

Relative luminance and figure-background segmentation problems: Using AMLA to avoid nondiscernible stimulus pairs in common and color blind observers

Julio Lillo Jover* and Humberto Moreira

Complutense University of Madrid (Spain)

Four experiments evaluated AMLA temporal version accuracy to measure relative luminosity in people with and without color blindness and, consequently, to provide the essential information to avoid poor figure-background combinations in any possible "specific screen-specific observer" pair. Experiment 1 showed that two very different apparatus, a sophisticated photometer and a common luxometer, provide equivalent measurements to compute: (1) screen gamma exponents and (2) relative luminance (Y/Y_n) of achromatic but not of chromatic stimuli. Experiments 2, 3 and 4 showed that the psychophysical task of AMLA temporal version provided, for any stimulus type, accurate relative luminance measurements. They were: equivalent to standardised photometric measurements for common observers (Experiment 2); similar to the expected distortions for simulated (Experiment 2) and real (Experiment 3) aged tritanomalous observers; concordant with the expected distortions of protanope observers (Experiment 4).

Maps, web pages or any type of visual display frequently use chromatic variations to divide a visible scene into large parts. At the same time, visual displays provide achromatic variations in order to facilitate visibility of the small changes (for example, contours that form letters) presented in each of these large parts. Such a choice is not a whim of visual designers but a consequence of the visual system's functional characteristics (Ware, 2000, chapter 4). More concretely, it is because the achromatic mechanism has better spatial resolution than chromatic mechanisms (De Valois & De Valois, 1988, chapter 7; Kaiser & Boynton, 1996, chapter 9) and, consequently, the visual system can only respond to high frequency variations when these are quantitative (changes in luminance) but not when they are purely qualitative (changes in chromaticity).

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Now let us consider a problem that is familiar to many Internet users (Nielsen, 2000): The backgrounds that accurately contrasted on the designer's monitor with whatever was presented on them, do not contrast: (a) on a different monitor, and/or (b) when observed by another person. This paper, after analysing the technological-perceptual origin of this problem, will describe the results obtained with a method, the AMLA, specifically designed to overcome this difficulty.

No change in software color specification and relative luminance variations: Changes due to screen characteristics.

The colors provided by a specific screen result from mixing, in different proportions, the light of its three primaries: a red (R), a green (G), and a blue (B). In the coding system popularised by Microsoft, a 255-level corresponds to the maximum primary luminance: zero to no activation. Logically, the lightest white is generated by the command $R=G=B=255$; the darkest black by $R=G=B=0$; the brightest yellow by $R=G=255, B=0$, etc. However, the same software command, the same RGB triad, can generate different colors on different screens (to perceive this, both monitors must be close to each other) because of the effects mediated by the following factors: (1) differences between screen primaries, and (2) variations in the gamma values used by different screens.

A recent paper (Lillo, Rodríguez, & Moreira, 2002, Table 1) reported the differences between common monitor luminances. For example, in the CRT screen used by a conventional computer, the following luminances were measured for the red, green and blue primaries: 27.5; 70 and 6.7 cd/m^2 (white provided a luminance, 104 cd/m^2 , equal to the sum of the previous three). On the other hand, the luminances corresponding to the primaries (Y_R, Y_G, Y_B) and white (Y_n) of a DSTN notebook screen were, respectively, 13.9, 26, 6.78 and 46.78 cd/m^2 . There are two ways of considering the relevance of these differences: focusing on absolute luminance values or, very important in relation to achromatic contrast, focusing on relative luminance (Y/Y_n) values.

Excluding aspects that concern blue primary, all the CRT measurements were over their equivalents for the DSTN. More important, there were also significant differences between the three relative luminances. For the CRT, they were $Y_R/Y_n \cdot 100 = 26.39\%$, $Y_G/Y_n \cdot 100 = 67.18\%$ and $Y_B/Y_n \cdot 100 = 6.43\%$. For the DSTN, were $Y_R/Y_n \cdot 100 = 29.78\%$, $Y_G/Y_n \cdot 100 = 55.70\%$ and $Y_B/Y_n \cdot 100 = 14.52\%$. Let us consider an example to better understand the relevance of the previous differences. Imagine that, having designed a web page, blue primary was chosen to present specific information written on a black background. Imagine also that blacks have 4% relative luminance on both screens. Using this value, we can calculate contrast proportions ($C_p = Y/Y$): For the DSTN, this parameter is equal to 3.63 and, consequently, text visibility is guaranteed. On the other hand, for the CRT, $C_p = 1.60$ and, therefore, the text would be difficult to read.

Let us now consider the other factor that can produce that the same pair of software commands generates different achromatic contrasts when changing the screen: the Gamma factor.

The gamma factor is an exponent used to relate relative stimulus luminance (Y/Y_n) with lightness (L^*). According to CIE (Hunt, 1995, chapter 3), such a relationship can be specified in the following way:

$$Y/Y_n = ((L^*+16)/116)^3 \quad (1)$$

Equation (1) uses a gamma value equal to 3. Based on this, in order to produce a medium grey ($L^* = 50$), a relative luminance equal to 18.41% ($Y/Y_n = 0.1841$) must be used. What would be predicted assuming gamma equal to 2? In such a situation, Equation (1) indicates that the same lightness ($L^* = 50$) would require a higher relative luminance ($Y/Y_n = 0.3237$). Synthesising, the gamma value used by a screen determines the relative luminance required to obtain a specific lightness level. Consequently, screens using different gammas provide different relative luminances in response to the same RGB command.

No change in software color specification and relative luminance variations: Changes due to observers.

Standard luminance measurements are based on the official CIE function of spectral efficiency (V_{\square}) homologated in 1931. Although CIE (1990) itself has recommended substituting it with V_M (a “modified” version), common measurement apparatus continue to work according to V_{\square} (Lynes, 1996) because of, among others, the following facts: (1) Empirically, and considering stimulations that accumulate energy in wide wavelength ranges, computing luminance using V_{\square} or V_M provides comparable results. (2) Some standard parameters (X , Y , Z) provided by common photocolourimetry allow the use of very accurate equations (2 and 3, Travis, 1991) to estimate relative response in the three types of retina cones (L , M , S). Therefore, they permit the computation of standard luminance (Y) and, currently more important, transformed versions (Y_T , transformed luminosity) adapted to the peculiarities of people with color perception alterations.

$$\begin{pmatrix} L \\ M \\ S \end{pmatrix} = F^{-1} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (2)$$

$$F^{-1} = \begin{pmatrix} 0.15516 & 0.54308 & -0.03287 \\ -0.15516 & 0.45692 & 0.03287 \\ 0 & 0 & 0.01608 \end{pmatrix} \quad (3)$$

Let us use one of our screen primaries (the red of a CRT monitor) to exemplify what we mentioned in the previous paragraph. Standardised measurement provided a 22.6 luminance (cd/m^2) and the following chromatic co-ordinates: $x = 0.596$; $y = 0.355$. From them (and using Lillo, 2000, equations 4.5; 4.6 and 4.7), the following trichromatic values were computed: $X = 37.94$; $Y = 22.6$; $Z = 3.12$. Equation (2) provided a relative response (100% is the maximum and corresponds to the reference white) equal to 27.61% for L, 12.65% for M, and 3.12% for S cones. As indicated by Equation (4), it was assumed that the standard luminance ($Y = 22.6$) derives from adding L and M responses and, most important, that these responses are differentially weighted (L weight factor equal to 66.53%, M weight factor equal to 33.47%; weighting factors are implicitly included in Equation (3)).

$$Y = L + M = 18.06 + 4.54 = 22.6 \quad (4)$$

When color blind people are considered, L and M weighting values should be changed in order to compute a transformed luminosity (Y_T) for the specific alteration studied. For example, in the protanopes' case, the unavailability of L cones (Birch, 1993) would imply that Y_T is only mediated by M and that, for the red primary, $Y_T = 13.57$. This value is nearly the half of the standard luminance (Y).

The two observer types for whom alterations in luminance–lightness are the most well known are protanopes and aged tritanomalous (op. cit. chapter 4). In the former, a reduced sensitivity to the right spectrum portion (“reds”, $Y_T < Y$) and the opposite for the left portion (“blues”, $Y_T > Y$) has been observed (Lillo, Collado, Vitini, Ponte, & Sánchez, 1998; Paramei, Bimler, & Cavonius, 1998). For aged tritanomalous persons, the pattern is exactly the reverse (Werner, 1998). In any case, the very existence of people with luminance–lightness perception alterations ensure that, for an important number of observers, some “adequate” figure-background relationships are problematic.

This paper describes the results provided by an experimental series related to the development of the AMLA method. As indicated in another publication (Lillo et al., 1999), the main goal of this method is to detect, for any pair “screen-observers”, poor figure-background combinations. It is considered that a poor pair arises when there is excessive similarity between the two effective luminances (Y_E) under consideration (or in the two relative effective luminances, Y_E/Y_{En}). For common observers, it is assumed that $Y_E = Y$. For noncommon observers, $Y_E = Y_T$ (note that, in this latter case, cd/m^2 can no longer be used: see Kaiser, 1988).

When a RGB scale with maximum of 255 is used, the Y_E value for any stimulus can be computed from the primary luminances according to the following equation:

$$Y_E = \frac{R}{255} Y_{ER} + \frac{G}{255} Y_{EG} + \frac{B}{255} Y_{EB} \quad (5)$$

where γ is the gamma value, Y_{ER} , Y_{EG} , Y_{EB} , the effective luminances of red, green and blue primaries when presented at maximum value, and R , G , B the specific RGB values used. Consequently, to compute a Y_E value from an RGB specification, it is necessary to know: (1) the gamma used by the screen (γ) and (2) the effective luminance of the primaries. For a common observer, these values can be obtained using a photometer, but this is not true for noncommon observers or, a very customary case, when only a luxometer is available. The AMLA method performs an operative equation (5) also in these last two cases.

AMLA is an acronym derived from two English expressions: “Achromatic Measurement” (AM) and “Luminosity Adjustment” (LA). They synthesise the essentials of a new method that is used to compute the Y_E/Y_{En} (relative effective luminance) corresponding to any stimulus generated by a computer screen. The expression “Achromatic Measurement” indicates that AMLA assumes that different apparatus (photometers and luxometers) provide equivalent relative luminance (Y/Y_n) measurements and, consequently, similar gamma estimations.

“Lightness Adjustment” is an expression that derives from the following AMLA premises: (1) It is assumed that, for chromatic stimuli, only high quality photometers provide accurate luminance measurements. (2) It is also assumed that common screens allow using adaptations of standard psychophysical tasks in order to determine when an achromatic stimulus has the same relative effective luminance as a target chromatic stimulus. Thus, (3) it is possible to measure the relative luminance of the equivalent achromatic stimulus and to assign this measurement to the chromatic target.

EXPERIMENT 1

AMLA, gamma and relative luminance.

Our first experiment was designed to test the partial equivalence premise on which AMLA is based, using two very different measurement instruments (a high quality photometer and a common luxometer). It was hypothesised that these apparatus: (1) would allow us to calculate equivalent gamma values and (2) would provide similar relative luminance values for achromatic stimuli (3) but not for chromatic ones.

For computing relative luminance values (Y/Y_n), measurements (Y) were divided by the white value (Y_n , $R=G=B=255$). Using relative luminance, it was expected that: (1) For achromatic stimuli, there would be no differences between the measurements provided by both measurement apparatus, but (2) there would be differences for chromatic stimuli. (3) Similar gamma values were computed for each screen when restricting calculus to a specific stimulus type.

METHOD

Apparatus. A CS-100 Minolta photo-colorimeter and a TES 1330 luxometer were used for the measurements. Stimuli were presented on two 17-inch screens: a Sony Trinitron Multiscan 17 SEII and an LG Studioworks 700 S. Both screens were connected to a Pentium III computer equipped with conventional Microsoft Office software.

Stimuli and procedure. The photo-colorimeter and the luxometer were used for measuring several stimulus series generated by the two screens. Each series included different stimulus types presented at, approximately, three luminance levels: maximum (100%), two thirds (66.66 %), and one third (33.33%). The stimulus types used were: (1) achromatic ($R=G=B$), red primary ($R>0$; $G=B=0$), green primary ($G>0$; $R=B=0$), blue primary ($B>0$; $R=G=0$), cyan ($R=0$; $G=B>0$), magenta ($G=0$; $R=B>0$), and yellow ($B=0$; $R=G>0$). Additionally, the black used by both screens was measured ($R=G=B=0$) to subtract the measured value from the rest of the measurements corresponding to each screen.

Measurements were performed individually for each "screen-measurement apparatus" combination, beginning 30 min after the screen was switched on. We used a simple PowerPoint program to successively present the stimuli included in the measured series on the screen and to record the RGB command used.

The photo-colorimeter was mounted on a tripod to ensure that luminance measurements always came from the same screen part (its centre). To obtain the luxometer measurements, the sensitive part of the luxometer was fixed to the screen centre with adhesive tape.

RESULTS

The $R=G=B=0$ command produced measurements equal to 0.13 cd/m^2 and 0.36 luxes for the Sony screen and to 0.01 cd/m^2 and 0.03 luxes for the LG screen. For both screens, luxometer measurements were exactly the same as the photometer measurements multiplied by a constant ("factor" in Tables 1 and 2). For example, measurements were equal to 167.64, 111.64 and 55.64 luxes for achromatic stimuli and the Sony screen. These values match those measured with the photometer (64.97, 43.27 and 21.57 cd/m^2) multiplied by 2.58 (the factor presented in the second column of Table 1).

After specifying the factor for each stimulus type, Tables 1 and 2 provide information about measured luminances for the maximum level (100%), approximately two thirds (66.66 %) and approximately one third (33.33 %).

Table 1. Luminance, RGB levels, and corresponding gamma for different stimuli presented on Sony Trinitron screen.

Stimulus type	Factor	Luminance (cd/m ²)			RGB-Gamma	RGB-Gamma	RGB-Gamma	RGB-Gamma
		100%	66.6%	33.3%	66% CRT (photometer)	66% CRT (luxometer)	33% CRT (photometer)	33% CRT (luxometer)
Achromatic	2.58	64.97	43.27	21.57	214 - 2.72	214 - 2.72	158 - 2.77	158 - 2.78
Red	1.44	21.97	14.60	7.24	213 - 2.67	213 - 2.69	154 - 2.66	154 - 2.69
Green	2.72	38.37	25.54	12.70	214 - 2.73	214 - 2.73	158 - 2.78	158 - 2.78
Blue	7.30	4.39	2.88	1.38	214 - 2.82	214 - 2.75	156 - 2.85	156 - 2.75
Yellow	2.24	60.67	40.40	20.14	214 - 2.72	214 - 2.73	157 - 2.74	157 - 2.74
Magenta	2.43	26.47	17.60	8.74	213 - 2.66	213 - 2.67	155 - 2.69	155 - 2.69
Cyan	3.17	43.17	28.74	14.30	214 - 2.73	214 - 2.73	158 - 2.78	158 - 2.78

Table 2 Luminance, RGB levels, and corresponding gamma for different stimuli presented on LG screen.

Stimulus type	Factor	Luminance (cd/m ²)			RGB-Gamma	RGB-Gamma	RGB-Gamma	RGB-Gamma
		100%	66.6%	33.3%	66% CRT (photometer)	66% CRT (luxometer)	33% CRT (photometer)	33% CRT (luxometer)
Achromatic	2.91	65.15	43.43	21.71	207 - 2.29	207 - 2.29	152 - 2.57	152 - 2.57
Red	1.44	16.10	10.73	5.36	213 - 2.65	213 - 2.63	157 - 2.73	156 - 2.69
Green	2.79	47.80	31.86	15.93	213 - 2.65	212 - 2.58	157 - 2.73	157 - 2.73
Blue	7.12	7.70	5.13	2.56	213 - 2.64	213 - 2.64	159 - 2.80	158 - 2.78
Yellow	2.46	61.60	41.06	20.53	212 - 2.58	212 - 2.52	156 - 2.70	155 - 2.66
Magenta	3.26	23.20	15.46	7.73	212 - 2.58	212 - 2.58	156 - 2.70	156 - 2.69
Cyan	3.39	54.40	36.26	18.13	212 - 2.58	212 - 2.58	156 - 2.70	156 - 2.70

The last columns of Tables 1 and 2 specify: (1) before the hyphen, the RGB commands used to adjust desired luminance levels; and (2) after the hyphen, the gamma (γ) values computed with the following equation:

$$\gamma = \frac{\log \frac{Y}{Y_n}}{\log\left(\frac{RGB}{2.55} + 16\right) - \log 116} \quad (6)$$

where Y_n is the measurement obtained when a stimulus type is presented at maximum luminance and Y the measurement corresponding to a specific level (66 or 33%). RGB is the Microsoft value used.

Table 1 shows that, for the Sony screen, the gamma values obtained in any combination “stimulus type-proportion of luminance” were highly similar. Minimum gamma (2.66) was computed using the photometer and the 33% red and 66% magenta stimulation, maximum gamma (2.85) using the 33% blue as measured by the photometer. Three types of statistical analyses were performed to compare Table 1 gamma values. First, a nonparametric Friedman analysis of variance indicated ($\chi^2 = 20.74$; $df = 6$; $p < 0.05$) that there were significant differences related to the stimulus type. However, because of the number of observations considered, a series of Wilcoxon analyses found no significant differences ($p > 0.05$) between stimulus types. The second type of statistical analysis compared relative luminance measurements provided by the two apparatus (photometer and luxometer), and no significant differences were found at either of the luminance levels ($p > 0.05$). The third type of statistical analysis compared the measurements obtained at the two different levels for the two apparatus. This time, the gammas computed using the 33% luminance (photometer median, 2.78; luxometer median, 2.75) were significantly higher than those computed at the 66% level (photometer median, 2.73; luxometer median, 2.73) for both measurement instruments.

Table 2 shows less similarity for the gamma values than does Table 1. Now, the range is between 2.29 (66% achromatic) and 2.80 (33% blue, photometer). The gamma variation is also greatly reduced when achromatic stimuli are not considered: Minimum becomes 2.52 (66% yellow, luxometer), maximum remains the same, and the variation range is reduced to 0.28. As with Table 1, three types of statistical analyses were performed to compare Table 2 gamma values. First, a non parametric Friedman analysis of variance revealed significant differences related to the stimulus type ($\chi^2 = 19.9$; $df = 6$; $p < 0.01$). However, because of the number of observations considered, a series of Wilcoxon analysis found no significant differences ($p > 0.05$) between stimulus types. The second type of statistical analysis compared relative luminance measurements provided by the two apparatus (photometer and luxometer), and significant differences were found at both luminance levels ($p < 0.05$), because, although very similar, those computed using photometer measurements (33% median, 2.696; 66% median, 2.581) were significantly higher than their luxometer equivalents (33% median, 2.694; 66% median, 2.579). The third type of statistical analysis compared the measurements obtained at the two different levels for the two apparatus. This time, the gammas computed using the 33% luminance (photometer median, 2.70; luxometer median, 2.69) were significantly higher than the ones computed at the 66% level (photometer median, 2.58; luxometer median, 2.58) for both measurement instruments.

All the Table 1 gamma values were higher than their Table 2 equivalents. Obviously, a Wilcoxon analysis indicated maximum significance value for this difference.

DISCUSSION

Results obtained were, in general, concordant with our expectations because:

(1) The common luxometer used allowed us to compute gamma values fully equivalent to the ones obtained from photometer measurements.

(2) Achromatic relative luminance measurement was not affected by the apparatus used. The explanation of this fact is that, for all the achromatic stimuli, luxometer measurements are equal to photometer measurements multiplied by a constant (“factor” in Tables 1 and 2), and this is also the constant corresponding to the reference white (Y_n).

(3) As the “factor” for chromatic stimulus type was different from the achromatic one, luxometer measurements were not accurate when estimating the relative luminance of these stimuli.

Although it was not included in our predictions, we detected an important performance difference between Sony and LG screens, using the photo-colorimeter. Because, only for the Sony screen, the luminance of the white (64.97) was very similar to the sum of the three primaries ($21.97 + 38.37 + 4.39 = 64.73$), just for this monitor was the activation of the primaries independent. On the other hand, the measured white was 65.15 for the LG screen, a value that is only 90% of the sum of the primaries (71.60).

Synthesising, the first experiment showed that gamma can be similarly estimated using a sophisticated photometer or a common luxometer. On the other hand, because of the differences in the factors that translate the measurements performed by both instruments, a luxometer cannot be used for measuring the relative luminances of chromatic stimuli, including the three primaries considered in Equation (5). Taking this limitation into account, the main goal of our second experiment was to evaluate whether the second stage of AMLA can be used to accurately measure the relative luminance of primaries for common and noncommon observers.

EXPERIMENT 2

AMLA, simulated aged tritans and standard relative luminance.

Most of the previous works related to AMLA (Lillo et al., 1999, 2002) used, in the LA (“lightness adjustment”) stage, adaptations of the minimally distinct border task (“Spatial AMLA”). They required observers to identify which grey background made it more difficult to read a written message, assuming that maximum difficulty indicates high similarity between the Y_E of the chromatic (text) and achromatic (background) stimuli.

Spatial AMLA is not a convenient choice for aged tritanomalous people¹, because they frequently have reduced visual acuity. Consequently, the experiments described below used an adaptation of flicker photometry (Kaiser & Boynton, 1996, chapter 9) that we called “Temporal AMLA”. It required observers to attend a square presented at the screen centre, where a variable luminance achromatic stimulus was alternated with the chromatic target stimulus. The observers’ task was to adjust the achromatic stimulus luminance to perceive minimum flickering. The monitor used a temporal frequency of 20 Hz to ensure that the achromatic mechanism was the main determinant of the adjustments.

Participants in the second experiment were observers with no color vision disturbances. They performed the AMLA psychophysical task in two different ways: using a filter to mimic tritanomaly and without the filter.

Considering the results previously obtained with Spatial AMLA, we expected, for common observers without the filter, that the temporal version would provide relative luminance estimations similar to standard photometric measurements. On the other hand, we expected distorted chromatic-achromatic luminance relations when using the filter. Filter optical characteristics determine the type and magnitude of such distortions.

In addition to temporal AMLA, observers also responded to a set of chromatic tests, with and without the filter. The tests were used to evaluate the filter capacity to specifically mimic tritan alterations (we wished to avoid a “general” color vision distortion). Consequently, we expected filter-produced tritan responses, but not protan or deuteran ones.

METHOD

Participants. Ten subjects (six women and four men) took part in the experiment. They were between 20 and 42 years old (median 24). All were screened for color vision by means of the Ishihara Pseudo-Isochromatic color plates, the City University Color Vision Test (CUCVT; Fletcher, 1980), and the Lanthony test (Lanthony, 1975).

Stimuli, apparatus and procedure. Temporal AMLA was performed using the Sony Trinitron Multiscan 17 SEII screen described in the previous experiment (Table 1). For the stimuli alternation, a 1.75-cm² square, located at the screen centre, was used. At the observation distance employed (1 meter), it projected an angular size of 1 degree. The rest of the screen was filled with a uniform grey background ($L^* = 50$). The three chromatic stimuli were low saturation versions of the three screen primaries. Their luminances and coordinates were: red ($Y = 26.5$; $x = 0.531$, $y = 0.352$), green ($Y = 43.1$; $x = 0.307$, $y = 0.497$) and blue ($Y = 9.55$; $x = 0.188$, $y = 0.126$). These

¹Lillo & Moreira (2004) provide an introduction to colour blindness. The term tritanomalous indicates that the third cone type (tritan means third in Greek) has some kind of anomaly. Ocular aging makes eye lens yellowish, reducing the energy in the spectrum short extreme end, consequently, distorting tritan cones response.

measurements were performed with a Minolta CS-100 photo-colorimeter mounted on a tripod.

For mimicking eye aging, a yellowish Supergel filter (#312 *Canary*) was adapted to a pair of goggles. This filter was selected because of the similarity between its transmittance function and changes due to aging in spectral luminous efficiency (Sagawa & Takahashi, 2001). For the screen white had a 48.85% transmittance. For the red, green and blue used, this parameter was, respectively, 66.42, 45.71 and 39.78%. Comparison between the transmittance for a chromatic stimulus and for the white (T_c/T_w , hereafter the “filter factor”) indicates relative filter effect. Because this comparison provided a value over 1 for the red (1.36), its relative effective luminance (Y_E/Y_{En}) increases when using the filter. On the other hand, the opposite is true when, as is the case for green (0.94) and blue (0.81), the comparison value is under 1.

RESULTS

Color diagnosis tests

Observers did not make errors when responding without wearing the yellowish goggles. However, errors were frequent, and very specific, when the filter was used: No protan or deutan errors were made in response to Ishihara and CUCVT. Tritan errors appeared in response to CUCVT (mean 1.62) and Lanthony (1.25). One-tailed Wilcoxon tests showed significantly more *tritan*-type errors when the pseudoisochromatic plates were seen through the filter (CUCVT: $Z = -2.80$, $p < 0.01$; Lanthony: $Z = -2.52$, $p < 0.01$).

AMLA Psychophysical task adjustments

Figure 1 indicates mean relative luminance for each target color (red, green and blue) and condition (with or without the filter). Dark bars correspond to adjustments with (centre-left) or without (centre-right) the filter. Light bars indicate the relative photometric luminance (right, measured with a photometer) and this same parameter transformed by the “filter factor” (left, “prediction” bars in Figure 1).

As can be seen in Figure 1, and as confirmed by two Wilcoxon tests (no significant differences, $p > 0.05$), there was high concordance: (1) between the “predictions” and the adjustments performed with the filter (left bars) and (2) between the no-filter adjustments and the standard photometric measurements. Another series of Wilcoxon tests indicated that the adjustments for blue and green stimuli were significantly reduced when using the filter (*blue*: $Z = -2.84$, $p < 0.01$; *green*: $Z = -2.81$, $p < 0.01$), but increased for the red stimulus (*red*: $Z = -2.80$, $p < 0.01$).

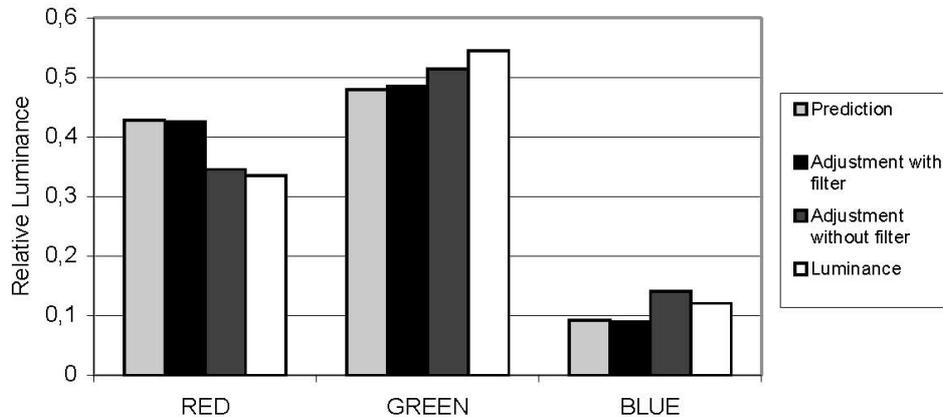


FIGURE 1. Experiment 2 mean relative luminance adjustments performed in AMLA task for each of the three target stimuli and under both experimental conditions: absence (dark grey bars) and presence (black bars) of the yellowish filter. The luminance of the stimuli (white bars) and the prediction of the adjustments to be made with the filter are also shown (light grey bars).

DISCUSSION

High error specificity was found when observers responded to chromatic tests because all the errors were: (1) of tritan type and (2) only appeared when the yellowish filter was used. Consequently, at least with the conventional clinical parameters, we achieved an adequate aged tritanomaly simulation. We also attained satisfactory results in relation with AMLA adjustments for common (no filter) and noncommon (simulated when using the filter) observers because, (1) as reported in previous studies for the “spatial AMLA” version (Lillo et al., 1999; 2002), the temporal version used here also provided relative luminance measurements fully equivalent to standard measurements for the no-filter condition and, even more important, (2) these measurements changed in the expected direction and magnitude when using the yellowish filter.

EXPERIMENT 3

AMLA, real aged observers and relative luminosity variations

Contrasting with Experiment 2, the third experiment was concerned with a situation where the non-equivalence between standard (Y) and effective luminance (Y_E) was not produced by using a filter, but was the consequence of a real perceptual disturbance: the ocular yellowing process related to tritanomaly due to aging (Werner, 1998).

Because of interindividual differences in the severity of color perception distortions of age-related tritanomaly, and because of the difficulties to obtain precise diagnoses in older people, it was not possible to make precise predictions for aged tritanomalous observers. However, it was possible to predict the sign of the distortions. That is, higher grey adjustments (positive sign) were expected when higher sensitivity to a chromatic stimulus was predicted for tritanomalous observers than for controls (they would see the stimulus as lighter). On the other hand, lower grey adjustments (negative sign) were expected for stimuli when reduced tritanomalous sensitivity was predicted.

In order to make the predictions about the sign of tritanomalous adjustments, we used Equations (2) and (3). They provide estimations of the relative response magnitude in the three cone types (L, M and S). We predicted that when L was higher than M (for example, “reds”), aged tritanomalous people would select lighter greys in AMLA. The opposite was predicted when an M response predominated (“blues”).

People who undergo cataract surgery are called aphakic. Most of these people were tritanomalous before crystalline lens extraction. Considering this, our third experiment compared a group of four tritanomalous persons' adjustments with standard luminance measurements and with adjustments performed by an aphakic.

METHOD

Participants. Four tritanomalous persons (2 men, 2 women; from 83 to 90 years) and a bilateral aphakic (a woman; 76 years old) took part in the experiment. They all lived in a residential institution.

The older people's color vision was diagnosed using the same chromatic test battery previously described (Ishihara, CUCVT and Lanthony). No observers produced protan or deutan responses. The tritanomalous group members produced a significant number of tritan responses (CUCVT mean = 3.63; Lanthony mean = 2.7).

Stimuli, apparatus and procedure. Except where explicitly indicated, everything was similar to Experiment 1. For applying temporal AMLA, a Sony Trinitron Multiscan 17 SEII screen was used. After the training stage, five stimuli were alternated two times with the achromatic stimulation in the AMLA psychophysical task: the red ($Y = 22.03$; $x = 0.612$; $y = 0.349$) and blue ($Y = 7.44$; $x = 0.149$; $y = 0.093$) primaries and three nonprimary stimuli: a red ($Y = 27.10$; $x = 0.545$; $y = 0.340$), a green ($Y = 44.53$; $x = 0.322$; $y = 0.491$) and a blue ($Y = 12.24$; $x = 0.184$; $y = 0.133$). To avoid problems derived from visual acuity limitations, AMLA stimulation dimensions were increased to 11.54 cm and the observation distance was reduced to 50 cm (projected angle equal to 13°).

RESULTS AND DISCUSSION

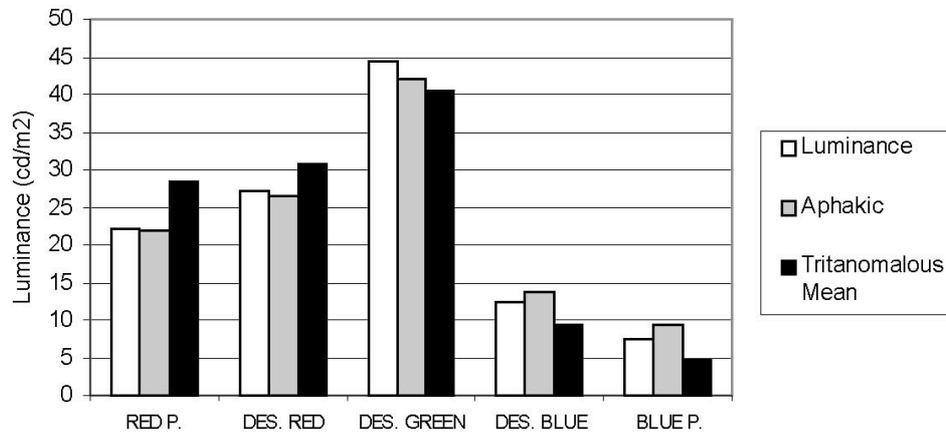


FIGURE 2. Experiment 3 AMLA adjustments. White bars show the stimulus luminance. Note that adjustments made by aged tritanomalous observers (black bars) were, in relation to standard luminance and bilateral aphakic observer adjustments (grey bars), lower for the stimuli perceived as “blue”, but higher for those perceived as “red”. P. = primary, DES. = desaturated.

Figure 2 bars indicate, for each stimulus, (1) standard luminance (left), (2) aphakic adjustments (centre) and (3) mean of tritanomalous adjustments (right). It can be observed that: (1) There was strong concordance between predicted and observed adjustment signs (black bars are higher than left ones for “reds”. The opposite is true for “blues” and the “green”). (2) There was high similarity between standard luminance and aphakic adjustments. (3) For reds and blues, differences between tritanomalous adjustments and luminance tended to increase when the latter parameter was substituted by aphakic adjustment. This is concordant with aphakic optical characteristics: An artificial lens, used to substitute the extracted lens, allows better transmission of short wavelength energy (Werner, 1998). To conclude, although the number of participants made statistical analysis impossible, the results of the AMLA Experiment 3 fully concord with the idea that aged tritanomalous observers, compared with the standard observer, have reduced relative sensitivity to short wavelengths, but increased sensitivity to the long part of the spectrum.

EXPERIMENT 4

AMLA, protanope observers and relative luminosity variations

Experiment 4 was designed to be performed by protanopes, an observer type with a pattern of spectral sensitivities that is the opposite of that of the tritanomalous: higher sensitivity to the left portion of the spectrum but lower sensitivity to the right portion.

Because of their genetic origin (Birch, 1993), protanopes offer two important advantages for research. First, it is relatively easy to find young people with this pathology and, consequently, there are fewer difficulties to perform relatively extended experimental sessions. Second, as the origin of protanopia is well known, Equation (2) affords very specific predictions about relative effective luminances: for protanopes, they must be equal to the relative M response.

Considering the possibility of using extended experimental sessions, we designed a chromatic stimuli sample in which was included, at least, and excluding black and white, an exemplar of every Spanish Basic Category (Lillo, Aguado, Moreira, & Davies, 2004). Except for this and for the participants' perceptual peculiarities, everything was similar to the two previous experiments.

METHOD

Participants. Two groups of observers took part in this experiment. The control group was formed by 10 participants (7 women, 3 men; ages ranging from 22 to 24 years) with normal color vision. The protan group was made up of two protanopes (men, 28 and 34 years).

Stimuli, apparatus and procedure. In addition to the battery of chromatic clinical tests previously described, the protanopes' clinical status was confirmed using a Nagel anomaloscope (Tomey, AF-1).

AMLA psychophysical task application was as described in Experiment 2, except that a set of eleven stimuli was used (Table 3). This was formed by the three screen primaries (red, green and blue), the three colors created by using two primaries at maximum luminances (yellow, magenta and cyan) and one exemplar of each Spanish derived basic category (pink, brown, orange, purple and grey). Table 3 indicates their standard luminance (Y), chromatic co-ordinates (x , y) and transformed luminosity (Y_T).

RESULTS

Figure 3 uses continuous lines to show the reference "luminances" for both groups: The thin line indicates standard luminance (we expected the control group's adjustments to be similar to it). The thick line indicates transformed luminosity (Y_T , we expected protanopes adjustments similar to it). Discontinuous lines correspond to the adjustments made by control (thin, circles) and protan (thick, triangles) groups. As is graphically obvious: (1)

There is a strong concordance between reference and adjusted luminances and (2) there are important differences between the two groups' adjustments. A series of "U" tests showed that, as predicted, protan observers adjusted significantly ($p < 0.05$) lower luminances for red, orange, magenta, purple, pink, yellow and brown. The reverse was true for blue, green and cyan. Of course, there were no differences for grey (all observers made the same adjustment!).

Table 3. Stimuli used in Experiment 4. Chromatic coordinates, luminance and transformed luminosity (see text for details) are indicated.

Stimulus Appearance	x	y	Y	Y_T
Red	0.596	0.355	22.6	13.57
Green	0.287	0.572	39	45.12
Blue	0.152	0.080	5.69	8.12
Yellow	0.438	0.476	61	58.35
Magenta	0.364	0.208	27	20.42
Cyan	0.215	0.325	43.7	52.34
Pink	0.345	0.298	50.8	48.07
Brown	0.484	0.395	11.2	9.27
Orange	0.522	0.413	34.3	27.26
Purple	0.309	0.181	19.7	16.76
Grey	0.339	0.335	36.80	36.80

GENERAL DISCUSSION

Experiment 4 provided, for the control group, a Pearson correlation of 0.997 between photometric measurements and AMLA adjustments. This is related to the close proximity between the two thin lines (continuous and discontinuous) in Figure 3 and is in accordance with the high similarity of the corresponding bars in Figures 1 and 2. Considering this evidence, it can be concluded that AMLA temporal version provides relative luminance measurements that are interchangeable with those provided by a standard photometer. Moreover, it was also observed that a common luxometer can be used to obtain a very accurate estimation of the gamma values used by CRT monitors (or to detect the presence of nonadditivity in the screen response).

Strong similarities were observed between predicted and adjusted luminances for simulated tritanomaly (Experiment 2), real tritanomaly (Experiment 3) and protanopes (Experiment 4), indicating that temporal AMLA is a useful tool to measure transformed luminosity (Y_T). Because last three experiments provided frequent examples of non-equivalence between Y_T

and Y, some figure-background combinations that are accurately perceived by common observers are certain to produce visibility problems in color blind people.

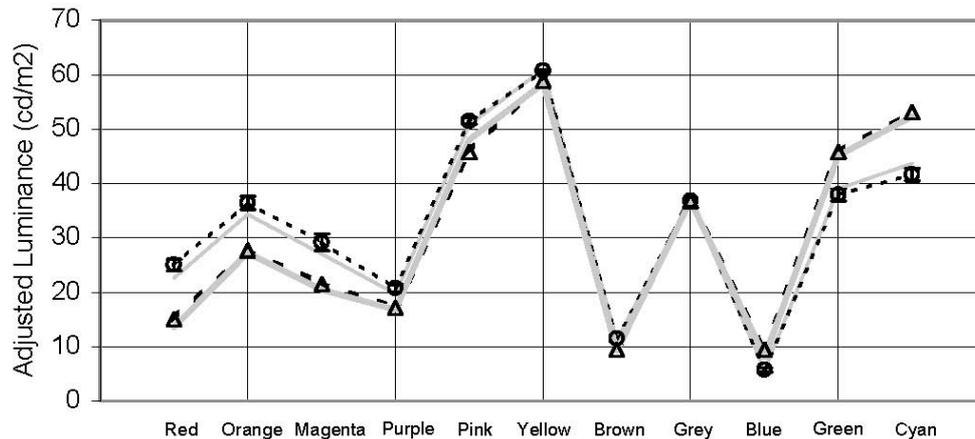


FIGURE 3. Experiment 4 AMLA adjustments performed by protan and control groups. Grey continuous thin line shows the luminance of each stimulus. Circles (dashed black thin line) show the mean adjustments of the control group. Error bars show, for each stimulus, the 95%-confidence interval for the control group. The predictions (dashed black thick line) for the protanope group adjustments were computed according to the model of Smith & Pokorny (1972, 1975), assuming a total loss of L cones functionality. Triangles (grey continuous thick line) show the (mean) adjustments made by protanope observers.

In a recent book (Nielsen, 2000) published by one of the most famous human-computer researchers, it is correctly indicated that, because most Web pages are “very visual”, color blind people and people with visual deficiencies have serious accessibility problems. When commenting their specific nature, Nielsen indicates (op. cit pg. 20) that:

“It is very common to see first plane-background combinations that make the page illegible for color blind users...To improve accessibility, a high contrast between font and background colors must be provided”.

We agree with Nielsen in considering poor figure-background achromatic contrast a serious problem for the increasing number of color blind people that use computers every day. We also recommend avoiding low contrast between figure and background effective luminance but, contrary to what is implicitly assumed by many people, this parameter value is not similar for every human. However, we want to emphasise, the results presented in this paper indicate that AMLA provides a convenient way to measure it.

There are two ways in which AMLA can be applied to avoid poor figure-backgrounds combinations. If the screen considered operates in terms of the “principle of gun independence” (Mollon, 1999), that is, if the luminous output resulting from every primary activation is independent of the other two, then Equation (5) can be applied and, after measuring every primary effective luminance, the one corresponding to any other stimuli can be correctly predicted. However, as Experiment 1 showed, there are screens where the principle of gun independence does not apply. In such situations, AMLA could be used: (1) to measure the degree and, consequently, the importance of the non-independence observed; (2) to measure the effects of changing the “brightness” and “contrast” screen control adjustments to make primary activation more independent; and lastly, (3) to measure directly the relative effective luminance corresponding to any target stimuli.

To conclude, we would like to indicate that, in the near future, our team will use the kind of effective luminance measurements provided by AMLA to study how this variable affects utilisation of basic chromatic categories by color blind people. We have two main reasons for working on this topic. First, in a previous investigation, it was found (Lillo, Vitini, Ponte, & Collado, 1999) that dichromats use chromatic terms (for example, green or brown) to name some achromatic stimuli and, even more important, that their utilisation depends on luminance. Second, use of chromatic basic categories is also modulated by luminance values in common observers (Lee, Luo, MacDonald & Tarrant, 2001; Lillo et al., 2004). Considering the results provided by the present paper, we hope AMLA will continue to provide an accurate way to measure relative effective luminance for any possible specific screen-specific observer combination.

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