Locating basic Spanish colour categories in CIE L*u*v* space: Identification, lightness segregation and correspondence with English equivalents

Julio Lillo*[1], Humberto Moreira*, Isaac Vitini, & Jesús Martín*

* Complutense University of Madrid

Five experiments were performed to identify the basic Spanish colour categories (BCCs) and to locate them in the CIE L*u*v* space. The existence of 11 BCCs was confirmed using an elicited list task and a free monolexemic naming task. From the results provided by a synonymicity estimation task, it was concluded that, in Spanish, 2 synonymous terms (*morado* and *violeta*) are used to name a category equivalent to the English category *purple*. Three experiments provided information about the colourimetric localization of the 11 Spanish BCCs. Two experiments used monolexemic naming tasks (free and restricted) and a third required the free signalling of prototypes and good exemplars. It was observed that Spanish and British BCCs are essentially equivalents in number and colourimetric delimitation and, therefore, our work can be considered to extend and complement previous research (on English BCCs) insofar as achromatic categories in colour space localization, the links between chromatic and achromatic categories (red and orange have no direct links with achromatic categories), and the dependence of the use of BCCs on lightness are concerned. Lastly, our results indicate the existence of 2 categories that are nearly basic: beige and garnet.

Our main research goal is to provide an accurate response to the following questions: What are the basic Spanish colour categories (BCCs)? What are their positions in the CIE (Commission Internationale de l'Éclairage) L*u*v* colour space? Are they different in number or position to the English ones? The experimental work carried out to answer these questions adopts the conceptual framework of the latest version of universalistic theory of basic colour categories (Kay, Berlin, Maffi, &

Merrifield, 1997). Consequently, all the empirical predictions tested in this paper are related to the following ideas: (a) Basic categories are associated with a set of colour experiences similar for all human beings who have no perceptual deficits; (b) there are different degrees of membership of a category. For a specific stimulus set, the maximum degree would correspond to what are often called "focal colours" (Schirillo, 2001), and the minimum level (different from zero) to the stimulus that would indicate, in colour space, the step from one category to the next one; (c) however, BCCs are commonly used to name surface colours and, consequently, to name relatively reduced saturation (s_{uv}) stimuli (Lillo, Moreira, & Gómez, 2002). The use of BCCs with this kind of stimulation should agree with the utilisation observed when monochromatic stimuli are used (Paramei, Bimler, & Cavonious, 1998; Wooten & Miller, 1997).

Most experimental work on BCCs (Schirillo, 2001) has focused on two aspects: BCC identification and mapping. To achieve both goals, different methods can be used (Berlin & Kay, 1969; Corbett & Davies, 1997). As will be explained below, the following three were selected: elicited lists, colour naming, and direct signalling.

Elicited lists are used to identify a BCC language (Davies & Corbett, 1994; Özgen & Davies, 1998). This method provides two measures: frequency and order. It assumes that the psychologically more relevant terms must appear in more lists and in the first positions. Pich and Davies (1999) found that Spanish children under 6 years old tend to use primary categories (English equivalents after the hyphen: *blanco*-white*, negro*-black*, rojo*-red, *verde*-green, *amarillo*-yellow, and *azul*-blue) more frequently than derived categories (*marrón*-brown, *rosa*-pink, *naranja*-orange, *lila*-purple, and *gris*-grey). They also found that, in general, basic terms (primary and derived) were more frequently used than non-basic ones. The first specific goal of our research was to verify these aspects in the Spanish adult population, taking into account frequency and order.

Colour naming requires naming sets of selected colour samples under controlled conditions. This method is useful: (a) to identify a BCC language (Davies & Corbett, 1994, 1997; Özgen & Davies, 1998) and (b) to map their use in colour space (Boynton & Olson, 1987, 1990; Jameson & Alvarado, 2003; Lin, Luo, MacDonald, & Tarrant, 2001a; Sturges & Whitfield, 1995, 1997). The method assumes that BCCs have specific perceptual referents and that consequently, participants must coincide in naming certain parts of colour space.

The number of stimuli to be named and the specific way that naming is performed vary as a function of the different applications of colour

naming methods. Let us consider the causes and consequences of these variations.

Calculations have shown that there are approximately 2.28 million discernible surface colours (Pointer & Attridge, 1998). Inevitably, the set used in a naming experiment is very much below this number, and the specific samples to be used depend on a more or less arbitrary decision. For example, research directly related to the Word Colour Survey (Kay et al., 1997) uses an array of 330 colour patches from the Munsell Atlas colour surface (maximum possible saturation for each hue and lightness) plus ten pure achromatic stimuli (a grey scale). Such a selection does not include exemplars of reduced saturation (s_{uv}), especially for medium lightness surfaces. Consequently, any study using either this set or a similar one (Berlin & Kay, 1969; Roberson, Davies, & Davidoff, 2000; Rosh Heider & Olivier, 1972) does not accurately map the use of BCCs in response to these types of stimuli.

The most influential series of colour naming studies (Boynton & Olson, 1987, 1990) used the full set of 424 stimuli included in OSA (Optical Society of America) colour atlas for mapping basic colour categories in adult English speakers. As Boynton and Olson explicitly indicated (Boynton & Olson, 1990, p. 13), the "most serious flaw" in their research was the bad mapping of achromatic basic categories. Two later studies (Sturges & Whitfield, 1995; Lin, Luo, McDonald, & Tarrant, 2001b) partially improved this situation by using sample sets with an accurate low-chroma stimuli representation. However, they did not provide enough information to fully map their results in terms of any CIE colour space. Moreover, in the work of Lin et al, the direct signal method was used instead of colour naming.

Considering the above-mentioned comments, we decided to use colour naming to achieve three specific goals: (a) to complement the Spanish BCCs identification process initiated in Experiment 1 (elicited lists); (b) to establish a mapping similar to the one of Boynton and Olson (1987), but with a representative set of low chroma stimuli. Considering the results previously obtained in a systematic colourimetric evaluation (Lillo et al., 2002), we decided to use the full set of stimuli contained in an NCS (Natural Colour Atlas) colour atlas because of the many low-s_{uv} stimuli they include; (c) to compare our mapping with Boynton and Olson's (1987) and, as far as possible, with Sturges and Whitfield's (1995). To achieve this goal we "translated" the results obtained by other authors' from the nomenclature corresponding to the specific atlas employed to a CIE "common language": the language of the *CIE L*u*v** space and its chromaticity diagram (*CIE u'v'*).

We call the method originally used by Berlin and Kay (1969) "direct signalling." It is used to locate the foci and map the relative positions of BCCs in colour space. Research performed in the context of the World Colour Survey (Kay et al., 1997; Kay, Berlin, & Merrifield, 1991) has restricted its use to the first goal. This is directly related to three specific aims of our research: (a) to locate the basic Spanish category foci, (b) to compare them with the English ones, and (c) to define their positions in the part of colour space corresponding to each category.

Considering that Spanish and English are at the same level of Berlin and Kay's (1969) colour term developmental hierarchy, we predict similarities in both languages in relation to: (a) the number of BCCs, (b) their mapping in colour space (positions and linking of categories), and (c) their relative foci positions. From this general framework, our first experiment used an elicited list method to identify the BCCs of Spanish. Taking previous research (Berlin & Kay, 1969; Pich & Davies, 1999) into account, we expected the following BCCs (the English equivalents appear after the hyphen, see Velázquez, 1967): *blanco*-white, *negro*-black, *rojo*-red, *verde*-green, *amarillo*-yellow, *azul*-blue, *marrón*-brown, *rosa*-pink, *naranja*-orange, *morado*-purple, and *gris*-grey. According to previous results with elicited list application, we expected higher frequencies and earlier occurrences for: (a) basic categories versus non-basic categories and (b) primary basic categories versus derived basic categories.

EXPERIMENT 1. ELICITED LISTS

METHOD

Participants. Fifty-two subjects (35 women and 17 men) took part in the experiment. This group was composed of 20 friends and relatives of our laboratory members and of 32 undergraduate students from the Complutense University of Madrid. Their ages ranged from 14 to 62 years ($M = 25.81$, $SD = 6.68$).

Materials and Procedure. To avoid the influence of visual stimulation, participants wrote the lists with their eyes closed. First, they wrote their names and then all the one-word colour names they could remember during a 2-minute interval.

RESULTS

For the six basic primaries, the following frequencies were computed: *blanco*-white, 48 (92.3%); *negro*-black, 49 (94.2%); *rojo*-red, 50 (96.2%);

verde-green, 48 (92.3%); *amarillo*-yellow, 51 (98.1%); *azul*-blue, 50 (96.2%). For the six derived basic categories, the frequencies and percentages were: *marrón*-brown, 38 (73.1%); *rosa*-pink, 34 (65.4%); *naranja*-orange, 36 (69.2%); *morado*-purple-1, 30 (57.7%); *violeta*-purple-2, 28 (53.8%); *"viomora"*-purple-1+2, 45 (86.5%); *gris*-grey, 41 (78.8%).

Only two non-basic terms appeared in more than 20% of the lists. These were *granate*-garnet, 20 (38.5%) and *beige*-beige, 15 (28.8%). Other non-basic terms were (no percentage information is provided): *plata*-silver, 9; *turquesa*-turquoise, 8; *lila*-lilac, 7; *ocre*-ochre, 7; *añil*-indigo, 6; *bermellón*-vermilion, 6; *burdeos*-marroon, 5; *malva*-mauve, 5; *púrpura*-purple, 5; *caqui*-khaki, 4; *carne*-flesh, 4; *celeste*-sky blue, 4; *dorado*-golden, 4; *fucsia*-fuchsia, 4; *oro*-gold, 4; *salmón*-salmon, 3; *ambar*-amber, 2; *carmín*-crimson, 2; *castaño*-chestnut, 2; *hueso*-bone, 2; *magenta*-magenta, 2; *aluminio*-aluminum, 2; and *vainilla*-vanilla, 2.

Before describing frequency results, the use of three terms associated with purple must be commented on. Only "morado" ("purple-1" in Figure 1) and "violeta" ("purple-2") appeared on the lists. The third term ("purple-1+2" = "morado + violeta") was introduced into our analysis because many Group 1 participants spontaneously indicated that they considered both terms synonymous. To compute the purple-1+2 frequency, we added the lists where "morado" and/or "violeta" appeared.

A series of χ^2 analyses were performed to evaluate the significance of the differences in term frequency on the lists. In Table 1, a simplification of the main results is displayed. The left column indicates the frequency with which a category could be used. The central column shows the first frequency significantly lower than this. For example, given that *amarillo*-yellow appeared in 51 lists, all the categories with frequencies equal to or lower than 45 had a significantly lower frequency ($p < .05$). Considering Table 1, the following conclusions can be reached: (a) There were no significant differences among primary BCCs; (b) in many cases, the primary BCCs were used more frequently than the derived BCCs; and (c) with the sole exception of *violet*-purple-2 versus *granate*-garnet, all the basic categories were used significantly more frequently than the non-basic categories ($p < .05$).

Figure 1 shows the median appearance order for each category with a frequency over 20%. To facilitate the statistical analysis description, the categories are presented in three groups: chromatic basic primaries (left), achromatic basic primaries (centre), and derived basic and non-basic categories (right). A series of Mann Whitney U analyses showed that, with only one exception (no significant differences between green and black), the four chromatic basic primaries (*rojo*-red, *azul*-blue, *amarillo*-yellow,

and *verde*-green) appeared significantly before the rest of the categories (*p* < .05). Moreover, *rojo*-red appeared significantly before *verde*-green and *amarillo*-yellow.

Table 1. Experiment 1. Comparison of frequencies and significance level of the elicited lists.

Higher frequency	Lower frequency	*p*
51	45	.030
50	41	.007
49	41	.021
48	41	.046
45	36	.029
41	30	.017
38	28	.033
36	20	.001
34	20	.005
30	20	.038
28	15	.008
20	15	.203
		(non-significant)

Note. The left column indicates the frequency with which a category could be used. The middle column indicates the first frequency that is significantly lower than this frequency (*p* < .05).

Blanco-white and *negro*-black, the achromatic basic primaries, is the second group of categories represented in Figure 1. There were no significant differences in their order. On the other hand, the Mann Whitney analyses showed that these categories appeared significantly after the basic chromatic primaries (*p* < .05) and significantly before the derived basic and non-basic categories (*p* < .05). The only exceptions to this pattern of results were the above-mentioned one (no significant differences between *verde*-green and *negro*-black) and those related to the comparison between *blanco*-white and the three purples.

As indicated above, Mann Whitney analyses showed that derived basic and non-basic categories tended significantly to be used after the other categories. Moreover, except for *granate*-garnet, *marrón*-brown and beige appeared significantly after the rest of the derived basic and non-basic categories (*p* < .05).
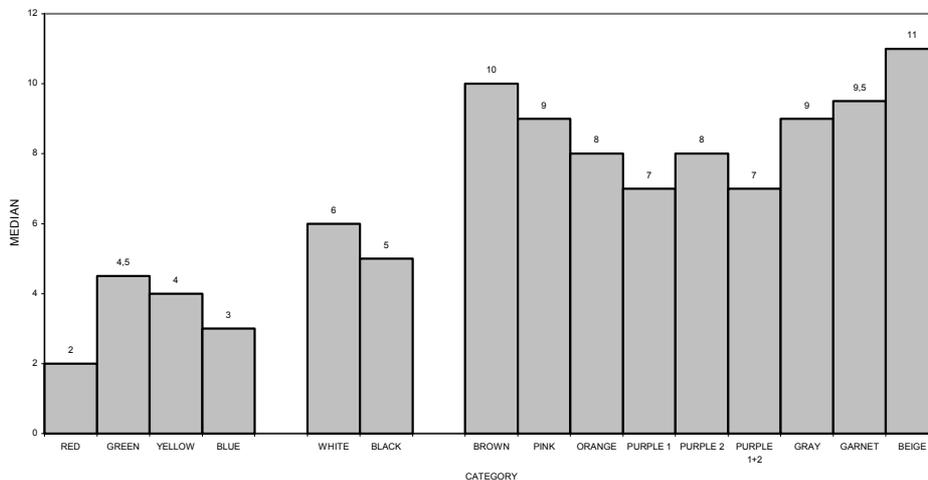
Figure 1. Colour term appearance order in the elicited lists (Experiment 1). The terms are grouped into three categories types: basic chromatic primaries (left), basic achromatic primaries (centre), and derived basic and non-basic (right).

DISCUSSION

Only Spanish terms with English basic colour equivalents were used in over 50% of the elicited lists. Coinciding with other languages used in developed countries (Davies, Corbett, & Bayo 1995; Özgen & Davies, 1998), all the basic primary categories appeared more frequently that the derived basic categories. However, concerning order, important differences were found between chromatic and achromatic primary categories: The former tended to be used before the achromatic. This result is very similar to the findings with regard to frequency of Pich and Davies (1999), working with Spanish children.

Our results differ from those of Pich and Davies (1999) in the Spanish terms related to purple. Their "malva" contrasts with our "morado" and "violeta." Why this difference? One could speculate that it is due to differences in the participants' origin. More specifically, Pich and Davies work in an area of Spain (the Balearic Islands) where Spanish is used in conjunction with Catalan. Unfortunately, this explanation is not consistent with the results obtained by Davies, Corbett, and Bayo (1995) concerning basic Catalan categories. Like us, they also discovered the coexistence of two terms related to purple, but these were "lila" and "violeta." Consequently, we have no plausible explanation for the discrepancy between our results and those of Pich and Davies.

Considering the two terms related to purple ("morado" and "violeta") discovered in Experiment 1, our research used two different approaches to study their possible equivalence (synonymicity). First (Experiment 2), we used a direct method of estimation of synonymicity, and second (Experiment 5), a direct signalling method.

EXPERIMENT 2. SYNONYMICITY ESTIMATION

As previously stated, Experiment 2 evaluated the possible equivalence of "morado" and "violeta" using a direct method of estimation of sinonimicity. This method was applied for all the possible pairs formed by terms used in over 50% of the Experiment 1. It was expected that, if "morado" and "violeta" were equivalent terms, the pair "morado-violeta" should produce sinonimicity estimations significantly over any other pair.

METHOD

Participants. After Experiment 1 ended, the same 32 undergraduate students that participated in that experiment, also took part in Experiment 2.

Stimuli and Procedure. On a classroom blackboard were written, in alphabetical order, the following Spanish terms: "amarillo," "azul," "blanco," "gris," "marrón," "morado," "naranja," "negro," "rojo," "rosa," "verde," and "violeta." With the colour terms always visible, participants were required to individually estimate the synonymicity between any possible pair of different categories. They were informed that, if two categories, "A" and "B," were fully interchangeable, synonymicity estimation had to be 100%. On the other hand, it had to be 0% for non-related categories. For all the pairs of colour terms, estimation was performed in both directions (How synonymous is A to B? and vice versa).

RESULTS

The first column of Table 2 indicates the category pairs with their sinonimicity estimation means over 5% in at least one direction (A with respect to B or vice versa). As can be seen, the 11 pairs presented are only a small subset of the 55 possible pairs. The scripts in the two most right-hand table columns indicate that, even for the pairs considered in Table 2, both medians were equal to zero. A series of Wilcoxon tests indicated that there were no significant differences between estimations corresponding to the two directions of the morado-violeta pair ($p > .05$). On the other hand,

estimated synonymicity for morado-violeta was significantly higher than that of any other pair of colour terms considered ($p < .05$). Lastly, except for morado-violeta, the estimation levels for the negro-gris and rojo-rosa pairs were higher than those of the rest of the colour pairs ($p < .05$).

Table 2. Synonymicity estimations from experiment 2.

Pairs of colour terms	Estimations means	Median 1	Median 2
Negro-Gris (Black-Grey)	21.80	20	-
Blanco-Gris (White-Grey)	6.94	-	-
Rojo-Naranja (Red-Orange)	9.49	-	-
Rojo-Morado (Red-Purple)	4.41	-	-
Rojo-Rosa (Red-Pink)	22.79	10	10
Verde-Amarillo (Green-Yellow)	5.29	-	-
Verde-Azul (Green-Blue)	7.20	-	-
Amarillo-Naranja (Yellow-Orange)	9.85	-	-
Azul-Morado (Blue-Purple 1)	6.62	-	-
Azul-Violeta (Blue-Purple 2)	4.41	-	-
Morado-Violeta (Purple 1-Purple 2)	62.06	75	80

Note. The left column indicates the pairs of categories with mean synonymicity estimation over 5% in, at least, one direction ("A" with regard to "B" or vice versa). Dashes in the two right-hand columns indicate that, even for the pairs considered in Table 2, the medians are equal to zero.

DISCUSSION

Table 2 indicates a mean sinonimicity of 62.06% for morado-violeta. This value is very important when considering the nature of most of the pairs presented in Table 2: They correspond to perceptually related colours. More explicitly, works using the "continuous judgmental colour-naming technique" have shown that, for English speakers, orange can be substituted by red and yellow (Sterheim & Boynton, 1966), purple by red and blue (Fuld, Wooten, & Whalen, 1981) and grey by black and white (Quinn, Wooten, & Ludman, 1985). Along the same lines, the "classical" relation between red and pink only produced an estimation of 22.80%, about one third of the corresponding value for morado-violeta. Consequently, we can conclude that our participants used a strict criterion to carry out the synonymicity estimations and that, even in this situation, the morado-violeta pair obtained very high values.

Synthesizing the evidence provided by the two first experiments and extrapolating their implications for the following ones, the identification in

Spanish of ten basic categories with direct English equivalence (after the hyphen) can be concluded: *blanco*-white, *negro*-black, *rojo*-red, *verde*-green, *amarillo*-yellow, *azul*-blue, *marrón*-brown, *rosa*-pink, *naranja*-orange, and *gris*-grey. We expected that, in our third experiment, all these categories would produce consistent naming in response to the same type of stimuli that produced their English equivalents (Boynton & Olson, 1987; Sturges & Whitfield, 1995). We had a similar expectation for purple after considering the Spanish terms "morado" and "violeta" to be synonymous.

Although our third experiment used stimuli from a different colour atlas (the NCS) than the ones used by Boynton and Olson (1987, 1990—the OSA atlas) and Sturges and Whitfield (1995, 1997—the Munsell atlas), these three works can be directly compared after "translating" their results to the same colour nomenclature. We chose the *CIE L*u*v** space (and their corresponding chromaticity diagram *CIE u'v'*) because of the easy psychophysical comprehensibility of their dimensions (see Hunt, 1995).

Because Boynton and Olson's (1987) Figure 1 identifies the OSA stimuli that produced the same naming in more than the 50% of their presentations, and because the NCS includes a high number of low chroma stimuli, our third experiment can be considered an extension of Boynton and Olson's in two essential aspects. First, it allowed us to accurately map the colour volume corresponding to achromatic categories (*blanco*-white, *negro*-black, and gris-grey) in the colour space. Secondly, it permitted a better delimitation of the links between these categories and the chromatic ones.

Comparison with Sturges and Whitfield's (1995, Table II) results cannot be complete because they only specified a subset of the stimuli that produced consistent naming: those that reached the consensus criterion (100% of denominations with the same category). However, we thought it would be very interesting to compare the results corresponding to these stimuli with our results, because the Munsell atlas includes stimuli with saturation superior to the maximums of OSA and NCS.

EXPERIMENT 3. FREE MONOLEXEMIC NAMING

METHOD

Participants. There were 8 participants (6 females and 2 males) in the experiment. They live in Madrid and speak Spanish. They were between 23 and 27 years of age ($M = 25.38$, $SD = 1.06$). All were screened for normal colour vision by means of the Ishihara Pseudo-Isochromatic colour

plates, the City University Colour Vision Test (CUCVT; Fletcher, 1980), the "Test para Identificación de los Daltonismos" (TIDA [Test to Identify Colour-Blindness]; Lillo, 1996), and Rayleigh matches on an anomaloscope.

Stimuli and Apparatus. The stimuli to be named were those of the 1795-tile set contained in the NCS index (SSI, 1996). This version was selected because it affords easy colourimetric measurement (Lillo et al., 2002) and is easy to use. Each colour sample measures 2×5 cm and appears in one of the 212 numbered rectangular bands (29×5 cm) of 2 to 9 samples.

Each stimulus presented in the naming task measured 2×2 cm and was binocularly observed at a distance of 40 cm, projecting a visual angle of 2.8 degrees. The stimuli were presented on a medium-grey (N 5000; L^*=50%) background. All the stimuli had been previously measured using a Photoresearch PR-650 spectroradiometer (a detailed psychophysical account of these measurement results can be found in Lillo et al., 2002). Like Boynton and Olson (1987), we used incandescent lamps for stimulus illumination. Rosco corrective filters allowed reaching a correlated colour temperature of 5754 K, a value between the 3000 K of Boynton and Olson and the 6500 K of Sturges and Whitfield (1995). The tiles were observed inside a booth that provided the aforementioned illumination after passing through a diffuser filter. Illuminance was between 225 and 250 lux. The booth structure and the angle between the participant and the tile prevented glare. These observation conditions were identical to those used to measure the tiles photocolourimetrically (Lillo et al., 2002).

Procedure. For each participant, two random orders were created to present the 1795 NCS tiles two times. Each tile was observed binocularly for 4 seconds. In this interval, its colour had to be named. The inter-stimulus interval was 2 seconds. To enhance continuous task attention, the participants were allowed to interrupt the task whenever they felt tired. Due to this, there were inter-participant differences in session duration (between one half and two hours), number of sessions, and number of breaks.

Participants sat at the viewing enclosure and were then asked to name each stimulus using any monolexemic colour term. Compound terms such as "blue-green" and modifiers such as "yellowish," "light," and "dark" were not allowed.

RESULTS

The left column of Figure 2 shows the mapping of NCS stimuli segregated by lightness. The top row refers to light stimuli ($L^* \geq 65$; real range between 65 and 93.5), the middle row to middle stimuli ($65 > L^* \geq 45$), and the bottom row to dark stimuli ($45 > L^*$; real range between 15 and 45). By separating the tiles according to these ranges, we divided the 1795 NCS tiles into three sets that were very similar in number. Specifically, there were 609 light samples, 638 middle samples, and 548 dark samples. The centre and right columns show, respectively, the mapping of the OSA stimuli of Boynton and Olson (1987) and the Munsell stimuli of Sturges and Whitfield (1995).

Inside every *CIE u'v'* chromaticity diagram, there is a thin black line delimiting the area occupied by all the NCS tiles. Hereafter, this will be called the "NCS global colour area." Inside this area, for each lightness level, a thinner grey line delimits the NCS light stimuli area (upper row), medium stimuli area (middle row), and dark stimuli area (lower row). The cross situated near each diagram centre corresponds to the illuminant used (due to stimulus clustering, it cannot be appreciated in the left column diagrams. The position for this stimulus was u'=0.19, u'=0.48).
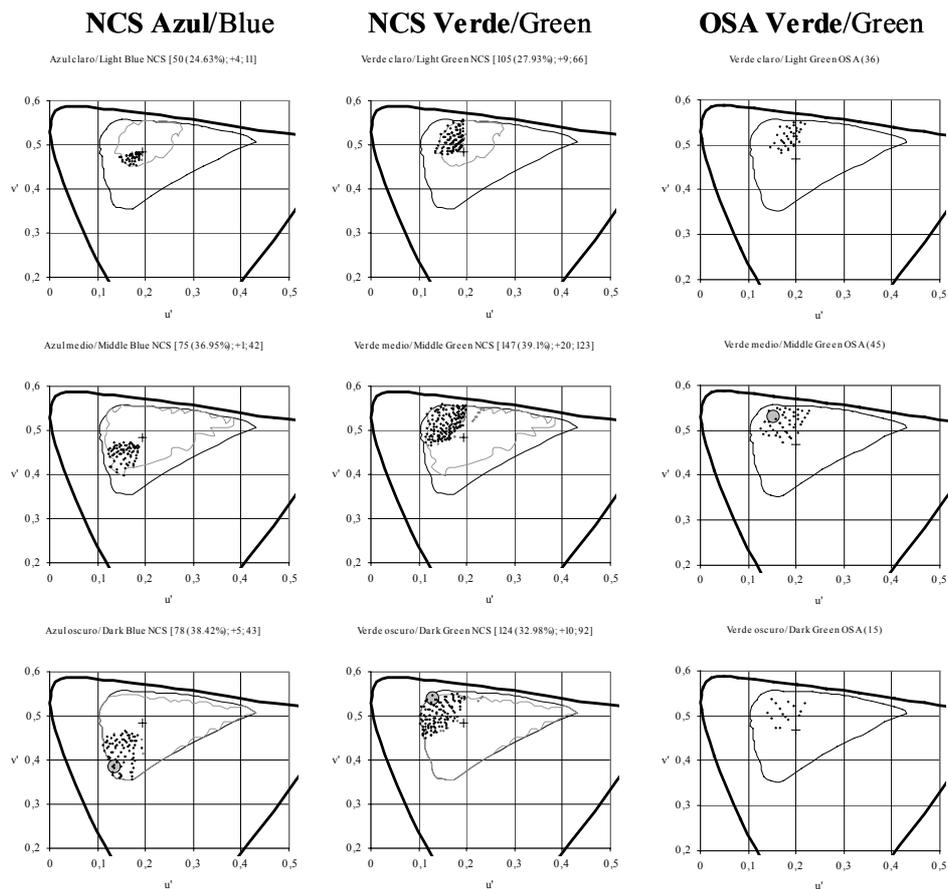
The central and right columns of Figure 2 show the respective mappings of the OSA and Munsell stimuli used by Boynton and Olson (1987, Figure 1) and Sturges and Whitfield (1995, Table II). To obtain the chromatic coordinates of these stimuli, two tables were used from Wyszecki and Stiles (1982, Table I, 6.6.1 and Table I, 6.6.4). As can be seen, OSA colour areas are very similar to NCS ones. In contrast, the sample of Munsell stimuli represented shows higher saturation levels (s_{uv}) than those of the other two atlases (many Munsell stimuli are beyond the NCS colour areas).

Figures 3 to 6 use black dots to indicate the chromatic coordinates of the stimuli consistently named in Experiment 3 (the same word used in more than 50% of stimulus presentations). Column headings indicate the atlas used in the naming task (NCS or OSA). With just an exception (Figure 3, right column), only our results are presented (NCS). However, a full comparison between our results and the ones obtained by Boynton and Olson (1987) and Sturges and Whitfield (1995) can be found in an Appendix available in the web site http://www.uv.es/psicologica
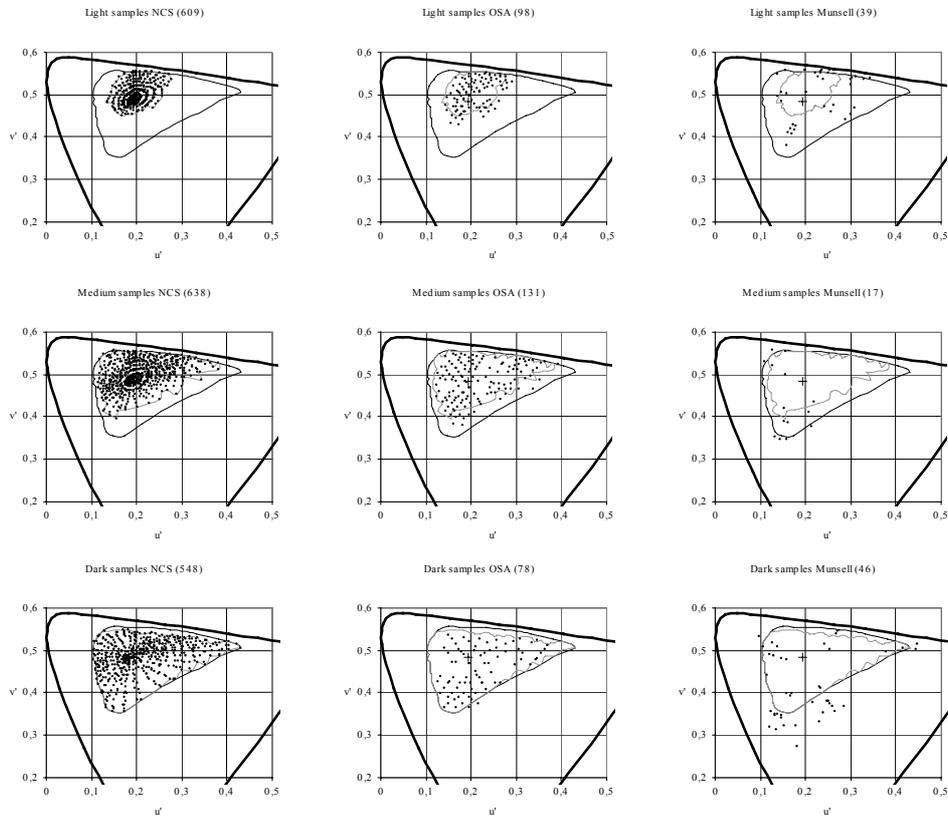
Figure 2. Mapping of Atlas stimuli divided according to lightness. Upper row = light stimuli (L* ≥ 65). Middle row = medium lightness stimuli (65 > L* ≥ 45). Lower row = dark stimuli (45 > L*). Left column = NCS stimuli. Medium column = OSA stimuli. Right column = Munsell stimuli.

Figures 3-6. **Chromatic coordinates and lightness level for the categories that produced consistent responses in Experiments 3, 4 and 5. For comparison, Figure 3 includes, in its right column, the results obtained by Boynton and Olson (1987) for the verde-green category. Every row head indicates the atlas used (NCS or OSA) and the BCC represented, in Spanish and English. This information is presented again in every chromaticity diagram. After it the first number indicates how many stimuli were consistently named in Experiment 3 (small black dots). The second number shows the relative percentage (computed from the total number of consistent responses at the three lightness levels). The third number indicates how many stimuli were consistently named with the same category in Experiment 4 (restricted monolexemic) but not in Experiments 3 (free monolexemic) (small grey dots). The last number indicates the number of good exemplars detected in Experiment 5. Black irregular line = NCS colour area. Rows indicate lightness level (as in Figure 2). Some diagrams incorporate a big grey circle to indicate the location of a focal colour (best exemplar of a category). The cross in each diagram centre indicates the illuminant.**

Figure 3. Azul-blue and verde-green.
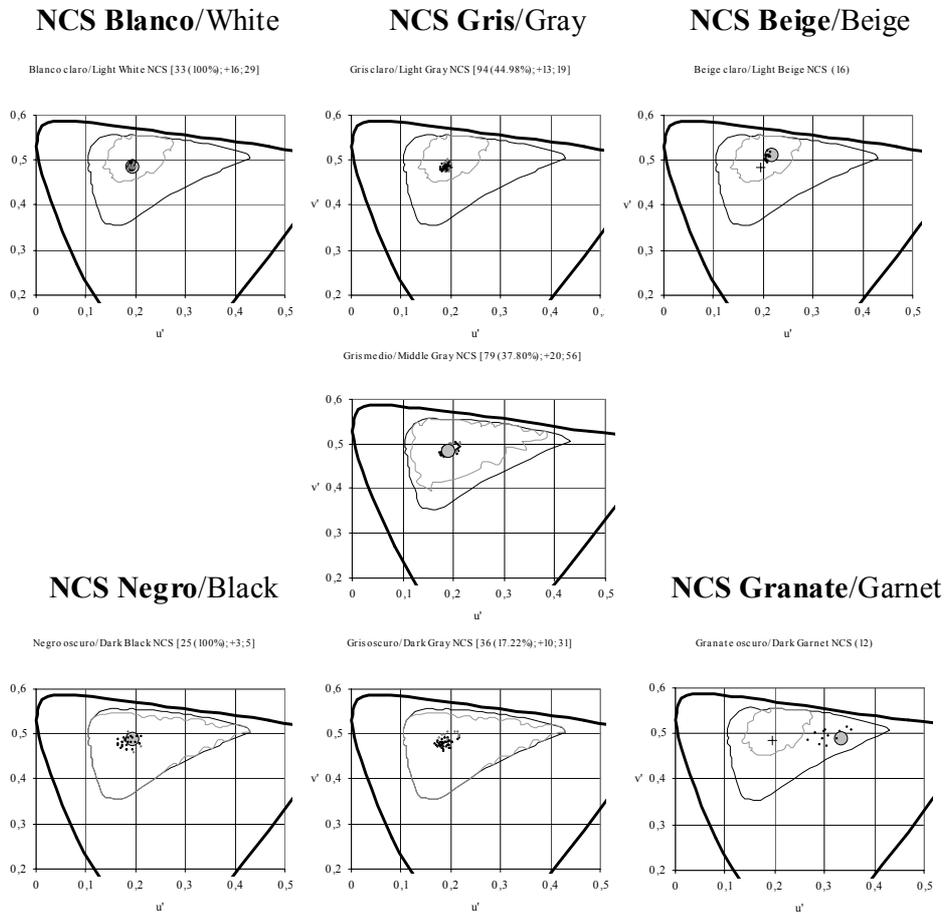
Figure 4. Low chroma BCCs (blanco-white, negro-black, gris-grey, beige-beige, granate-garnet).

Figure 3 central and right columns show a strong correspondence between our results (central column) and the ones provided by Boynton and Olson (1987) for the *verde*-green BCC, after their "translation" to *CIE u'v'* coordinates. For both cases, this category was consistently used for naming stimuli in the three lightness levels considered, and produced stimuli localizations in positions very similar in the diagrams. On the other hand, it can also be observed that, because of the higher number of stimuli contained in the NCS atlas, our results provided a better spatial delimitation (less empty spaces) of the *verde*-green BCC.
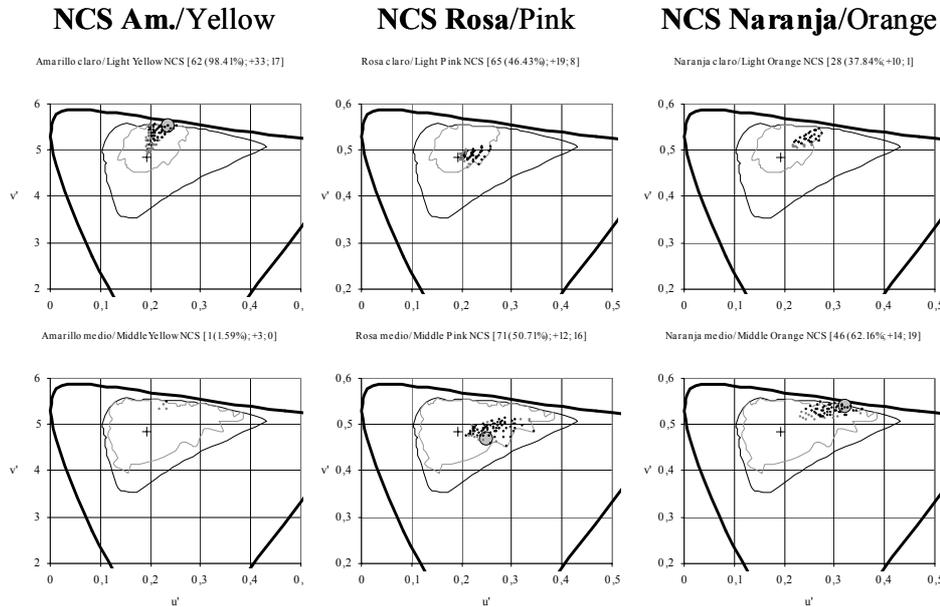
Figure 5. Light-middle lightness BCCs (amarillo-yellow, rosa-pink and naranja-orange).

Figures 3 to 6 also indicate that there were important BCC differences related to lightness. More specifically, only three BCCs allowed the consistent naming of an important number of stimuli (over 20%) in the three lightness levels (light, middle and dark): *Azul*-blue, *verde*-green and *gris*-grey (Figures 3 and 4). On the other hand, six categories were used always (100%) or almost always (over 80%) for consistently naming stimuli belonging to just one lightness level. It was light for *blanco*-white, *beige*-beige and *amarillo*-yellow (Figures 4 and 5). It was dark for *negro*-black, *granate*-garnet and *rojo*-red (Figures 4 and 6). Finally, four categories concentrated more than 95% in two lightness levels. These were light and middle for *rosa*-pink and *naranja*-orange (Figure 5), and middle and dark for *marrón*-brown and *morado*-purple (Figure 6). As it can be observed in the supplementary material (Appendix available in http://www.uv.es/psicologica) the relations between lightness and BCCs observed in Spanish, were fully concordant with the ones observed by Boynton and Olson (1987) and Sturges and Whitfield (1995) in English.

NCS **Rojo**/Red   NCS **Marrón**/Brown   NCS **Morado**/Purple

Rojo medio/Middle Red NCS [4 (15.38%); +0; 1]   Marrón medio/Middle Brown NCS [59 (36.20%); +34; 3]   Morado medio/Middle Purple NCS [11 (24.44%); +15; 0]

Rojo oscuro/Dark Red NCS [22 (84.62%); +16; 11]   Marrón oscuro/Dark Brown NCS [104 (63.80%); +24; 54]   Morado oscuro/Dark Purple NCS [33 (73.33; +11; 0]
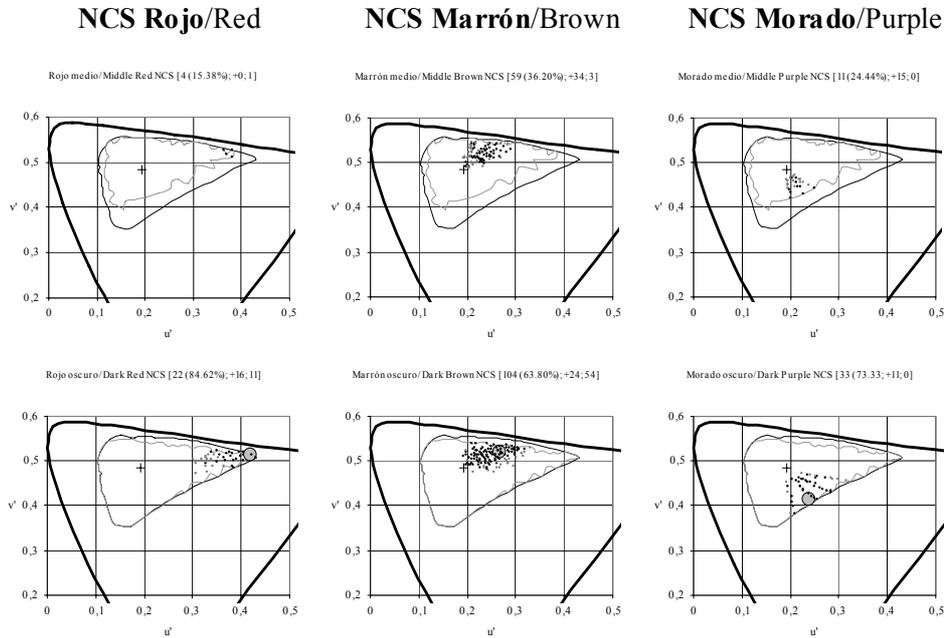
Figure 6. Middle-low lightness BCCs (rojo-red, marrón-brown and morado-purple).

Chromaticity diagrams located at Figure 4 right column indicate that 16 NCS stimuli were consistently named "beige." They all were light, low in saturation (s_{uv}), and had chromatic angles near 45 degrees. In contrast, the lower diagram indicates that 12 NCS stimuli were consistently named *granate*-garnet. They all were dark, relatively low in saturation, and had chromatic angles near to zero degrees.

Table 3 shows, above the diagonal, the most relevant information related to transitions (links) between categories observed in Experiment 3. We considered that a stimulus produced a "consistent-shared" use between two categories (and, consequently, located a link between categories) when: (a) it was named with both categories with a similar, or almost similar, frequency (at the most, their frequencies differed by 1); (b) the conjoint use of both categories occurred in over 50% presentations (their frequency was over 8). Besides indicating the number of stimuli that fulfilled this requirements for the relevant categories pair, Table 3 uses asterisks (*) and pounds (#) to show the links (shared use) observed by Boynton and Olson (1987) and Sturges and Whitfield (1995), respectively. With just one exception (the shared use of *rojo*-red and *morado*-purple), we confirmed the

full set of links found by Boynton and Olson. Additionally, 14 new links were found (we only provide their English equivalents): one link was between a pair of chromatic categories (pink-orange), four between an achromatic and a chromatic category (white-blue, white-pink, grey-pink, and grey-purple), four links between garnet and some other category (garnet-red, garnet-brown, garnet-pink, and garnet-purple), and five links between beige and some other category (beige-green, beige-yellow, beige-brown, beige-pink, and beige-grey).

Table 3. Number of consistently-shared tiles using two categories.

	White	Black	Red	Green	Yellow	Blue	Brown	Pink	Orange	Purple	Grey	Beige	Garnet
White	■			#	#	2#	#	6#		#	#	#	
Black		■				#	#			#	#		
Red			■				4*#	6*#	2*#	*#			4
Green	#			■	8*#	10*#	20*#		#		13*#	1#	
Yellow	4#			4*#	■		1*#		1*#			4#	
Blue	5#	2#		5*#		■				6*#	1*#		
Brown	#	#	3*#	8*#	3*#		■	7*#	4*#	2*#	8*#	2#	8
Pink	3#		6*#		2		6*#	■	6#	8*#	2#	1#	2
Orange			2*#	#	2*#		3*#	6#	■			#	
Purple	#	#	1*#			3*#	*#	1*#		■	4#		2
Grey	5#	1#		6#*	1	6*#	11*#	3#		1#	■	3#	
Beige	-#	-	-	-#	-#	-	-#	-#	-#	-	-#	■	
Garnet	-	-	-	-	-	-	-	-	-	-	-	-	■

Note. Above the diagonal are the results from Experiment 3 (unrestricted monolexemic naming). Below the diagonal are the results from Experiment 4 (restricted monolexemic naming).

* shows pairs of shared-categories detected by Boynton and Olson (1987).

shows pairs of shared-categories detected by Sturges and Whitfield (1995).

Excluding the links related to garnet, all the links discovered were also detected by Sturges and Whitfield (1995). They also found: three links between two chromatic categories (red-purple, orange-beige, and green-orange), eight between an achromatic and a chromatic category (white-green, white-yellow, white-brown, white-purple, white-beige, black-blue, black-brown, and black-purple), and two links between two achromatic categories (white-grey and black-grey).

DISCUSSION

Kaiser and Boynton (1996) have emphasised the relevance of lightness for specifying basic chromatic categories colourimetrically. Like us, they found that most categories only are applicable to a restricted lightness range, as shown in Figures 3-6 and supplementary material (Appendix available in http://www.uv.es/psicologica).

For several decades, the minimum number of categories required to name maximum purity stimuli has been studied (Sterheim & Boynton, 1966; Fuld et al., 1981; Quinn et al., 1985; Wooten & Miller, 1997). Thanks to these studies, we know that the following categories can be used consistently to name such stimuli: red, green, yellow, blue, orange, and purple. These categories, the "chromatic spectrals," tend to be used in response to a specific range of wavelengths (and chromatic angles). As shown by Figures 3-6, the tiles located near the NCS chromatic area perimeter allow us to postulate a colourimetric continuity between our results (obtained with surface colours and represented by dots located on the inner diagram) and the results of naming studies in which monochromatic stimuli were used. This continuity is very easy to appreciate considering the high purity levels provided by the Munsell Atlas (see Figure 2 right column), and the complementarily between our results and those obtained by Sturges and Whitfield (1995, see supplementary material in Appendix, http://www.uv.es/psicologica).

As expected because of the NCS stimuli characteristics, the most singular results provided by Experiment 3 are related to reduced chroma (C^*_{uv}) and/or saturation (s_{uv}) stimuli (Figure 4). Concerning achromatic categories (*negro*-black, *blanco*-white; *gris*-grey), it is easy to observe more dispersion in dot positions as L^* value decreases (compare, for example, the two left diagrams). This is consistent with the prediction of the equation $C^*_{uv} = s_{uv} \cdot L^*$ (that is, because an achromatic category is only compatible with reduced C^*_{uv} levels, higher s_{uv} levels imply reductions in L^* levels).

Comparison between the chromaticity diagrams corresponding to the two chromatic non spectral categories (*rosa*-pink, Figure 5; *marrón*-Brown, Figure 6) with their equivalents in Boynton and Olson (1987) and Sturges

and Whitfield (1995), shows that our research improved the mapping of these BCCs. Undoubtedly, this improvement was possible because of the high number of low saturation samples used. This number also allowed us to obtain consistent denominations for *beige*-beige and *granate*-garnet (see Figure 4). Our results indicate that these categories were used consistently in response to a restricted number of samples with very specific characteristics. The use of both categories was associated with reduced C^*_{uv} levels (far from the NCS chromatic area limit for *beige*-beige, not as far but associated with low L^* for *granate*-garnet). *Beige*-beige was used only in response to light stimuli. *Granate*-garnet only was used for dark ones.

Our next two experiments, 4 and 5, were designed to improve the colourimetric mapping of the 11 BCCs identified in the elicited lists task (Experiment 1), and confirmed by Experiment 3 (free monolexemic naming). Experiment 4 required the naming of all the NCS atlas stimuli using, always and exclusively, one of these 11 categories. This restriction had two goals. The first one was to obtain "bad exemplars" of each category. We thought that comparing good and bad exemplars would make it easier to specify the colourimetric description of the categories.

The second reason for obliging participants to respond with the 11 basic categories in Experiment 4 was to reach a deeper comprehension of the nature of the beige and *granate*-garnet categories. If these categories were similar to *naranja*-orange and *morado*-purple (two basic categories), then beige and *granate*-garnet responses would be replaced by two or more linked categories (similarly to replacing *naranja*-orange with *rojo*-red and *amarillo*-yellow, see Sterheim & Boynton, 1966). On the other hand, if they were similar to *marino*-navy or *celeste*-sky (two non-basic categories), the replacement would be done using just one basic category (both categories can be substituted by blue).

Our Experiment 5 used a direct signalling method very similar to the version originally used by Berlin and Kay (1969). It required participants to perform two different tasks: (a) identifying the best category exemplar (focal colour), and (b) signalling the stimuli that, "for any common observer were unquestionably members of a category ("good exemplars")." Experiment 5 improved previous direct signalling technique applications in two important aspects. First, a larger number of samples (1750) were used. Second, there was a rigorous control of the illumination.

Graphic analysis of the results of Experiment 3 allowed us to make very precise predictions about the expected differences between good and bad exemplars. It was assumed that, when possible (remember that NCS space is only a part of the *CIE L*u*v** colour space and, consequently, of the *CIE u'v'* chromaticity diagram), bad exemplars had to be located at the

periphery of the black dots in Figures 3-6. As we expected consistent naming at such peripheral positions, we also expected to discover new links between categories (see Table 3).

Regarding saturation (s_{uv})-chroma (C^*_{uv}), it was expected that the foci and the "good exemplars" of the spectral chromatic categories (*rojo*-red, *verde*-green, *amarillo*-yellow, *azul*-blue, *naranja*-orange, and *morado*-purple) would be at the maximum possible levels and, consequently, they would be significantly higher than "bad exemplars" in these two parameters. Logically, the opposite pattern was predicted for the achromatic categories (white, black, and grey). Lastly, no significant differences were predicted for the chromatic non-spectral categories.

Concerning lightness, it was expected that foci and good exemplars would be concentrated at the levels at which Experiment 3 had detected more consistent responses. Therefore, it was predicted that for black, red, purple, and brown, bad exemplars would be lighter than good ones. The opposite was predicted for white and yellow and for orange and pink. For the two latter categories, this prediction was made after considering that, although Experiment 3 showed a relative predominance for the medium lightness level, it also showed many more consistent namings for light than for dark stimuli.

With regard to chromatic angles, it was expected that foci and good exemplars would be concentrated at the central positions of the black dots in Figures 3-6. In contrast, it was expected that bad exemplars would be concentrated at the periphery of these areas.

EXPERIMENT 4. RESTRICTED MONOLEXEMIC NAMING

METHOD

Except where explicitly indicated, everything was the same as in Experiment 3.

Participants and Procedure. Eight subjects (5 women and 3 men) took part in the experiment. They were between 24 and 42 years of age (M = 27.22, SD = 5.95). Participants were required to name each stimulus using exclusively one of the following Spanish terms: blanco-white, negro-black, rojo-red, verde-green, amarillo-yellow, azul-blue, marrón-brown, rosa-pink, naranja-orange, morado-purple, and gris-grey.

RESULTS

Figures 3 to 6 provide information, in two different ways, about the consistent naming observed in Experiment 4. The first is related to the heading of each graph. The first two numbers indicate, for each category, the frequencies and relative percentages from Experiment 3. The third number (preceded by a plus sign) indicates how many tiles were consistently named in Experiment 4 but not in Experiment 3. Such "bad exemplars" are graphically represented using small grey dots. For all the figures, the grey dots are located contiguously to the black dots (Experiment 3, consistent naming).

Seven of the 12 tiles consistently named *granate*-garnet in Experiment 3 were named *rojo*-red in Experiment 4. Another 4 tiles were named *marrón*-brown and, lastly, 1 tile did not produce consistent naming. Eight of the 16 tiles consistently named *beige*-beige in Experiment 3 were named *marrón*-brown in Experiment 4. Another 7 were named *amarillo*-yellow, and 1 did not produce consistent naming.

Table 3 shows, below the diagonal, the most relevant information related to transitions between categories provided by Experiment 4. (It can easily be compared with its equivalent from Experiment 3: the same table, above the diagonal). The information provided by Table 3 can be synthesized in as follows: All the links discovered in Experiment 3 were confirmed with just one exception (the shared use of *marrón*-brown and *morado*-purple). Additionally, seven new links were found: two between pairs of chromatic categories (red-purple and yellow-pink), three between an achromatic and a chromatic category (white-yellow, black-blue, and grey-yellow), and two between two achromatic categories (white-grey and black-grey).

DISCUSSION

As expected, the forced utilization of the 11 basic categories increased the number of detected links. This increase was especially notable in relation to low saturation stimuli: Five of the seven new links involved at least one achromatic category.

As in Experiment 3, the results from Experiment 4 are consistent with those of Boynton and Olson (1987) and Sturges and Whitfield (1995) in not finding links between the red or orange categories and any of the achromatic ones (*blanco*-white, *negro*-black, and *gris*-grey). Comparing chromacititicy diagramas corresponding to *rosa*-pink, *naranja*-orange, *rojo*-red and *marrón*-brown (Figures 5 and 6) , it can be observed that the positions for the "missing" links between, on the one hand, red or orange

and, on the other hand, the achromatic categories, correspond to the two non-spectral chromatic categories: pink and brown.

The unavailability of the use of *beige*-beige and *granate*-garnet to name stimuli in Experiment 4 produced the typical result associated with any derived basic category. That is, beige was substituted by *marrón*-brown and *amarillo*-yellow, and *granate*-garnet by *rojo*-red and *marrón*-brown. This is similar to the substitution observed by Sterheim and Boynton (1966) in relation with orange (substituted by red and yellow) or the one observed by Fuld et al. (1981) in relation with purple (substituted by red and blue).

EXPERIMENT 5. DIRECT SIGNALLING OF FOCI AND GOOD EXEMPLARS

METHOD

Participants. Eight individuals (6 women and 2 men) participated. They live in Madrid and speak Spanish. They were between 24 and 29 years of age ($M = 26.11$, $SD = 1.96$). All were screened for normal colour vision as described in Experiment 3.

Stimuli and Apparatus. The stimuli to be named comprised the 1750-tile set contained in the NCS index (SCI, 1997). This new version was selected because of the larger tile dimensions (2.5×5 cm), which allowed the simultaneous observation of the full Atlas set from a distance of approximately 3 m. To enable this global vision, the tiles were displayed on a 2.7×5.6 m medium grey (N = 5000, $L^* = 50\%$) wall. They were placed in a similar order to the one used by the atlas (alternating triangles, one point-up, another point-down; in each triangle, the NCS-hue denomination remained constant).

The wall on which the tiles were placed was illuminated with a set of incandescent lamps similar to the ones habitually used in television studios and with a set of Rosco colour correctives filters that allowed reaching a colour temperature of 5800 K and an illuminance of approximately 250 lux.

Procedure. A 5-minute interval was used to adapt each participant to the illumination conditions. During this interval, they were informed about the general characteristics of the two tasks to be performed. The first task (direct foci signalling) trials always began indicating to participants the name of a colour category, and requiring them to look systematically (from

left to right, from top to bottom) at the full stimuli set before performing any stimulus pointing. This procedure was also used for the second task (directly signalling good exemplars), but now participants had to point to "every stimuli that common observers would assign without doubts to a specific category."

For both tasks, the following 14 categories were considered: *blanco*-white, *negro*- black, *rojo*-red, *verde*-green, *amarillo*-yellow, *azul*-blue, *marrón*-brown, *rosa*-pink, *naranja*-orange, *morado*-purple-1, *violeta*-purple-2, *gris*-grey, *beige*-beige*, and *granate*-garnet. Participants signalled these categories consecutively following a random order that was changed between participants. Both tasks were performed in the same experimental session. There was a 10-minute interval between the end of the first task and the beginning of the second.

RESULTS

Table 4 shows the averaged lightness (L*) and chromatic coordinates for the foci of the 11 Spanish BCCs, computed from direct signalling task results. This table also shows the BCC English equivalents as determined by Boynton and Olson (1987, "OSA" in Table 4) and Sturges and Whitfield (1995, "Munsell" in Table 4). All foci chromatic coordinates are represented by a big grey circle in Figures 3 to 6. As can be observed in Table 4, there was a strong similarity between the chromatic coordinates of Spanish BCCs and their English equivalents. To locate the Spanish foci in the *CIE L*u*v** colour space, u* and v* were computed from the L*, u', and v' values using the appropriate algorithm (Hunt, 1995, p. 73). The resulting values and, in parenthesis, the nearest NCS tile were: *blanco*-white (N-0500), u* = 0.0, v* = 0.0; *negro*-black (N-9000), u* = 0.0, v* = 0.0; *rojo*-red (Y90R-1085), u* = 114.81, v* = 15.12; *verde*-green (G10Y-3065), u* = -38.42, v* = 29.15; *amarillo*-yellow (Y-0580), u* = 40.20, v* = 65.17; *azul*-blue (R90B-2065), u* = -28.84, v* = -51.80; *marrón*-brown (Y60R-6030), u* = 26.99, v* = 12.90; *rosa*-pink (R30B-1050), u* = 47.57, v* = -17.10; *naranja*-orange (Y50R-0580), u* = 96.12, v* = 40.15; *morado*-purple (R50B-4050), u* = 17.95, v* = -30.8; and *gris*-grey (N-5500), u* = -1.41, v* = -2.47.

Four of the eight participants spontaneously indicated that, in their opinion, it made no sense to perform the direct signalling tasks both for morado (purple-1) and violeta (purple-2), because both terms referred to the same colour category. However, upon our insistence, they performed both tasks for both categories. A series of Wilcoxon analyses detected no differences in L*, u* and v* for the stimuli selected for morado (purple-1) and violeta (purple-2) in both signalling tasks ($p > .05$).

Table 4. Averaged lightness (L*) and chromatic co-ordinates for the foci of the 11 Spanish BCCs (Computed from the Direct Signalling Task Results with the NCS) and their English equivalents*

Spanish BCC Foci	NCS			OSA			Munsell		
	L*	u'	v'	L*	u'	v'	L*	u'	v'
Blanco-White	89.90	0.19	0.48	82.32	0.20	0.47	96.00	0.20	0.47
Negro-Black	17.97	0.19	0.48	28.77	0.20	0.47	4.85	0.20	0.47
Rojo-Red	38.89	0.42	0.51	36.91	0.36	0.49	41.22	0.45	0.51
Verde-Green	44.85	0.13	0.53	58.98	0.15	0.53	41.22	0.11	0.51
Amarillo-Yellow	74.16	0.24	0.55	84.20	0.23	0.55	86.21	0.24	0.56
Azul-Blue	38.31	0.14	0.38	26.30	0.22	0.37	51.58	0.15	0.35
Marrón-Brown	29.36	0.26	0.52	28.72	0.26	0.51	30.77	0.27	0.54
Rosa-Pink	62.01	0.25	0.47	75.30	0.24	0.46	71.60	0.26	0.46
Naranja-Orange	56.88	0.32	0.54	60.10	0.30	0.52	61.70	0.33	0.54
Morado-Purple	32.19	0.24	0.41	38.06	0.21	0.40	41.22	0.24	0.35
Gris-Grey	54.25	0.19	0.48	51.95	0.20	0.47	56.66	0.20	0.47

*As determined by Boynton and Olson (1987, see "OSA" column) and Sturges and Whitfield (1995, see "Munsell" column).

With just one exception, the results confirmed our predictions about foci chroma levels. That is, the foci were located on the boundaries of the chromatic area corresponding to their lightness level for chromatic spectral categories (Figures 3, 6 and 7), near the achromatic point (central cross of the diagram) for the achromatic categories (Figure 4), and in a central position (between the achromatic point and the boundaries of the chromatic area) for a chromatic non-spectral category (*marrón*-brown, Figure 6). *Rosa*-pink (Figure 5) was the exception to the general pattern of confirmations, because its prototype was within the NCS perimeter.

After describing the results concerning foci localization, we will comment on the results related to good exemplars. In order to be considered a good exemplar, a stimulus had to be signalled by at least half of the participants in Experiment 5. For all the categories, good exemplars were a subset of the set identified in Experiment 3. The number of stimuli consistently signalled for the different categories were: *blanco*-white (29), *negro*-black (5), *rojo*-red (12), *verde*-green (281), *amarillo*-yellow (17),

azul-blue (96), *marrón*-brown (57), *rosa*-pink (24), *naranja*-orange (20), *morado*-purple (10), beige.*beige* (3), and *granate*-garnet (5).

A series of Mann-Whitney tests were performed to compare good (Experiment 5) and bad (Experiment 4) exemplars in C^*_{uv}, L^*, and h_{uv} (h_{uv} = CIE hue parameter, see Hunt, 1995). As expected (see the Discussion in Experiment 3), for all the chromatic spectral categories, good exemplars had significantly higher C^*_{uv} levels than did bad exemplars ($p < .05$). Also in accordance with our predictions, the reverse was true for achromatic categories ($p < .05$). Our predictions were not confirmed for the two non-spectral chromatic categories (brown and pink) because good exemplars were significantly more chromatic than bad ones ($p < .05$).

In the Mann-Whitney tests performed to compare good and bad exemplars, L^*, provided a mixture of confirmation and non-confirmation of our previsions. As expected, good exemplars were significantly darker for brown and purple ($p < .05$), and the reverse was true for white. However, contrary to our predictions, good red exemplars were significantly lighter than bad ones, and the reverse was true for yellow and orange. Lastly, no significant differences were found for black and pink.

To compare the h_{uv} of good and bad exemplars, the following procedure was used: (a) For each category, the mean h_{uv} of consistently named stimuli was computed from the results of Experiment 3; (b) for bad (Experiment 4) and good (Experiment 5) exemplars, the absolute difference between their h_{uv} and the mean was computed. As expected, the series of U Mann-Whitney analyses performed indicated that, for all the chromatic categories, bad exemplars had larger h_{uv} eccentricities than good exemplars ($p < .05$).

DISCUSSION

With the limitations associated with the finite extension of NCS colour space (see Figure 2, left column), we expected bad exemplars to be located at the periphery of the colour space positions occupied by good exemplars. With two notable exceptions, the specific predictions derived from this idea received empirical support.

The first exception was that good exemplars of non-spectral chromatic categories (brown and pink) were significantly superior in chroma ($p < .05$) to bad exemplars. Why did non-spectral categories show the same pattern as spectral categories? A plausible explanation is that, because of the limits of NCS colour space, there were more "positions" in which to place bad exemplars at low rather than at high saturation-chroma levels. Two results are consistent with this speculative interpretation. First, their foci locations were near (Figure 6, *marrón*-brown) or on (Figure 5,

rosa-pink) the boundaries of the NCS areas. Second, the presence of high and low saturation levels for brown and pink bad exemplars was observed. Also in line with the proposed interpretation, we performed a pilot study in which participants were required to estimate the degree of "brownness" and "pinkness" of a subset of stimuli selected from the Munsell atlas (this atlas provides the highest saturation levels). As expected, we obtained maximum estimations for a medium saturation level (similar to the ones corresponding to our foci) and a decreasing pattern for purities above and below this level.

The second exception is related to some predictions about lightness differences between bad and good exemplars. The more notable non-confirmations were related to red and yellow. Our predictions were derived from the following logic: Experiment 3 indicated that these categories concentrate consistent naming at one extreme lightness level (low for red, high for yellow). This level must be predominant for the good exemplars and, consequently, bad exemplars must have predominantly medium lightness levels. A glance at Figures 5 (*amarillo*-yellow) and 6 (*rojo*-red) helps understand why this reasoning was wrong: Bad exemplars tended to appear at the same lightness levels as good ones (but with reduced saturation).

The germinal idea for all the proposed comparisons between good and bad exemplars in h_{uv}, C^*_{uv}, and L^* was that, for all the basic categories, the foci and good exemplars would delimit a specific volume inside the colour space. Bad exemplars were expected on the periphery of this volume. Although it was not initially formulated, there was a very direct way to test this germinal idea: For each BCC, the $L^*u^*v^*$ distance between a stimulus and the category focus was measured. For all the categories, a series of Mann-Whitney U analyses indicated that these distances were larger for bad than for good exemplars ($p < .001$).

GENERAL DISCUSSION

At least from the times of Galileo and Newton, no one in the scientific community denies the perceptive nature of chromatic experiences. That is, in contrast to what common sense tells us, physical light properties only have *"the aptitude to produce this one or another colour"* (Newton 1730, p. 124). Assuming this, the next step is to determine the relations between certain physical properties of light and the properties of perceived colours. To reach this final goal, the development of CIE colour spaces was an important advance. Among other things, because it cleverly simplified the problem of using the metamerism phenomenon: In a CIE space, every point do not attempt to represent a physical stimulus, but all the stimuli that, for a

common observer, and under certain observation conditions, produce the same colour experience.

The external surface of colour spaces and the perimeter of their chromaticity diagrams correspond to maximum saturation (s_{uv}) stimuli. As Figure 2 explicitly shows, these levels are not reached by the NCS atlas stimuli (or by any sample of surface colours). Consequently, surface colours only produce a subset of the full gamut of chromatic experiences. The psychophysical characteristics of *CIE L*u*v** space and of the *CIE u'v'* chromaticity diagram facilitate establishing relations between that subset and purer stimuli because, contrary to what occurs in *CIE L*a*b** space, in *CIE L*u*v**, equality in dominant wavelength implies equality in chromatic angle.

In the framework of the English-speaking population, a significant number of works (Fuld et al., 1981; Gordon, Abramov, & Chan, 1994; Paramei et al., 1998; Sterheim & Boynton, 1966; Wooten & Miller, 1997) have required participants to name the monochromatic stimuli using spectral BCCs (red, green, yellow, blue, orange, and purple). From their results, two important conclusions can be reached. First, only four colours (the elemental chromatic colours: red, green, yellow, and blue) are strictly necessary to name the entire visible spectrum. Second, despite the existence of Bezold-Brücke effect, there is a clear relationship between wavelength and the use of BCCs.

Two results provided by our research are related to the above-mentioned facts. First, Experiment 1 indicated that the four elemental chromatic BCCs, plus white and black (the achromatic elementals), were more frequent in the elicited lists than the rest of the BCCs. Second, Experiment 5 located prototypes in chromatic angles compatible with those observed in works where monochromatic stimuli were used. For example, the chromatic co-ordinates for the yellow prototype (Table 4) allow us to compute a chromatic angle of 59.75º and, consequently, a 576.5 nm dominant wavelength (see Lillo et al., 2002, Table 1). This value is among those corresponding to yellow in Paramei et al. (1998, Figure 1).

Concordantly with Pich and Davies (1999), our experimental series confirmed the existence of 11 BCCs for Spanish. Their denominations are: *blanco*-white, *negro*-black, *rojo*-red, *verde*-green, *amarillo*-yellow, *azul*-blue, *marrón*-brown, *rosa*-pink, *naranja*-orange, *gris*-grey, and *morado*-*violeta*-purple. Additionally, Experiments 2 and 5 showed that the last category is named with two equivalent synonyms (*morado* and *violeta*). More specifically, Experiment 2 showed that these two terms produced synonymicity estimations clearly higher than any pair of BCCs.

Furthermore, Experiment 5 showed no differences between morado and violeta for both direct signalling tasks (foci and good exemplars).

Figure 3 and the ones presented in the Appendix (see http://www.uv.es/psicologica) lead us to conclude that, in their main aspects, there is a strong similarity between the location of Spanish BCCs and the location of their English equivalents. This similarity applies to chromatic co-ordinates and lightness ranges. For example, for both languages, only three categories, *verd*e-green *az*ul-blue and gris-grey were used in the three lightness levels considered. On the other hand, the other BCCs were only used in one or two lightness levels.

The similarity between Spanish and English BCCs and the "translation" of Boynton and Olson's (1987) and Sturges and Whitfield's (1995) results performed in Figure 3 and (Appendix in http://www.uv.es/psicologica) has two positive consequences. First, they made it possible to make explicit some important facts that were only implicit in the two cited investigations. Second, they allowed us to consider our research a complement of those investigations. Let us analyse these two aspects in more detail.

Two types of evidence indicate that red and orange are peculiar in relation to the other chromatic BCCs because they are not used to name stimuli low in s_{uv}. That is, as can be seen in Figures 5 (*naranja*-orange) and 6 (*rojo*-red), there is a significant gap between the achromatic point (the black cross in figure centre) and the positions of the stimuli named *rojo*-red or *naranja*-orange. This gap explains why we did not detect links (Table 3) between these two categories and the achromatic ones (other chromatic BCCs are linked with, at least, one achromatic category). As can be seen by comparing, first the chromaticity diagrams for the achromatic categories (Figure 4, *blanco*-white, *negro*-black and *gris*-grey) and second the diagrams for *naranja*-orange (Figure 5) and *rojo*-red (Figure 6), it can be seen that these last two BCCs do not overlap the positions occupied by achromatic stimuli. This fact, which is implicit in Boynton and Olson (1987) and in Sturges and Whitfield (1995), is very much explicit if one looks at the graphic presentation of our results.

Because of the important presence of low saturated stimuli in NCS atlases, our research complements Boynton and Olson's (1987) and Sturges and Whitfield's (1995) works concerning the use of BCCs to name this type of stimuli. Three results must be emphasised within this framework: First, for the achromatic categories, the increase in the stimulus lightness level reduced the area occupied in the *CIE u'v'* chromaticity diagram. Second, excluding *naranja*-orange and *rojo*-red, all the categories (chromatic and achromatic) were used to name low saturation stimuli. Third, except for the

fact that they had a much reduced frequency in Experiment 1 (elicited lists), *beige*-beige and *granate*-garnet behaved like BCCs. That is, they were used consistently to name specific parts of the colour space (Experiment 3, Figure 4), they were not substituted by a single BCC in Experiment 4, and finally they had prototypes and good exemplars in locations differentiable from those corresponding to any of the 11 Spanish BCCs. Concluding, it is important to indicate that in Sturges and Whitfield's (1995, Table VIII) paper, the English beige/cream produced links very similar to those we found for Spanish *beige*. Because of the location in the colour space of the beige/cream category, these authors indicated that "Boynton and Olson suggested that there may be a missing basic colour . . . the non-basic colour naming data from the present study suggests that this "missing" colour could be a composite representing beige and cream" (p. 372). According to our research, in Spanish, the name of the "missing" colour that fascinated Boynton and Olson is "beige."

We had indicated that our work was complementary to that of Boynton and Olson (1987) and Sturges and Whitfield (1995), especially because of the NCS atlases colourimetric characteristics (the important presence of low saturation stimuli). Considering this fact, it is important to analyse the similarities and differences between our work and the series of papers by Lin, Luo, MacDonald, and Tarrant (2001a, 2001b, 2001c). Like us, they required participants to name a set of stimuli (Lin et al., 2001a) and also, the NCS was used in a version of the direct signalling method (Lin et al., 2001b) very similar to the one used in our Experiment 5 (foci and good exemplar identification). Because of these similarities, we coincide with Lin et al (2001 b, 2001 c) in our main conclusions. That is, (a) for the 11 BCCs, the prototypes of Lin et al. (2001b) were very similar to ours; (b) these authors also observed that, for some chromatic angles (the ones close to 90° in Lin et al., 2001c, and the angles more related to Figures 5 and 6 in our paper), the darkening of the stimuli produced a change from yellow to the green; (c) in general, there was a strong concordance between the colour space positions detected for the 11 English BCCs (Lin et al., 2001c, Figure 7) and their Spanish equivalents (Figures 3-6).

In our opinion, the most important differences between our results and those of Lee et al. (2001) derive from differences in our respective goals. For example, they were interested in determining the use of non-basic colour categories in English and Chinese-Mandarin. Because of this difference in the goals, they performed a less precise colourimetric specification than we did, especially concerning the links between categories. This aspect is especially notable upon examining their Figure 7 (Lee et al., 2001c). A reduced distance can be observed between the positions depicted for, on the one hand, the red category and, on the other,

achromatic categories. This short distance contrasts with the gap between the positions of the yellow and the achromatic categories and could lead to infer, erroneously, that there is a link between red (but not yellow) and the achromatic categories. As we indicated previously (Table 3), and as Sturges and Whitfield (1995) also discovered previously, the situation is exactly the reverse.

The relevance of the links becomes notable upon considering the extension of the differences in colour volumes (compare, for example, our Figures 4, 5, and 6), while at the same time, readers are reminded of the origin of *CIE L*u*v** space (and the *CIE u'v'* chromaticity diagram). That is, as it was developed to provide an accurate metric measurement of the perceptual differentiability of near stimuli (see Hunt, 1995, Figure 3.6), it is not a good guide for selecting distant stimuli. More specifically, if the use of a relatively reduced number of stimuli ensures their discriminability—as is usual in BCC-related research—performing a stimuli selection in the attempt to obtain an evenly spread sample in *CIE L*u*v** space makes it unavoidable for there to be important differences in the number of stimuli related to the different BCCs. For example, in a work by Davies and Corbett (1997) the 65-stimuli sample used only included one white and one black. In our opinion, the results provided by our research would allow generating more representative samples. These could include: (a) the 11 BCC foci (and, possibly, the beige and *granate*-garnet ones), (b) pairs of stimuli located at both sides of a between-categories link, and (c) stimuli located at different distances (25%, 50%, and 75%), from the line defined by a focus stimulus and a between-category link.

RESUMEN

Localización de las categorías cromáticas básicas del español en el espacio CIE L*u*v*: Identificación, segregación por claridad y correspondencia con las equivalentes inglesas. Se realizaron cinco experimentos para identificar las categorías cromáticas básicas (CCB) del español y ubicarlas en el espacio CIE L*u*v*. Empleando una tarea de listas elicitadas y otra de denominación monolexémica libre, se confirmó la existencia de 11 CCB. Mediante una tarea de estimación de sinonimia, se concluyó que, en español, se emplean 2 términos sinónimos (*morado* y *violeta*) para denominar una categoría equivalente a la inglesa *purple*. Tres experimentos proporcionaron información acerca de la localización colorimétrica de las 11 CCB del español. Dos emplearon tareas de denominación monolexémica (libre y restringida) y el tercero requirió la señalización de prototipos y de buenos ejemplares. Se observó que las CCB del español y del inglés son esencialmente equivalentes en número y delimitación colorimétrica, por lo puede considerarse que nuestro trabajo extiende y complementa la investigación previa (sobre CCB inglesas) en lo referente a la localización de las categorías acromáticas en el espacio de color, los vínculos entre categorías cromáticas y acromáticas (ni rojo ni naranja tienen vínculos directos con las categorías acromáticas), y la dependencia de la claridad que muestra el uso de las CCB. Por último, destaca la existencia de 2 categorías próximas a ser básicas: beige y granate.

REFERENCES

Berlin, B., & Kay, P. (1969). *Basic color terms: Their universality and evolution.* Berkeley, CA: University of California Press.

Boynton, R. M., & Olson, C. X. (1987). Locating basic colors in the OSA space. *Colour Research and Application, 12,* 94-105.

Boynton, R. M., & Olson, C. X. (1990). Salience of chromatic basic color terms confirmed by three measures. *Vision Research, 30,* 1311-1317.

Corbett, G. G., & Davies, I. R. L. (1997). Establishing basic color terms: Measures and techniques. In C. L. Hardin & L. Maffi (Eds.), *Color categories in thought and language* (pp. 197-223). Cambridge: Cambridge University Press.

Davies, I. R. L., & Corbett, G. G. (1994). The basic color terms of Russian. *Linguistics, 32,* 63-89.

Davies, I. R. L., & Corbett, G. G. (1997). A cross-cultural study of colour grouping: Evidence for weak linguistic relativity. *British Journal of Psychology, 88,* 493-517.

Davies, I. R. L., Corbett, G. G., & Bayo, J. (1995). Colour terms in Catalan: An investigation of eighty informants, concentrating on the purple and blue regions. *Transactions of the Philological Society, 9,* 17-49.

Fletcher, R. J. (1980). *The City University Color Vision Test (2nd Ed).* London: Keeler.

Fuld, K., Wooten, B. R., & Whalen, J. J. (1981). The elemental hues of short-wave and extra-spectral lights. *Perception and Psychophysics, 29,* 317-322.

Gordon, J., Abramov, I., & Chan, H. (1994). Describing color appearance: Hue and saturation scaling. *Perception and Psychophysics, 56,* 27–41.

Hunt, R.W.G. (1995). *Measuring colour* (2nd ed.). London: Ellis Horwood.

Jameson, K. A., & Alvarado, N. (2003). Differences in color naming and color salience in Vietnamese and English. *Color Research and Application, 28,* 113-138.

Kay, P., Berlin, B., Maffi, L., & Merrifield, W. (1997). Color naming across languages. In C. L. Hardin & L. Maffi (Eds.), *Color categories in thought and language* (pp. 21-58)*.* Cambridge: Cambridge University Press.

Kay, P., Berlin, B., & Merrifield, W. (1991). Biocultural implications of systems of color naming. *Journal of Linguistic Anthropology, 1 ,* 12-25.

Kaiser, P. K., & Boynton, R. M. (1996). *Human Color Vision (2nd Edition).* Washington: Optical Society of America.

Lillo, J. (1996). Manual del test de identificación de daltonismos (TIDA). Madrid: TEA. Lillo, J., Moreira, H., & Gómez, N. (2002). Reflectance and energetic imbalance: Colorimetric evaluation of NCS Colour Atlas. *Psicológica, 23*, 209-232.

Lin, H., Luo, M. R., MacDonald, L. W., & Tarrant, A. W. S. (2001a). A cross-cultural colour-naming study. Part I: Using an unconstrained method. *Color Research and Application*, *26*, 40-60.

Lin, H., Luo, M. R., MacDonald, L. W., & Tarrant, A. W. S. (2001b). A cross-cultural colour-naming study. Part II: Using a constrained method. *Color Research and Application*, *26*, 193-208.

Lin, H., Luo, M. R., MacDonald, L. W., & Tarrant, A. W. S. (2001c). A cross-cultural colour-naming study. Part III: A colour-naming model. *Color Research and Application*, *26*, 270-277.

Newton, I. (1730). *Opticks (4th ed.).* London: William Innys. Reprint New York: Dover. 1952.

Özgen, E., & Davies, I (1998). Turkish color terms: Tests of Berlin and Kay's theory of color universal and linguistic relativity. *Linguistics, 36,* 919-956.

Paramei, G. V., Bimler, D. L., & Cavonious, C. R. (1998). Effect of luminance on color perception of protanopes. *Vision Research, 38,* 3397-3401.

Pich, J., & Davies, I. (1999). La adquisición de los términos para el color en niños castellano y catalano-parlantes. *Infancia y Aprendizaje, 85,* 95-112.

Pointer, M. R., & Attridge, A. (1998). The number of discernible colours. *Colour Research and Application, 23,* 52-54.

Quinn, P. C., Wooten, B. R., & Ludman, E. J. (1985). Achromatic colour categories. *Perception and Psychophysics, 37,* 198-204.

Roberson, D., Davies, I., & Davidoff, J. (2000). Color categories are not universal: Replications and new evidence from a stone-age culture. *Journal of Experimental Psychology: General, 129,* 369-398.

Rosh Heider, E., & Olivier, D. C. (1972). The structure of the color space in naming and memory for two languages. *Cognitive Psychology, 3,* 337-354.

Schirillo, J. A. (2001). Tutorial on the importance of color in language and culture. *Color Research and Application, 26,* 179-192.

SCI. (1997). *NCS Index Edition 2*. Stockholm: Scandinavian Color Institute.

SSI. (1996). *Standardiseringen I Sverige Swedish Standards Institution: Atlas 96.* Stockholm: Scandinavian Colour Institute.

Sterheim, C. E., & Boynton, R. M. (1966). Uniqueness of perceived hues investigated with a continuous judgmental technique. *Journal of Experimental Psychology, 7,* 770-776.

Sturges, J., & Whitfield, T. W. A. (1995). Locating basic colours in the Munsell space. *Color Research and Application, 20*, 364-376.

Sturges, J., & Whitfield, T. W. A. (1997). Salient features of Munsell colour space as a function of monolexemic naming and response latencies. *Vision Research*, *37*, 307-313.

Velázquez, M. (1967). *New revised Velázquez Spanish and English dictionary.* Chicago, IL: Follett Publishing Company.

Wooten, B., & Miller, D. (1997). The psychophysics of colour. In C.L. Hardin & L. Maffi (Eds.), *Color Categories in thought and language* (pp.59-88). Cambridge: Cambridge University Press.

Wyszecki, G., & Stiles, W.S. (1982). *Color Science: Concepts and Methods. Quantitative Data and Formulae (2nd Edition).* New York: John Wiley & Sons.