the National Institute of Rationalization and Standardization (IRANOR), and we know that Lorenzo Plaza Montero (1923–2012), Research Professor at the Spanish National Research Council, worked on the development of these specifications. However, the specific method followed to arrive at the values indicated in reference [10] are unknown. In any case, it is worth noting that the legal colorimetric values currently in force for the Spanish flag refer to CIE illuminant C, which is not a CIE standard illuminant [6]; these should therefore be updated using current CIE standard illuminants (D65, D50 and A).

Among the methods used for quantitative specifications of the colors of national flags, we might mention the consultation of legislative provisions [8] and the performance of instrumental measurements of historical flags [11] or flags displayed at relevant state institutions [7]. In this paper we propose a different approach to analyzing the color of a national flag, reporting results of a visual experiment in which native adult observers were asked to choose the flag they considered as best representing their country. As far as we know, this approach is original and has not been used for any national flag in previous literature. One advantage of our approach is that it allows estimations of average colors of flags, as well as visual color tolerances that could be useful for both legislators and flag manufacturers. As with any other physical quantity, it must be remembered that the numerical specification of color is just as important as its uncertainty or tolerance.

We might think that the most representative colors of a country's flag are, on the one hand, those established by its official legislation and, on the other hand, those that resonate with the people who were born and live in that country. For various reasons, it is possible that the colors legally established for a national flag may not be representative of a significant percentage of the country's citizens. In such a case, lawmakers should be aware of this fact and take it into account in future regulations. This article focuses on the colors of the current national flag of Spain, comparing those considered most representative by a national population with those established in legislation. Hopefully, the results in the current article may inspire future studies on useful quantitative specifications of colors of other national flags.

2. Materials and methods

2.a. Observers

We recruited 56 volunteer observers with normal color vision, all of whom were born and live regularly in Spain, to perform a visual experiment concerning the most representative colors of the Spanish flag. These 56 observers were divided into two main groups: one comprising 20 professional soldiers from the Spanish Army, the other comprising 36 civilian observers drawn from students and staff from the University of Granada and the Complutense University of Madrid. A distinction between military and civilian observers was made because it was suspected that military observers might be more familiar with the national flag. Among civilian observers, the proportion of men and women was balanced, but this was not possible for the group of military observers due to the nature of the military unit in which these observers worked. Observers wearing non-tinted glasses or contact lenses for near vision used them during the experiment. As described below, visual results in our experiment indicated the presence of three outlier observers, who were discarded from our analyses; Table 1 thus shows the principal characteristics of the remaining 53 observers who participated in this visual experiment. The 53 observers were adults with an average age of 47 years (standard deviation of 12 years).

TABLE 1. Main characteristics of the 53 observers (3 outliers discarded) participating in the visual experiment.

	Number	Average age (years)	Standard deviation (years)
Male civilian	11	55	11
Male military	16	47	5
Female civilian	24	42	14
Female military	2	46	4

The visual experiment was carried out in darkened rooms at two universities and a military barracks. First, each observer confirmed that he/she was born in Spain, lived regularly in Spain, and had normal color vision (if necessary, this was tested using the Ishihara test). Next, each observer was instructed in the use of experiment's interface (see next subsection) and the task to be performed which was to obtain the colors of the flag of Spain would be considered as most representative by Spanish citizens (i.e., the flag that would be unanimously agreed upon by most people born in Spain). The experimenter briefly explained to each observer the concepts of lightness, chroma, and hue, and used the sliders in the interface to demonstrate how adjusting each slider affected in a different way the color appearance of each stripe on the flag. Once it was confirmed that the observer had understood the requested task and how to carry out the experiment, he/she was asked to take control of the mouse to start the experiment. In a previous paper, researchers in China had asked native observers about the colors of their national flag under different contexts and reported the influence of such contexts for selected colors [12]. In our experiment, however, the observers were told that the goal was not to obtain the flag they personally preferred nor the flag they would associate with a specific context. Each observer performed two replications of the experiment on consecutive days. In this way, it was possible to compute intra-observer variability (i.e., the color difference between the two trials), as well as inter-observer variability (i.e., the mean color difference between results for each observer and the average of the 53-observer panel), which was useful for quantifying the magnitude of visual tolerances in our experiment.

2.b. Experimental setup

The experiment was carried out using an ASUS UX430UA-GV264T laptop with a 14-inch screen and software developed by us. Legal regulations indicate that the flag of Spain for general use does not feature the coat of arms [13], whose elements have regulated color coordinates [14]. Therefore, in the interest of simplicity, for our experiment we used the flag of Spain without the coat of arms. Starting with a flag of standard dimensions but with very different colors from the official ones [10] (see Figure 1, above), each observer adjusted the six sliders on the right-hand side of the screen, which allowed independent modifications of lightness, chroma, and hue (the three main color attributes) for the two red stripes and the yellow stripe of the Spanish flag. The observers adjusted the sliders in whatever order they wished and had no time limit for completing the requested task, which was to obtain the flag of Spain that he/she considered most representative or acceptable for native Spanish citizens. Color is three-dimensional, and it was necessary for observers to be able to modify the lightness, chroma, and hue [15] of the stripes independently to achieve the proposed goal. When the observer indicated that this goal was achieved (see Figure 1, below), the positions of the sliders were recorded using the icon "Copy" and the visual experiment was finished. Usually, the time spent by observers to achieve the goal was under five minutes.

More specifically, the flag shown to observers measured 16.5 cm wide by 11.2 cm high, while the background behind the flag was 21.0 cm wide by 14.5 cm high. Each slider measured 2.4 cm wide by 0.8 cm high and the right area of the screen where all sliders are shown measured 9.5 cm wide by 14.5 cm high. The observers looked at the screen from approximately 40 cm away, and at a right angle to it. The position of the laptop on the table and the tilt of the screen were the same for all observers. The screen of the ASUS UX430UA-GV264T laptop features an anti-glare display with IPS (In-Plane Switching) technology minimizing color changes with variations of viewing angle. Fixing the heads of all observers in the same position using a chin rest was considered sophisticated and unnecessary for the goal of our experiment. The white background behind the flag and sliders (Figure 1) had CIELAB coordinates L^*=94, a^*=1.0, b^*=0, assuming the laptop screen as reference white with R=G=B=255. The number of steps for each slider was 100. Their ranges were considerably wide and fixed before the execution of the visual experiment, enabling all observers to easily perform the requested task.

Fig.1. Interface of the software employed in the visual experiment. Upper plot: Observers saw a flag with the legal dimensions of the flag of Spain but with colors that were very different from the official ones [10]. They then had to use the 6 sliders shown on the right side of the screen to perform the requested task. Lower plot: An example of the final flag proposed by an observer after modifying the initial positions of the sliders.

2.c. Color instrumental measurements

After the visual experiment was completed, we measured the tristimulus values X_{10}, Y_{10}, Z_{10} of the colors selected by each observer for the red and yellow stripes using a Konica-Minolta CS2000 spectroradiometer. To measure what each observer saw, the optical axis of the spectroradiometer was perpendicular to the laptop screen and its head was 40 cm from the screen. The spectroradiometer was focused on the center of the upper red and the central yellow stripes, with a measurement field of 1.0 degree. Our spectroradiometric measurements assumed the CIE 1964 standard colorimetric observer [6] according to the sizes of measured color stimuli (e.g., in our experiment each red stripe of the flag subtended a visual angle of 23.3 x 4.0 degrees). As indicated before, the legal colors of the flag of Spain currently refer to the CIE illuminant C and the CIE 1931 standard colorimetric observer [10]. Therefore, for proper comparison, all measured tristimulus values were referred to these conditions, using the two-step chromatic adaptation transform [16] adopted in the CIECAM16 color-appearance model [17], assuming average surround conditions (F=1) and an adapting luminance of 191 cd/m^2 corresponding to an outdoor illuminance of around 3000 lx. Finally, tristimulus values of corresponding colors were transformed into CIELAB coordinates to compute color differences. According to previous studies [18], color differences below 1.1 CIELAB units are perceptible for observers with normal color vision. In the present case, most color differences were above 5.0 CIELAB units, the upper limit for the current CIE/ISO recommended color-difference formula, CIEDE2000 [19], which was not employed in the current paper for this reason.

3. Results and discussions

3.a. Outlier observers

As indicated above, the results of our visual experiment were analyzed in CIELAB color space, under CIE illuminant C and CIE 1931 standard observer, because these are the legal specifications of colors of the flag of Spain [10]. A preliminary statistical analysis revealed violations of normality in the a* and b* coordinates of the color red, and so it was decided to use robust methods that do not rely on that assumption. Specifically, we detected outliers using the robust Mahalanobis distance, calculated with the MCD (Minimum Covariance Determinant) estimator from the R package "robustbase", which identifies the subset of observations whose covariance matrix has the smallest possible determinant [20]. The procedure was applied separately to the L*, a*, b* coordinates of the colors red and yellow, using scaled data (mean 0, standard deviation 1). The exclusion threshold was set at the 95th percentile of the chi-square distribution with three degrees of freedom: $\chi^2(0.95, 3) = 7.815$. We adopted a conservative approach, in such a way that an observer was excluded when he/she was an outlier for both red and yellow. Of the initial 56 observers, three met this dual criterion, which resulted in a final sample of 53 observers for subsequent analyses.

3.b. Observer's variability

As previously stated, each observer performed two replications of the visual experiment. The Box M test [21] assessed the equality of covariance matrices across groups. When applied to the six color variables corresponding to the two replications, the results found were $\chi^2(21) = 16.37$, p = 0.748. Therefore, the hypothesis of homogeneity is not rejected, and it can be stated that the two replications of the experiment exhibit a comparable pattern of variability. Table 2 shows that the average intra-observer variability for the 53 observers was 14 and 17 CIELAB units for red and yellow, respectively. Table 2 also shows the three components of CIELAB color differences (i.e. percentage of lightness, chroma, and hue differences in total color difference, designated as $\%\Delta L^*$, $\%\Delta C^*_{ab}$ and $\%\Delta H^*_{ab}$, respectively), and it can be noted that the two replications made by each observer differed mainly in chroma (46% for red and 49% for yellow).

TABLE 2. Average intra-observer variability and its components in CIELAB units (values rounded to the nearest integer number) for the 53 observers in our experiment.

	Average	$\%\Delta L^*$	$\%\Delta C^*_{ab}$	$\%\Delta H^*_{ab}$
Red	14	23	46	31
Yellow	17	17	49	34

To analyze the influence of the civil/military and male/female factors, we used a robust MANOVA implemented in rrcov::Wilks.test with method = 'MCD' and found that neither factor reached statistical significance [20]. For civil/military, Robust Wilks' lambda=0.644, Chi^2(Bartlett)=5.838 (df=3.36), p=0.150; for male/female, Robust Wilks' Lambda=0.784, Chi^2(Bartlett)=3.148 (df=3.38), p=0.432. We conclude that when the analysis is performed using robust estimators, there is no multivariate evidence that the factors civil/military or male/female produce significant differences in the selected colors. Table 3 shows the average inter-observer variability (also known in the literature as "mean color-difference from the mean," MCDM [22]) and its three components in CIELAB units for the colors red and yellow.

TABLE 3. Average inter-observer variability (MCDM) and its components in CIELAB units (values rounded to the nearest integer number) for the 53 observers in our experiment.

	Average	$\%\Delta L^*$	$\%\Delta C^*_{ab}$	$^*\Delta H^*_{ab}$
Red	13	18	43	39
Yellow	17	13	63	24

From Tables 2 and 3 we can note that intra-observer and inter-observer variability have similar magnitudes in the range of 13-17 CIELAB units, and in both cases chroma differences are the main components of total variability. This variability of 13-17 CIELAB units for selected colors relates to the specific task requested of the observers, which was to arrive at the most representative flag of Spain. Most likely, Spanish observers can recognize the flag of Spain with larger color differences from legal value than 13-17 CIELAB units in the red and yellow stripes. Therefore, the tolerance of five CIELAB units established in current legal regulation for the colors of the Spanish flag [10] is not related to visual aspects, but perhaps based only on the desirable goal of achieving consistent color reproduction in the manufacturing process. It has been stated [23] that 0.56 CIELAB units is the minimum color difference perceptible to the human eye; values between 1.1 and 2.8 CIELAB units represent strict color tolerances; between 2.8 and 5.6 CIELAB units represent a standard requirement in most situations; and values above 5.6 CIELAB units represent generous color tolerances.

3.c. Red-yellow color differences

The task for observers participating in our visual experiment was to report the flag of Spain they considered as most representative. Therefore, it can be hypothesized that our observers did not focus only on the individual colors of red and yellow, but more generally on the overall appearance of the flag itself. To confirm this hypothesis, we analyzed the CIELAB vectors joining the red and yellow colors selected by individual observers and found that they had relatively similar lengths: an average of 73 CIELAB units with a standard deviation of 13 CIELAB units (i.e., a variation coefficient of 18%). The average angle between individual red-yellow vectors and average red-yellow vector for all observers was 10 degrees, confirming the hypothesis that red-yellow contrast played an important role in our visual experiment.

3.d. 95% confidence ellipsoids

From CIELAB coordinates (illuminant C, CIE 1931 standard observer) corresponding to the visual results reported by the 53 observers, we have fitted ellipsoids that include 95% of the red and yellow selected colors, using the corresponding variance-covariance matrices [24]. These ellipsoids (Equation 1) are characterized by the values of their metric coefficients b_{ij} (i,j=1,2,3), which are shown in Table 4.

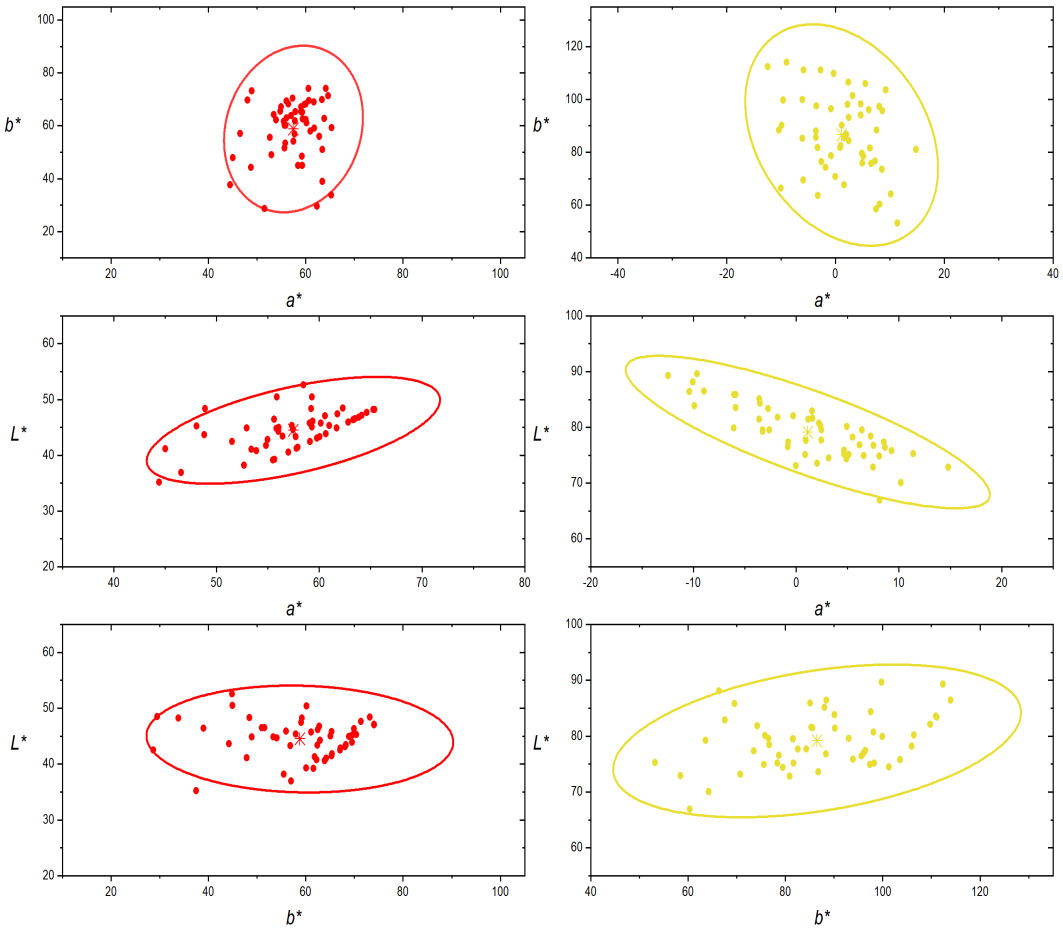
$$7.815 = b_{11}(\Delta a^*)^2 + b_{22}(\Delta b^*)^2 + 2b_{12}(\Delta a^*)(\Delta b^*) + 2b_{13}(\Delta a^*)(\Delta L^*) + 2b_{23}(\Delta b^*)(\Delta L^*) + b_{33}(\Delta L^*)^2 \quad (1)$$

TABLE 4. Metric coefficients (Equation 1) for the red and yellow 95% confidence ellipsoids obtained from average visual results of two replications made by the panel of 53 observers.

	b_{11}	b_{22}	b_{12}	b_{13}	b_{23}	b_{33}
Red	0.059468	0.008261	-0.004668	-0.051393	0.005514	0.129948
Yellow	0.074925	0.005173	-0.000188	0.079504	-0.006108	0.132859

Figure 2 shows the orthogonal projections (shadows) of the two 95% confidence ellipsoids with metric coefficients shown in Table 4 in the a^*b^*, a^*L^* and b^*L^* planes. The points in Figure 2 correspond to colors selected by each observer (average of two replications). The semiaxes lengths (rounded values to the nearest integer number) were 7, 16 and 32 CIELAB units for the ellipsoid of the red color, and 6, 20 and 43 CIELAB units for the ellipsoid of the yellow color, which indicates that neither of the two ellipsoids comes anywhere near being a sphere (Figure 2). Specifically, the variability of the L^* coordinate is considerably lower than the variability in the a^* and b^* coordinates for both ellipsoids. These ellipsoids are a more accurate representation of observer's variability than the MCDM values in Table 3. Anyway, 13 and 17

CIELAB units shown in Table 3 for colors red and yellow, respectively, are consistent with average lengths of 3 semiaxes of 95% confidence ellipsoids: 18 and 23 CIELAB units for red and yellow, respectively. As expected, ellipsoids containing 95% of selected colors had greater sizes than mean color-differences from the mean (MCDM). While most experimental chromaticity discrimination ellipses were radially oriented in



the a^*b^* plane [25,26], this is not the case in Figure 2. For example, for the red color the orientation of the major axis of the a^*b^* ellipse with respect to the +a* axis was 86 degrees, and the centre of the ellipse was at 46 degrees with respect to the +a* axis (i.e., there was a deviation of 40 degrees with respect to the radial orientation). This is not in fact surprizing, as the task of observers in our current experiment was not related to chromatic discrimination.

Fig. 2. Orthogonal projections (shadows) in the a^*b^*, a^*L^* and b^*L^* planes of fitted 95% confidence ellipsoids for the red (left column) and yellow colors (right column). The points in these plots indicate the average colors of two replications performed by the panel of 53 observers. The asterisks indicate the centers of the ellipses.

3.e. Comparison between legal and selected colors in our experiment

Table 5 shows the legal color coordinates for the red and yellow colors of the flag of Spain [10] and the corresponding average values found in our visual experiment. Table 6 shows CIELAB color differences (with their components) between the legal values [10] and the average experimental results, which were slightly

higher for red than for yellow (24 vs. 20 CIELAB units). This means that the colors on the legal flag of Spain and the average colors selected by the 53 observers were clearly different, as tried to show in Figure 3.

More specifically, from the CIELAB values in Table 5 we can note that the red selected in the experiment is lighter, more saturated and considerably more yellowish than the red of the legal flag (note that hue difference $\Delta \boldsymbol{H}^*_{\boldsymbol{ab}}$ is the main component in Table 6). For the yellow, the discrepancy between legal and experimental values is mainly in chroma ($\boldsymbol{C}^*_{\boldsymbol{ab}}$ 86.5 vs. 95.0 in Table 5, leading to 58% of the total color difference in Table 6). It is well known that visual chroma tolerances strongly increase with chroma [25, 26], which here have very high values (70.0 and 95.0 for red and yellow, respectively [10]). For this reason, we cannot clearly perceive in Figure 3 the high chroma differences shown in Tables 5 and 6.

TABLE 5. CIE x,y,Y and CIELAB L^*, C^*_{ab}, h_{ab} color coordinates for the flag of Spain under CIE illuminant C and CIE 1931 observer. The legal values [10] are shown on the left side and the average visual values found in the current experiment on the right.

	Legal values [10]						Average values in our current experiment					
	x	y	Y	L^*	C^*_{ab}	h_{ab} (◦)	x	y	Y	L^*	C^*_{ab}	h_{ab} (◦)
Red	0.614	0.320	9.5	37.0	70.0	35.0	0.619	0.347	14.2	44.5	82.2	45.6
Yellow	0.488	0.469	56.7	80.0	95.0	85.0	0.468	0.473	55.2	79.2	86.5	89.3

TABLE 6. CIELAB colour differences (and their lightness, chroma and hue components) between legal values [10] and average values in the current experiment.

	Average	$\%\Delta L^*$	$\%\Delta C^*_{ab}$	$^*\Delta H^*_{ab}$
Red	24	19	38	43
Yellow	20	11	58	31

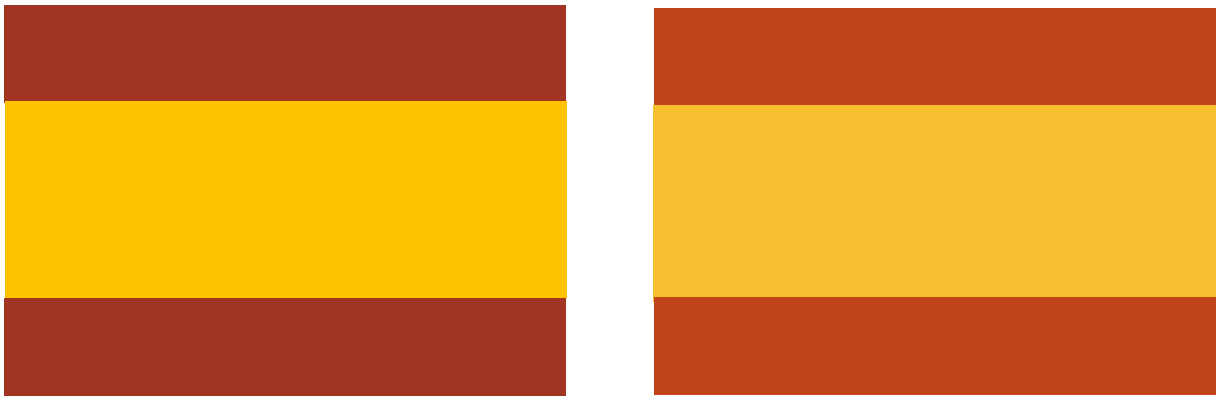


Fig. 3. The flag of Spain with its legal colors (left) and with the average colors found in our experiment (right). The colors in these two plots are only approximate, and may strongly depend on the specific monitor or printing system employed by each reader.

3.f. Color coordinates under CIE standard illuminants

Bearing in mind that the current regulation for the colors of the flag of Spain assumed the CIE illuminant C [10], which is not a CIE standard illuminant, Tables 7 and 8 show x,y,Y and CIELAB coordinates for the two colors of the flag under current CIE standard illuminants D65, D50 and A assuming the CIE 1931 and the CIE 1964 standard colorimetric observer, respectively. The values shown in Tables 7-8 were computed from the legal values in [10] (last two rows in Table 7), using the two-step chromatic adaptation transform [16] adopted in the CIECAM16 color-appearance model [17], assuming average surround conditions (F=1) and an adapting luminance of 191 cd/m^2, which corresponds to an outdoor illuminance of around 3000 lx. As expected, results under illuminant A differ considerably from those under illuminants D65, D50, and C, which are all relatively similar. Differences between the results found for the CIE 1931 (Table 7) and the CIE 1964 (Table 8) standard colorimetric observers were very small. Reference [10] states that the color coordinates provided assume the CIE 1931 standard observer, but in some situations, as, for example, the current visual experiment, the size of visual stimuli imply that the CIE 1964 standard observer [6] should instead be used. The values in Tables 7 and 8 are theoretical results, and some of the colors indicated in Table 7 may fall outside the color gamut for specific textiles or visual displays.

TABLE 7. Color coordinates of the red and yellow stripes of the Spanish flag under the current CIE standard illuminants D65, D50, and A, as well as under the CIE illuminant C adopted in [10], assuming the CIE 1931 standard colorimetric observer.

Illuminant	Color	x	y	Y	a^*	b^*	L^*	C^*_{ab}	h_{ab} (◦)
D65	Red	0.6149	0.3236	9.5	59.3	40.3	37.0	71.7	34.2
	Yellow	0.4858	0.4750	56.6	10.2	95.5	80.0	96.0	83.9
D50	Red	0.6315	0.3245	9.6	60.3	41.4	37.0	73.1	34.5
	Yellow	0.5057	0.4701	56.6	14.9	99.5	79.9	100.6	81.5
A	Red	0.6730	0.3153	9.7	57.0	48.7	37.4	75.0	40.5
	Yellow	0.5592	0.4413	56.6	20.2	140.6	80.0	142.0	81.8
C	Red	0.614	0.320	9.5	57.3	40.2	37.0	70.0	35.0
	Yellow	0.488	0.469	56.7	8.3	94.6	80.0	95.0	85.0

TABLE 8. Color coordinates of the red and yellow stripes of the flag of Spanish flag under the current CIE standard illuminants D65, D50 and A, as well as under the CIE illuminant C, assuming the CIE 1964 standard colorimetric observer.

Illuminant	Color	x_{10}	y_{10}	Y_{10}	a^*_{10}	b^*_{10}	L^*_{10}	$C^*_{ab,10}$	$h_{ab,10}$ (◦)
D65	Red	0.6155	0.3240	9.5	59.5	40.3	37.0	71.9	34.1
	Yellow	0.4862	0.4755	56.6	10.6	95.6	80.0	96.2	83.7
D50	Red	0.6325	0.3243	9.6	60.2	41.4	37.0	73.1	34.5
	Yellow	0.5057	0.4701	56.6	14.9	99.5	79.9	100.6	81.5
A	Red	0.6745	0.3141	9.7	56.5	48.9	37.4	74.7	40.9
	Yellow	0.5619	0.4388	56.6	20.0	141.7	80.0	143.1	82.0
C	Red	0.6139	0.3206	9.5	57.8	40.2	37.0	70.4	34.8
	Yellow	0.4871	0.4703	56.7	8.7	94.8	80.0	95.2	84.7

4. Conclusions and future work

A group of 53 people with normal color vision, all born and usually residing in Spain, identified the colors of the flag they considered most representative of their country. Our main conclusions are as follows:

1. No statistically significant differences were found between the colors selected by civilian and military observers, or by males and females.

2. Intra- and inter-observer variability in selected colors were very similar: approximately, 13 and 17 CIELAB units for red and yellow, respectively. This variability consisted mainly of discrepancies in the selected chroma.

3. Variation in the red and yellow colors chosen by observers was characterized by 95% confidence ellipsoids in CIELAB color space, the coefficients of which are given in Table 4. The centres of these ellipsoids differed considerably from the legally established values: 24 and 20 CIELAB units for red and yellow, respectively.

4. CIELAB vectors joining the red and yellow selected by observers were quite similar, suggesting that contrast was an important factor in the selection of the most representative colors of the flag of Spain.

The methodology in this article can be applied to the quantification of the average colors and tolerances of other countries' flags as well. This may make it easier in the future for the colors of national flags to be rigorously specified in a standardized manner, using the CIELAB color space, in accordance with CIE recommendations on color specification.

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