Black-level offset: Characterization and correction

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Abstract — The correct setting of the black level is an important step in the (re)calibration of an electronic display. This study looks at the consequences of black-level offset, the possibilities for display characterization with offset, offset correction, and the ability of average untrained users to visually correct the black-level setting with the contrast and brightness controls on the display. In an experiment, 32 subjects were asked to optimally set the black level according to two types of instructions (short and extensive, between subjects) under two levels of illumination (low and office, between subjects) for two types of displays (CRTs and LCDs, within subjects). Most subjects were not able to set the black level near optimal for either display, with any combination of instruction and illumination level. The LCD did not have an optimal black level. For the CRT, optimal black level did not provide minimal differences with the sRGB standard tone reproduction curve.

Keywords — *sRGB standard, black level, user calibration.*

1 Introduction

For the reliable reproduction of colors over the Internet, several color-management standards are proposed or already in use. The critical factor in these standards is the characterization of the user display. For an accurate characterization luminance and chromaticity measurement, instruments are required. Special display characterization kits combining measurement instruments and software for stimulus generation and color management are now available, but for the general computer user the additional cost does not outweigh the gains. PC users can fall back on the simple and less-reliable default RGB color space (sRGB) for color management. The sRGB standard was initiated by the International Color Consortium and adopted by the International Electrotechnical Commission as standard 61966 and is primarily designed for cathode-ray tubes (CRTs). It assumes the computer display adheres to the sRGB definition or at least does not deviate much from this definition. The standard sets reference values for

- phosphor chromaticities (primary-color coordinates),
- white point or correlated color temperature (CCT): $x = 0.3127$, $y = 0.3290$ (D65),
- transfer function, tone reproduction curve (TRC), or gamma: $\gamma = 2.2$,
- display-model offset or black-level offset: 0.0 cd/m^2,
- display luminance level: 80 cd/m^2,
- veiling glare (reflection level): 1%.

Indeed, most computer displays currently on the market have an sRGB setting, which is supposed to set the right voltage levels to produce the correct TRC, white point, and luminance levels. To check or recalibrate the computer-display settings, a user without measurement instruments needs to fall back on the usually minimal support provided by the manual or apply visual calibration methods provided as part of software applications or freely available on the Internet.

In this study, we look at the consequences of black-level offset for color fidelity and the effect it has on the characterization of other display parameters. We also look at the potential of visual calibration methods to correct the black-level offset, the usability issues concerned with the use of these methods, and the capabilities of the average untrained user to visually calibrate his/her computer monitor with these methods. We look especially at the influence of the black-level offset on the tone-reproduction curve (TRC), which defines the relationship between the code value d on the graphics card, with the maximum code value d_{max} (usually 255) and the resulting luminance Y on the display screen. The sRGB standard assumes a reference display characterization of a CRT based on a simple gamma function with $\gamma = 2.2$:

$$Y(d) = Y_{\max}\left(\frac{d}{d_{\max}}\right)^{2.2}. \tag{1}$$

A linear portion is integrated into the encoding specification of the transfer function of the dark end signal to optimize encoding implementations. According to the standard, the equations below closely fit Eq. (1). This should maintain consistency with the legacy of desktop and video images.

$$Y(d) = Y_{\max}\frac{d}{d_{\max}}\Big/12.92, \quad \text{for } \frac{d}{d_{\max}} \leq 0.04045, \tag{2a}$$

$$Y(d) = Y_{\max}\left(\frac{\left(\frac{d}{d_{\max}}+0.055\right)}{1.055}\right)^{2.4}, \quad \text{for } \frac{d}{d_{\max}} > 0.04045. \tag{2b}$$

There are several potential problems with the TRC characterization in this standard:

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- some monitors have no sRGB settings,
- the sRGB monitor settings are not tested for conformation to the standard,
- the user can change the monitor's brightness and contrast settings,
- the monitor's luminous output changes over time,
- the TRC of the standard is based on the gamma model for the CRT and other display technologies have different TRCs that do not conform to this model.
- recent studies have shown that gamma might not be constant over the range of code values, but higher for lower code values.[1,2]

There are two ways in which these problems show up in the TRCs for the primary-color channels of a CRT. The first is a black-level offset; if this offset is positive, it means $Y(0)$ does not equal 0, black looks gray, and the image might look washed out. If the offset is negative, clipping will occur: several code values are mapped to black and the image will look dark. The black-level offset can be corrected by adjusting the contrast and brightness controls on the display.

The second is a difference in gamma parameters between the primary-color channels, which means white and neutral grays do not have the same color. The gamma parameters can be measured by a visual matching task and then be corrected by setting a look-up table (LUT) on the graphics card.

2 Characterization and correction of black-level offset

For color-management purposes, there are two problems related to the black-level offset. If the display has to be used in an illuminated environment where veiling glare cannot be avoided, a black-level offset might be desired to preserve the color differences within the darker parts of the image. In that case, a correct characterization is needed to provide an optimal color fidelity for the circumstances. If the level of veiling glare is low, then the black-level offset should be corrected. A correct characterization of the display can be helpful in determining the brightness and contrast control settings that produce the lowest black-level offset. The direct measurement of the black-level offset requires sensitive measurement equipment and a controlled measurement environment. It is possible to estimate the black level by model fitting from measurements at higher luminance levels, but the estimations become more reliable with accurate measurements at lower luminance levels. Some combinations of models and estimation methods are extremely sensitive to measurement errors at low luminance levels.

Display characterization by fitting gamma to the slope in the log-luminance – log-digital-code domain is especially sensitive to black-level offsets. Roberts[3] demonstrated the influence of luminance and voltage offsets on gamma fitting in the log–log domain and developed a method based on differential slope analysis to characterize these offsets. The combination of differentials and the log–log domain is bound to enlarge possible measurement errors. Berns[4] developed the Gain-Offset-Gamma (GOG) model, of which Eq. (2b) is an example, later refined by Katoh, Deguchi, and Berns[5,6] in the gain-offset–gamma-offset (GOGO) model, which relates the amount of light Y_P generated by the CRT gun of primary P (which could be R, G, or B) to CRT parameters:

$$Y_P(d) = k_P\left\{a_P\left[(v_{\max} - v_{\min})\left(\frac{d}{d_{\max}}\right) + v_{\min}\right] + b_P - v_{C,P}\right\}^{\gamma_P} + Y_{0,P}. \tag{3}$$

The amount of light of a computer-controlled display depends on the digital counts or code values in the DAC (d, d_{max}), the video generator voltages (v_{min}, v_{max}), the video amplifier parameters (a_P, b_P), the CRT gun ($v_{C,P}$, γ_P), and the properties of the faceplate and phosphor materials (k_P). $Y_{0,P}$ is the black-level offset, originating from sources other than the primary channel P.

Note that a_P and b_P are supposed to correspond to the contrast and brightness settings of the monitor, and that γ_P is assumed constant under all conditions. By normalization, the number of model parameters can be reduced to three: gamma (γ_P), the normalized gain/offset parameter $k_{g,P}/k_{0,P}$ and the black-level offset $Y_{0,P}$:

$$\begin{aligned} &Y_P(d) = (Y_{\max,P} - Y_{0,P})\times \\ &\left(k_{g,P}\frac{d}{d_{\max}} + k_{0,P}\right)^{\gamma_P} + Y_{0,P}, \quad \left(k_{g,P}\frac{d}{d_{\max}} + k_{0,P}\right) \geq 0, \\ &Y_P(d) = Y_{0,P}, \qquad\qquad\qquad\qquad\quad \left(k_{g,P}\frac{d}{d_{\max}} + k_{0,P}\right) < 0, \end{aligned} \tag{4}$$

with

$$k_{g,P} = \frac{a_P(v_{\max} - v_{\min})}{a_P v_{\max} + b_P - v_{C,P}}, \tag{5}$$

$$k_{0,P} = \frac{a_P v_{\min} + b_P - v_{C,P}}{a_P v_{\max} + b_P - v_{C,P}} \quad \text{and} \quad k_{g,P} = 1 - k_{0,P}. \tag{6}$$

Notice that the gain is also dependent on the monitor offset (brightness) setting, and the offset is also dependent on the monitor gain (contrast) setting, which could explain possible problems users have to correctly set their display configuration.

According to Poynton,[7] the names used for these controls for a CRT are misleading with respect to their functions: "The control called brightness mainly affects reproduced contrast, and the control called contrast ideally affects only brightness!." He argues that "brightness" should be named "black level." This corresponds with Eq. (6), which shows that b_P can be used to level out the cut-off voltage, $v_{C,P}$, in the CRT gun to produce the desired offset, assuming v_{min} is nearly 0 and therefore $a_P v_{min}$ is small compared to $v_{C,P}$. If the total offset is 0, then black will be truly black, contrast will be maximal, and changing a_P will only affect the brightness of the picture.

In practice, CRTs will not adhere to the ideal model and some black-level offset will always be present. On most computer monitors, there are no controls available to individually adjust the gain and offset of the primaries R, G, and B, only brightness and contrast controls are available to adjust all primaries at once. In practice, the parameters of the electronic circuits for the three primaries will differ, resulting in at least offset in one primary for any brightness/contrast setting. Any positive offset $k_{0,P}$ for one primary will manifest itself as (part of) a luminance offset $Y_{0,P}$ in another primary.

In their search for a more robust model fitting method, Deguchi and Katoh[8] looked at the effect on color for 12 different combinations of contrast and brightness control settings for a CRT. Their main purpose was to find the gamma model with the best fitting performance for the different settings. They found the gamma-offset–gain-offset (GOGO) model performed best with the largest variation in the offset and gain parameters and the least variation for the gamma parameter. This latter conclusion was based on the constant gamma assumption for CRTs. Recent research suggests that this assumption at least does not hold for all CRTs. Through extensive measurements of the electrical characteristics of a CRT gun, Olson[1] showed that gamma is not constant over the working range of voltages. In an earlier study,[2] we showed that a GOGO-like model optimized in the CIE lightness domain with an increasing gamma for lower digital counts better fitted the TRCs and black-level offsets for three CRTs.

3 Minimizing the black level

Park *et al.*[9,10] devised two methods based on polynomial fittings of part of the TRC for different settings of contrast and brightness to calculate the brightness setting with minimal black-level offset. One method is based on the GOG model, the other approach is very similar to that of Roberts[3] discussed above. The second-order-polynomial fitting parameters can be expected to be rather sensitive to measurement errors and deviations from the model, but the use of more measurement series might make this method more robust.

Based on a multiple measurements series, the optimum brightness can also be estimated with non-linear fitting methods based on Eqs. (4)–(6). With the estimates of $k_{g,P}/k_{0,P}$ for several brighness and contrast settings and assuming linear relationships b_P = brightness setting/100 and a_P = contrast setting/50, estimates can be made for v_{min}, v_{max}, and $v_{C,P}$. And the optimum brightness setting for a given contrast setting can be found for $a_P\, v_{min} + b_P - v_{C,P} = 0$.

Models are rarely perfect, and with the circuitry and firmware in displays getting more and more complex, it is unlikely that one model can be used to describe the behavior of all available CRTs. In providing a choice between preset correlated color temperatures (CCT) in CRTs, *e.g.*, 9300°K, 6500°K, and 5000°K, designers have to make concessions regarding optimal settings. The CCT can only be changed by changing the ratio of the brightness and contrast parameters of the individual primaries: this is bound to lead to black-level offset for some primary.

For LCDs, there is always some black-level offset: the liquid crystal is unable to achieve zero transmittance. The brightness control of an LCD typically alters the backlight luminance and therefore the black-level offset as well. The natural TRC of liquid crystal does not have the shape of the gamma function but more of an S-shape, with saturation effects for high code values. Conversion to a gamma-shaped TRC can be reached by a LUT or conversion circuit in the display. If an LCD has a contrast control, it probably changes the gain at the output of this LUT. Setting the contrast to maximum for an LCD might therefore lead to saturation problems. For the LCD used in the experiment, setting the contrast to maximum for CCT 6500°K clearly saturated the red primary at about code value 223.

4 Effect of black-level offset on color

A positive black-level offset adds an amount of light in a usually neutral color to the intended color, shifting the color coordinate towards the neutral point. This shift will be larger for dark colors. Based on this fact, Berns *et al.*[11] devised a method to estimate the black-level offset by minimizing the variation in the estimated primary-color coordinates from color measurements of the primaries at series of digital counts. They reached good results with measurement series 16, 32, ... 255. The advantage of this method is that it can be used for any display technology.

In practice, users can expect considerable color differences from the sRGB standard. Bodrogi *et al.*[12] looked at the differences between measured tone reproduction curves and the sRGB TRC for the primary-color channels for 11 different CRT monitors with nine different settings, including three brightness/contrast control settings. They found considerable color differences in CIELAB space, mean $\Delta E_{ab}^* > 20$ for a large set of colors, which seem to be mainly stemming from black-level offsets and differences between the TRCs of the primary-color channels.

To compare displays to the sRGB standard, the ideal gamma function [Eq. (1)] is more helpful than the optimized encoding implementation with the linear portion [Eq. (2)]. The difference in luminance between these two functions is indeed small, but the difference on a perceptual scale with a reference white luminance, the CIE lightness domain from the CIELAB, and CIELUV color spaces is noticeable with color differences $\Delta E_{ab}^* > 1.0$ for many code values, as shown in Fig. 1 for the primary sRGB colors. This lightness difference can also lead to chromaticity differences; for about the worst case, sRGB-designed magenta color RGB = (176, 32, 176) on a display with a TRC according to Eq. (1), this will mean a significant loss of saturation. A CRT without a built-in LUT will have a continuous

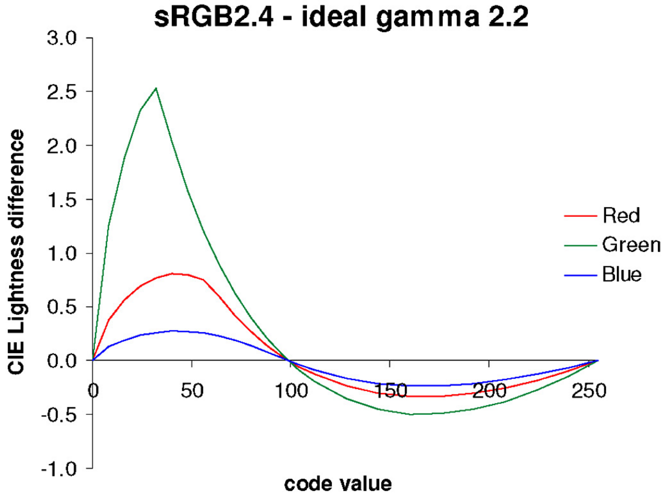

FIGURE 1 — CIE lightness differences between sRGB TRC and an ideal gamma = 2.2 function.

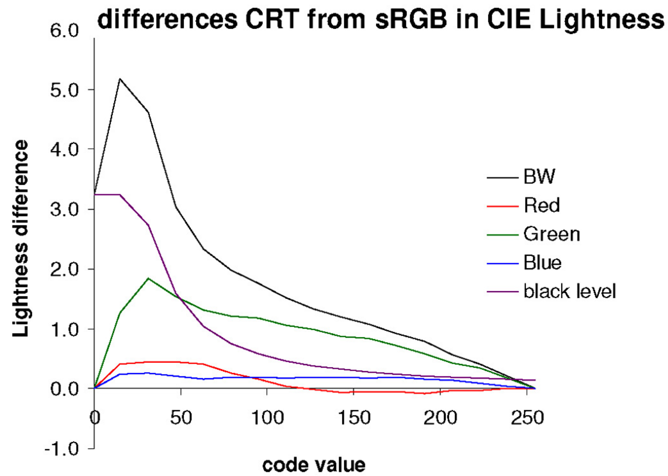

FIGURE 2 — Differences in CIE lightness from sRGB for the CRT in the experiment. BW gives the overall difference for neutral stimuli. Red, green, and blue give the differences for the separate primaries corrected for black level, which shows the difference if only the black-level offset were present.

gamma function such as Eq. (1) over the entire scale, and in a comparison with Eq. (2) the discontinuities would at the least distract.

5 Visual offset-correction experiment

Calibrating the display by adjusting the brightness and contrast settings to set only code value 0 to be precisely black while keeping a bright enough image is an essential step in maintaining compliance to the sRGB standard. In an experiment, 32 participants were asked to optimally adjust the brightness and contrast settings of a CRT and LCD (within subjects) according to types of stimuli with instructions, short and elaborate (between subjects), under two levels of illumination, low and office (between subjects). The design (see Table 1) was balanced over the participants to eliminate sequence effects.

After finishing the brightness and contrast adjustment, the values from the on-screen display were put on record. Then the participants performed a control visual detection task on the display to determine the threshold code value that provided a recognizable stimulus. This test was added to check if the subject's visual capabilities could be the cause of non-optimal settings. The experiment was performed in combination with a visual gamma matching experiment not reported here.

TABLE 1 — Experimental design.

Instruction	Simple		Elaborate	
Illumination	Low	Office	Low	Office
Display	CRT and LCD	CRT and LCD	CRT and LCD	CRT and LCD
Number of subjects	8	8	8	8

6 Participants

The participants were psychology students from the University of Twente, participating as part of their first year curriculum. Thirty-two Students participated, six students were Dutch and 26 were German with a sufficient knowledge of the Dutch language, 24 students were female and 8 were male, ages ranged from 17 to 26. All subjects had corrected or uncorrected 20/20 or better visual acuity for stereoscopic vision measured by the TopCon Screenoscope-II, Tokyo Optical Co., Ltd. All subjects were tested for color-vision deficiencies with the Ishihara test for color blindness; one male subject had a weak red–green color deficiency. This was judged to have no consequences for the monochromatic brightness matching task in this experiment.

7 Apparatus

A CRT and an LCD connected to two separate Windows-operated personal computers were used in the experiment. The CRT was a 2-year-old Philips 17-in. model 107T5 controlled by an Intel Extreme Graphics 2 graphics card at a 800 × 600 resolution at a frame rate of 100 Hz. The LCD was a Philips 17-in. model 170B4MG02, also 2 years old, controlled by an NVIDIA GeForce2 MX 100/200 graphics card at the native 1280 × 1024 resolution at 60 Hz. Both displays were connected to the graphics card with a D-SUB cable. Care was taken that no color-management was used.

Brightness and contrast settings could be adjusted by an on-screen dialog displaying a blue bar on a white background with a percentage between 0 and 100 just above the middle of the screen, and minus and plus push buttons on the bottom of the screen. The effect of contrast and brightness settings on the light output of the displays for rectangular stimulus patches of 1/25 of the active area on a black background of white, RGB = (255, 255, 255), and black, RGB =

TABLE 2 — (a) LCD black level in cd/m^2, (b) LCD white level in cd/m^2, (c) CRT black level in cd/m^2, (d) CRT white level in cd/m^2, (e) Luminance for sRGB settings in cd/m^2.

(a)

%contrast \ %brightness	0	50	100
0	0.18	0.35	0.50
50	0.21	0.37	0.53
100	0.20	0.38	0.51

(b)

%contrast \ %brightness	0	50	100
0	42.6	85.4	118.5
50	55.8	108.8	146.0
100	65.4	120.8	164.0

(c)

%contrast \ %brightness	0	50	100
0	0.01	0.33	6.13
50	0.02	0.23	5.47
100	0.04	0.16	4.47

(d)

%contrast \ %brightness	0	50	100
0	0.01	0.91	8.84
50	11.00	30.50	59.50
100	65.60	99.50	109.90

(e)

	CRT	LCD
black	0.333	0.459
white	92.77	154.44

(0, 0, 0), measured with a L203 photometer with a 6° field-of-view luminance probe from Macam photometrics, Ltd., is shown in Table 2(a–e). Ambient illumination was excluded by a dark gray foam cover and care was taken that no pressure was exerted on the LCD screen.

The displays were measured with the default sRGB settings. The differences in CIE lightness with the sRGB TRC, assuming equal white luminance, are shown in Fig. 2 for the CRT and in Fig. 3 for the LCD. The figures show that the effect of black-level offset is relatively large for the CRT compared to the deviations from the ideal gamma curve; for the LCD, the deviations from the gamma curve have a larger effect on luminance and color than the black level offset.

8 Lighting conditions

Half the subjects performed the experiment in office lighting conditions provided by the standard experiment room fluorescent tube lighting. The other half worked under low illumination conditions provided by a small incandescent lamp reflected from the back wall. Under office conditions, the illuminance on the desktop measured with a Macam

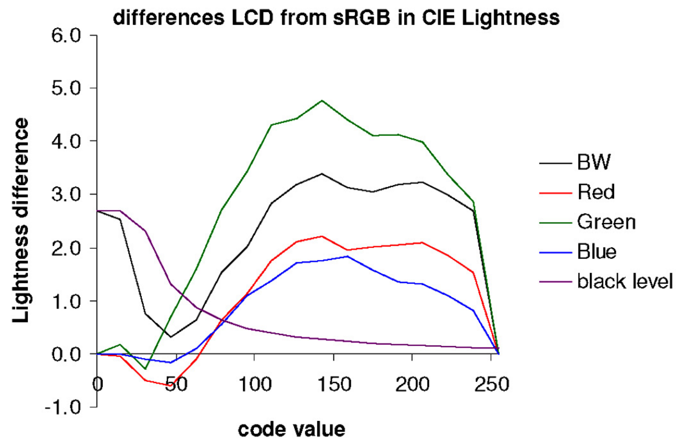

FIGURE 3 — Differences in CIE lightness from sRGB for the LCD in the experiment. BW gives the overall difference for neutral stimuli. Red, green, and blue give the differences for the separate primaries corrected for black level, which shows the difference if only black-level offset were present.

L203 photometer with a illuminance probe was 530 lux; on the CRT, 266 lux; and on the LCD, 296 lux.

For low light conditions, the illuminance on the desktop was 38.1 lux, on the CRT, 12.6 lux; and on the LCD, 13.1 lux.

9 Stimuli and instructions

Several applications are available to help the user in calibrating the display. These applications provide visual stimuli and instructions on the sequence of operations and optimal state of the visual stimuli. In this experiment, two types of black-level setting tools were compared. The simple tool chosen for the experiment was the Adobe™ Gamma Wizard, part of Photoshop™ CS from Adobe Systems, Inc., consisting of one dialog box with a visual stimulus and a two-step instruction, as shown in Fig. 4. The visual stimulus

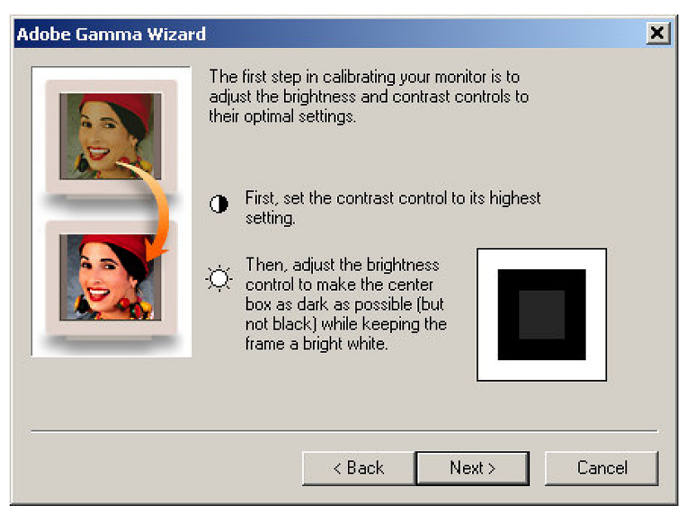

FIGURE 4 — Adobe Gamma Wizard instruction dialog box for optimal brightness and contrast settings.

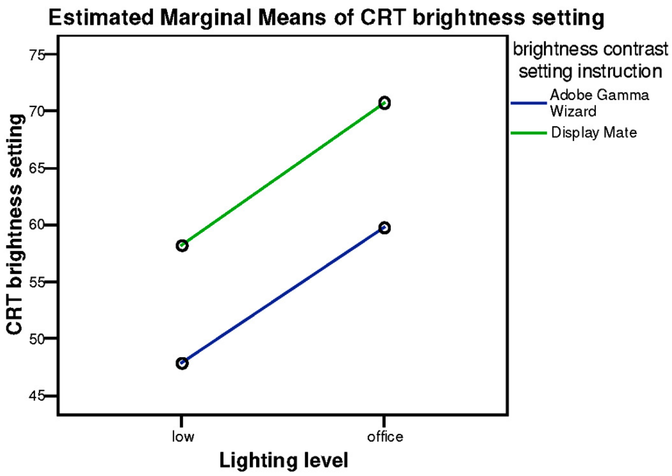

FIGURE 5 — Effects of lighting level and type of instruction on the user CRT brightness setting.

consists of a neutral gray square of value 38 [RGB = (38, 38, 38)] in a black square of value 0 in a white square of value 255.

The more elaborate tool was part of the calibration program DisplayMate for Windows video edition 1.21 from Sonera Technologies™, consisting of three pages of screen-wide visual stimuli with instructions provided on paper. The first page consists of lines of texts at different contrasts in gray and white (values 128, 192, and 255) to the black background (0) and is meant to be a coarse setting for brightness and contrast. These settings are refined with the second page showing two groups of overlaid rectangles, one with dark gray tones (values 0, 24, and 48) and one with bright gray tones (values 208, 232, and 255). The third screen consists of 32 rectangles of dark gray tones (values 1–64) on a black background and is meant for fine-tuning only the brightness setting.

The participants were hand-written general instructions about the design and purpose of the experiment and a manual for handling the on-screen dialog and display push-buttons. Depending on the type of instruction used in the experiment, the participants were provided with written instructions in Dutch, comprising the relevant instructions from the DisplayMate manual pages or a written translation in Dutch of the Adobe dialog box. Participants were asked to read all instructions carefully before starting the adjustments. The adjustments were started with the displays in the default sRGB settings.

The experiment leader was present during the experiment to clear possible questions, demonstrate the working of the display controls, and register the resulting brightness and contrast settings.

The visual threshold recognition task was based on the stimuli in the Screenoscope visual acuity task. The character “E” was displayed in one of four possible orientations, the participants had to respond by pressing the arrow key on the keyboard with the arrow pointing towards the open side of the “E”. The first “E” was displayed at code value 76, for every correct answer the code value was decreased and for every false answer the code value was increased until the threshold was found. This process was repeated starting at code value 0. If the resulting threshold code value was no more than one apart, the lowest value was taken as threshold, otherwise the result for the subject was discarded.

The results can be compared in different domains. First, there are the brightness and contrast settings, scales from 0 to 100, which the user actually controls, but stand in a complex relation to the ultimate result: the black level. The perceptual scale for the black level is its CIE lightness with display white as the most obvious choice for the reference white luminance. With this specific task focusing on the black and dark grays and given the absence of white in the last DisplayMate instruction screen, it is necessary to evaluate the luminance of the black level as well.

The experiment was setup to test the following hypotheses for the three independent variables:

1. Display: black-level setting will be nearer to the general optimum for the CRT than for the LCD. The minimum luminance and CIE lightness for display black that a CRT can produce is much lower than that of an LCD.

2. Type of instruction: Black-level settings will be more accurate for the elaborate type of instruction. For the short type of instruction, the comparison between black and nearly black is between code values 0 and 38. For the elaborate type of instruction, comparison is made between code values 0 and 1.

3. Illumination: black levels will be higher for office-lighting conditions than for low-lighting conditions. Due to veiling glare, the minimum luminance of the display will increase. It is more difficult to perceive small brightness differences if the average brightness is higher.

10 Results

To be able to test the hypotheses, an optimal black-level setting must be defined for CRTs and LCDs. With the results from expert visual inspection before the experiment and the luminance measurement conducted after the experiment, the optimal black-level setting for the CRT was determined for a contrast at 100% and a brightness at 31%. It should be noted that the optimal black-level setting does not guarantee an optimal TRC, which is close to the sRGB standard. For the CRT in the experiment, the optimal black-level setting turned out to increase the differences with the TRC of the sRGB standard. A brightness setting of about 40% with a small black-level offset produces an improved fit to the standard.

For the LCD, it was not possible to define an optimal setting. The lowest possible value for the black level of the LCD appeared to be 0.18 cd/m^2 for brightness and contrast settings of 0%. If we look at the brightness of black in relation to the brightness of white with the CIE lightness value, we see that for 100% contrast the lightness varies negligibly from 2.762 over 2.842 to 2.809. It is no wonder that a number of subjects expressed difficulties in setting the black level: changing brightness and contrast settings seemed to make little difference. Comparison of the tables shows that the black level is determined by the brightness setting and the contrast settings determines the contrast ratio between black and white; for 0% contrast, the contrast ratio is about 237 and for 100% about 321. These changes may seem considerably large, but are negligible on a perceptual scale like the CIE lightness for black or, for instance, Michelson's contrast (0.9916 and 0.9938, respectively, on a scale from 0 to 1). The changes are also small compared to the changes between settings for the CRT. Here, the contrast ratio pattern is more complex with a minimum contrast ratio of 1 (no contrast) for contrast and brightness settings of 0% and a maximum contrast ratio of 1640 for a brightness setting of 0% and a contrast setting of 100%; Michelson's contrasts of 0 and 0.9988, respectively. The CIE lightness of black varies substantially more than that for the LCD; for 100% contrast setting, it varies from 0.551 at 0% brightness setting to over 1.453 at 50% to 23.89 at 100%; indicating that black for 50% brightness setting and higher has a clearly visible luminance.

10.1 Differences between displays

Due to the small contrast range of the LCD, it seems there is little use in testing the display hypothesis with the experiment because the LCD had no optimal black-level setting. The results of the experiment show as might be expected that the variance in the brightness settings for the LCD was high, with ranges near 80 on a scale of 100 for the LCD within groups with equal conditions. But for the CRT, the range of brightness settings was large as well, about 50. For the LCD, the variance in contrast settings was high for the elaborate instruction, CRT contrast settings showed a smaller range.

10.2 Differences between type of instruction

Effects of the type of instruction and lightning level were tested with an analysis of variance (ANOVA) test including both between-subject factors and their interaction. Contrast settings for the CRT differed significantly for the type of instruction $F(1, 28) = 16.481$, $p < 0.001$. Partial eta squared = 0.371, representing a large effect: the short type of instruction leading to higher contrast settings (see Fig. 5). It should be noted that the variances of the settings for the type of instruction were significantly different for Levene's test [$F(3, 28) = 4.185$, $p = 0.014$].

Contrast settings for the LCD differed significantly for the type of instruction $F(1, 28) = 18.630$, $p < 0.001$. Partial eta squared = 0.400, representing a large effect. It should be noted that the hypothesis that the distribution differs from a normal distribution cannot be rejected. These results are not surprising as Adobe Gamma first instructs the user to set the contrast control to the highest setting.

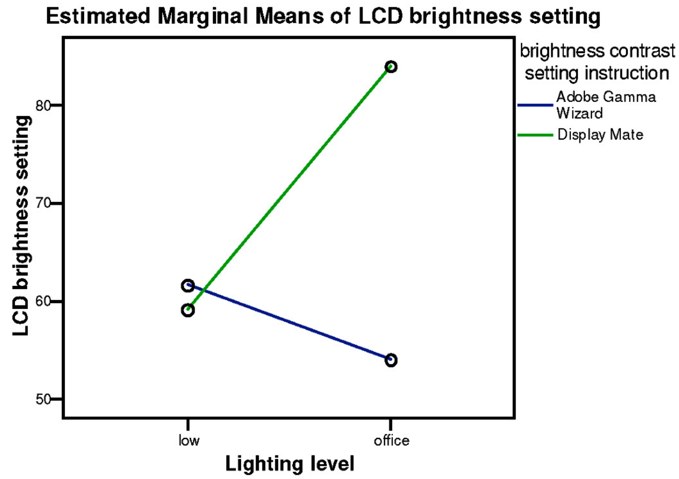

FIGURE 6 — Effects of lighting level and type of instruction on the user LCD brightness setting.

Subjects clearly failed to complete this instruction in two cases for the CRT (82 and <u>92</u>%) and in four cases for the LCD (<u>67</u>, 53, 64, and 92%) (underlined scores for same subject).

There were no large effects on the brightness settings, but there was a trend for the CRT for the type of instruction; $F(1, 28) = 2.680$, $p = 0.113$, partial eta squared = 0.087 representing a middling effect: Adobe Gamma results in lower brightness settings. These results oppose the hypothesis for this type of instruction. There were no significant effects on the luminance and the CIE lightness of CRT black for this type of instruction.

10.3 Differences between lighting conditions

There were no effects on the contrast settings and no large effects on the brightness settings, but there was a trend for the CRT for lighting level $F(1, 28) = 3.486$, $p = 0.072$, partial eta squared = 0.111, representing a large effect: low lighting results in lower brightness settings. There was an interac-

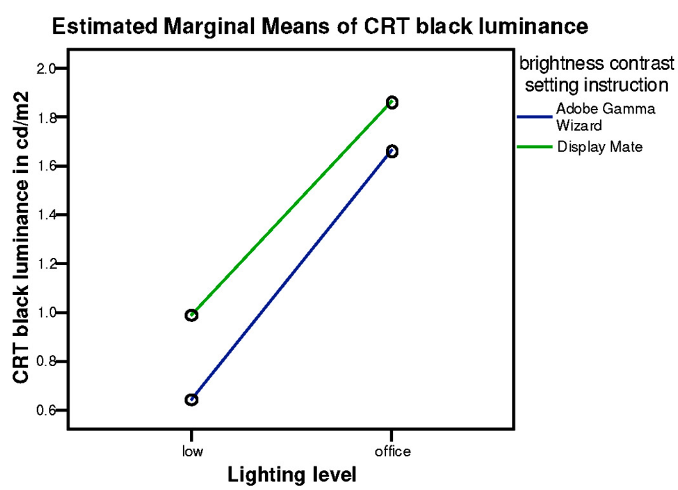

FIGURE 7 — Effect of lighting level and type of instruction on luminance of CRT black level.

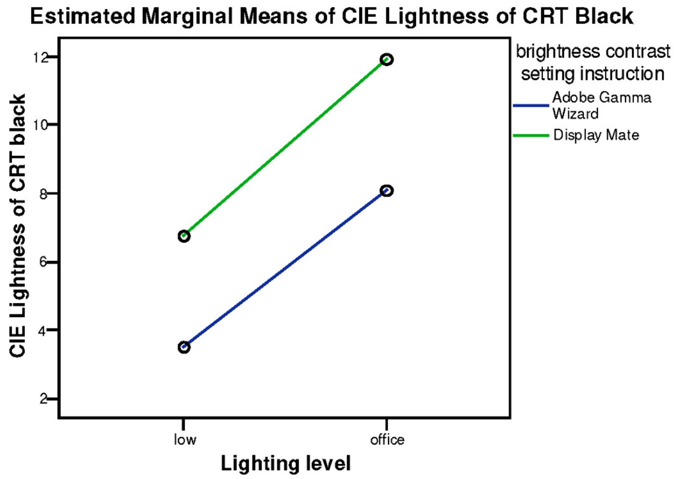

FIGURE 8 — Effect of lighting level and type of instruction on CIE lightness of CRT black level.

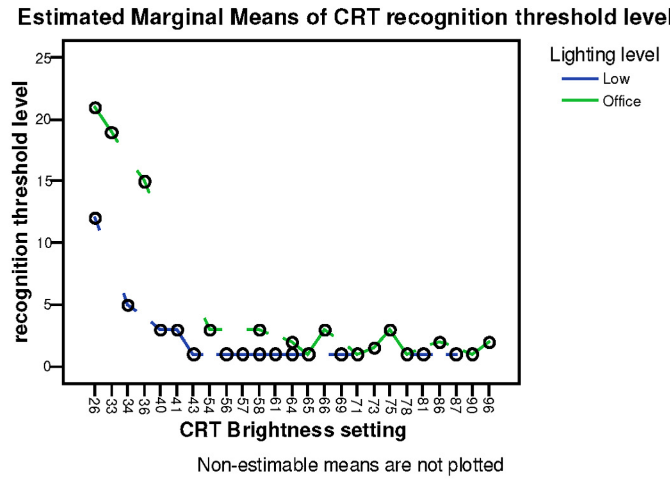

FIGURE 9 — User CRT brightness settings with related recognition threshold levels.

tion trend for the LCD [$F(1, 28) = 2.480$, $p = 0.127$, partial eta squared = 0.081, representing a middling effect (DisplayMate) resulting in higher settings for office lighting (see Fig. 6). For CRT black luminance and CIE lightness, the results were somewhat clearer [$F(1, 28) = 3.766$, $p = 0.062$, partial eta squared = 0.119 and $F(1, 28) = 4.301$, $p = 0.047$, partial eta squared = 0.133]. These results (see Figs. 7 and 8) are in agreement with the hypothesis on illumination.

10.4 The recognition test

The results shown in Fig. 9 show that only four from the 16 subjects working with the Adobe Gamma instruction on the CRT have threshold detection values that lie somewhere near the nearly black value of 38 in the picture from the Adobe Gamma dialog, all other values were ≤5. The CRT brightness settings [$F(24, 3) = 196.358$, $p = 0.001$, lighting level $F(1, 3) = 144.000$, $p = 0.001$ and the interaction $F(2, 3) = 57.000$, $p = 0.004$] had a significant effect on the threshold values of the recognition test for the CRT. For values below 40% of the brightness setting scale, threshold values increased with decreasing brightness. The threshold level for office-lighting conditions is higher and steeper.

10.5 General performance

In general the average user performed worse than the default sRGB settings with higher mean values for CRT black luminance: $F(1, 28) = 15.439$, $p = 0.001$, partial eta squared = 0.355 and CRT black CIE Lightness: $F(1, 28) = 13.568$, $p = 0.001$, partial eta squared = 0.326, with only 10 subjects out of 32 producing lower black level settings. For low illumination levels the performance did not differ significantly from de default settings, with 7 subjects out of 16 producing lower black level settings.

11 Conclusions

From the results of this experiment, it can be concluded that most of the average untrained users are not able to find the optimal black-level setting with the provided instructions by adjusting the contrast and brightness controls. This is not surprising for the LCD used in the experiment because it did not have a clear optimal setting. The contrast control on the LCD had no real purpose: the range of adjustment of perceived contrast was small and the red primary could be driven in saturation for high settings. For the CRT though both controls clearly have a function and an optimal setting would have significantly improved the color-management properties of the display. Black-level settings were clearly closer to optimal with low ambient illumination: black-level adjustments should be made under low ambient illumination. There are several improvements that can be made to the black-level optimizing procedure. More or more-detailed brightness and contrast controls setting instructions do not seem to work for the average user. During the experiment it could be observed that settings made with the first page of stimuli and instructions of the elaborate type of instruction were completely undone in the next page. The common user is served better by simple instructions presented one at a time. The Adobe Gamma instruction dialog seems very simple, but still has three instructions for the user. The dialog could best be split in two steps: First, set the contrast control to its highest setting. Then click OK, and in the next dialog adjust the brightness setting with the test stimulus. It is possible that the performance could be improved if the gray in the test stimulus had a lower value. This might even make the additional requirement "while keeping the frame a bright white," redundant.

The black-level matching instruction to make a gray patch nearly but not quite black is not working for the average untrained user. Often there is no reference black available for the display screen and the user is asked to evaluate brightness differences, which is more difficult than matching brightness. The procedure used by the European Broadcasting Union (EBU) for black-level setting of television sets[13] seems to have a better matching procedure. The picture line-up generating equipment (PLUGE) signal has fields with a +2% and –2% voltage value, and the black level can then be positioned directly in between. Roberts[3] assumes the margin might not be not accurate enough though.

The on-screen settings dialogs should be adapted: the white background is very disturbing when setting the black level, the position in the middle of the screen takes the view from the relevant stimuli, and for the CRT in the test the allowed period of inactivity of just 3 sec before the dialog disappears leads to many errors.

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