Just noticeable differences in perceived image contrast with changes in displayed image size

Triantaphillidou S, Park JY and Jacobson RE

This is the final author formatted copy of a paper published in *SPIE Proceedings 9016, Image Quality and System Performance XI*, San Francisco, USA.

It is available from the publisher at:

http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=...

Just noticeable differences in perceived image contrast with changes in displayed image size

Jae Young Park*, Sophie Triantaphillidou and Ralph E. Jacobson
University of Westminster, Watford Road, Harrow, HA1 3TP, UK

ABSTRACT

An evaluation of the change in perceived image contrast with changes in displayed image size was carried out. This was achieved using data from four psychophysical investigations, which employed techniques to match the perceived contrast of displayed images of five different sizes. A total of twenty-four S-shape polynomial functions were created and applied to every original test image to produce images with different contrast levels. The objective contrast related to each function was evaluated from the gradient of the mid-section of the curve (gamma). The manipulation technique took into account published gamma differences that produced a just-noticeable-difference (JND) in perceived contrast. The filters were designed to achieve approximately half a JND, whilst keeping the mean image luminance unaltered. The processed images were then used as test series in a contrast matching experiment. Sixty-four natural scenes, with varying scene content acquired under various illumination conditions, were selected from a larger set captured for the purpose. Results showed that the degree of change in contrast between images of different sizes varied with scene content but was not as important as equivalent perceived changes in sharpness [1].

Keywords: Image quality, image appearance, perceived image contrast, image size, contrast matching, liquid crystal displays, LCDs, just-noticeable-differences, JNDs

1. INTRODUCTION

Changes in image size, or the viewing distance have been reported to lead to changes in various aspects of image appearance [2-7].A study concerning the identification of image attributes that are most affected by changes in the displayed image size was previously carried out by the authors [7]. It considered various image attributes, including both spatial and color aspects and identified *sharpness* and *contrast* to be the two most affected attributes by changes in the displayed image size. Similar results were found in a recent study conducted by Wang *et al* [8].

In a recent study [1], a series of psychophysical experiments were carried out to quantify changes in perceived sharpness with respect to changes in displayed image size. Results from the sharpness matching experiment showed that perceived sharpness increased when image size was decreased, but the magnitude of the perceived differences was scene dependent.

Here, first we investigated the effect of bi-cubic interpolation on image contrast by measuring root-mean-square (RMS) luminance contrast [9-12]. No significant effect of bi-cubic interpolation on image contrast was evident. So we specifically focused our study on the quantification of changes in perceived global contrast with respect to changes in displayed image size. This was achieved by collecting data from psychophysical investigations that used techniques to match the perceived contrast of displayed images of five different sizes. The preparation of the test stimuli is presented in Section 2. Section 3 describes the psychophysical experiment and test conditions. Results are included and discussed in Section 4 and conclusions are drawn in Section 5.

2. TEST STIMULI PREPARATION

* J.Park2@westminster.ac.uk; +44-(0)203-5068308

2.1 Image capture

A large number of test images were acquired, using a Canon EOS 30D digital SLR camera, equipped with a CMOS sensor of 3504(*h*) x 2336(*v*) pixel resolution and an EF-S10-22mm zoom lens that provide a 35mm equivalent focal length of 16-35mm. A fixed focal length of 22mm was used for capturing images at different ISO settings and lens apertures. A total of sixty-four captured scenes were selected, after visual inspection of image quality and scene content. The selected scenes included architectural and natural scenes, portraits, artworks, and still and moving objects. They were recorded under various illumination conditions, had different original scene contrast and recorded noise levels, various amounts of fine detail, and strong lines and edges.

2.2 Creation of a series of filters for contrast manipulation with n-JND intervals

The contrast of reproduced scenes depends on the tone reproduction of the imaging systems employed. In display systems, tone reproduction is defined as the functional relationship between the input pixel values and the output luminance, and contrast can be expressed by gamma, γ. Bilissi *et al* [13] have conducted various psychophysical experiments to evaluate acceptable and just perceptible gamma differences using cathode ray tube (CRT) displays under both controlled and uncontrolled environments, for a small image size, occupying 75 x 112mm of the faceplate area (corresponding to approximately 15 visual degrees when viewed from the viewing distance suggested in their paper). The just perceptible differences in gamma were 0.12 and 0.10 under controlled and uncontrolled environments, respectively.

The purpose of creating the filters was to produce test images with different contrast levels and thus enable us to quantify the changes in perceived image contrast with respect to changes in displayed image size. In this task, it was essential to take into account the perceptual gamma differences, whilst keeping the mean image luminance unaltered. Image manipulation using sigmoid functions to adjust image contrast has been used successfully in investigations in other laboratories [14, 15] and was adopted for this work. This technique is based on the phenomenon of simultaneous lightness contrast. Thus, it is possible to make the highlight area in an image appear lighter by making the shadow area darker, which results in an increase in perceived image contrast.

A set of S-shaped filters, employed to increase image contrast and their corresponding inverse functions to decrease image contrast were created using the following steps. The step intervals were calculated by adjusting the gamma of the input to output transfer curve.

1. Pixel values (PV) ranging between 0 and 128 (half way the pixel values range) were selected and normalised (divided by 128).
2. Corresponding output PVs were calculated using a power function with exponent (gamma, γ), ranging between $\gamma = 1.6$ and $\gamma = 1/1.6$ with intervals of 0.05 gammas (approximately half a perceptible gamma difference).
3. Normalised original and corresponding PVs were reverted to their original range (0 to 128).
4. Corresponding output PVs were then mirrored at PV of 128 for the calculation of PVs between 128 and 255.
5. 6^{th} order polynomials were fitted successfully to the calculated output pixel values using a curve fitting tool [16].
6. Actual gammas of each filter function were derived for the mid-tones (linear) section of the functions.

Filter functions for the gamma adjustment are illustrated in Figure 1.

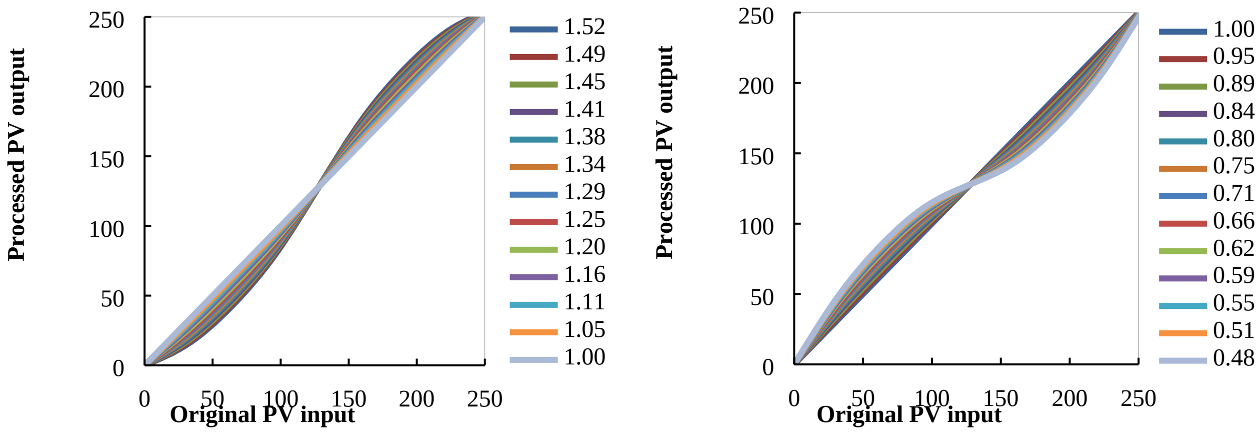

Figure 1. A series of gamma increasing filters (left) and gamma decreasing filters (right).

2.3 Contrast manipulation and bi-cubic interpolation

The filter operation was carried out using MATLAB. The filter functions were applied directly to the sixty-four original version images on the R, G, and B channels. A total of 25 ruler images, each possessing different contrast level with equal gamma difference (original, 12 contrast decreased versions, and 12 contrast increased versions), were generated in spatial domain. Sample image and its filtered versions were present with image histograms in Figure 2. The filtered images were then resized, using bi-cubic interpolation, to obtain five versions of the same scenes of different sizes. The test image dimensions were 744(*h*) x 560(*v*) pixels, 635(*h*) x 478(*v*), 526(*h*) x 396(*v*), 449(*h*) x 338(*v*), and 372(*h*) x 280(*v*) and represented large, large-medium, medium, medium-small and small sizes commonly displayed on computer and mobile device monitors. The small size was based on prevalent dimensions of the LCD on DSLR capturing devices. The large size was approximately half of the EIZO ColorEdge CG245W24.1''LCD's native horizontal and vertical resolution, which was later used for image appearance matching.

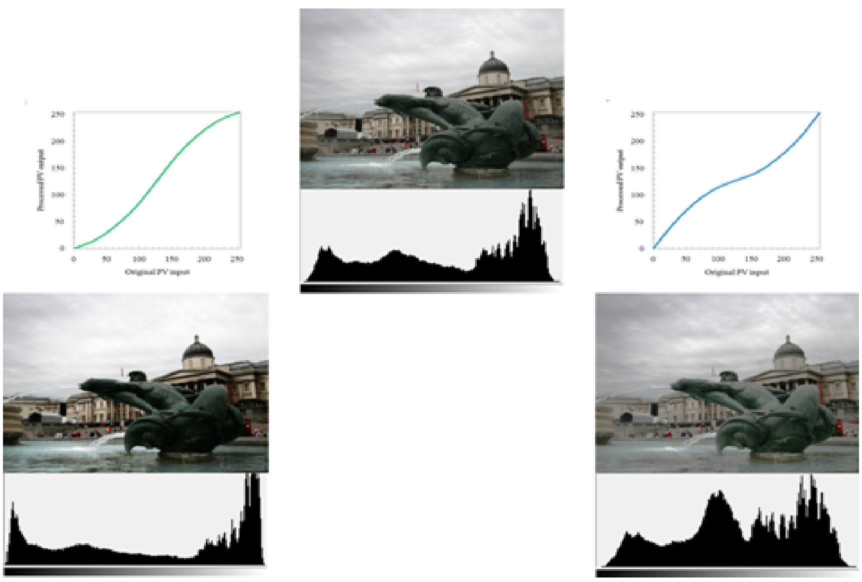

Figure 2. Sample S-shaped filters and the contrast manipulated images. Original image (top), contrast increased version at γ= 1.52 (bottom left) and contrast decreased version at γ= 0.48 (bottom right).

2.4 Objective contrast measurement of the ruler images

In order to confirm the changes in contrast of ruler images (i.e. test images with defined JNDs) objectively, the root mean square (RMS) contrast, which is one of the most commonly employed metrics for this purpose, was measured[17]. RMS contrast has been shown to correlate successfully with human contrast detection not only for the laboratory stimuli but also for natural images [11, 18]. RMS contrast, C_{RMS}, of a two dimensional image is defined in Equation 1, adapted from Peli [17].

$$C_{RMS} = \sqrt{\left[\frac{1}{R * C}\sum_{x=1}^{C-1}\sum_{y=1}^{R-1}\left(I_{xy} - \bar{I}\right)^2\right]} \tag{1}$$

where *R* and *C* are the number of rows and columns in the image, I_{xy} is the normalised luminance of $x^{th}y^{th}$ pixel, $\bar{I}$ is the mean normalised luminance of the image.

C_{RMS} of all sixty-four test images and that of their ruler versions were measured in display luminance space. Each original scene possessed a different C_{RMS} value and the degrees of change in C_{RMS} differed on ruler versions of each scene. However, changes in C_{RMS} on filtered images showed a linear trend. C_{RMS} values of four selected images of the large version are plotted in Figure 3 for illustration purposes. The selected scenes include those possessing the highest C_{RMS} and the lowest C_{RMS} and two scenes possessing average C_{RMS}.

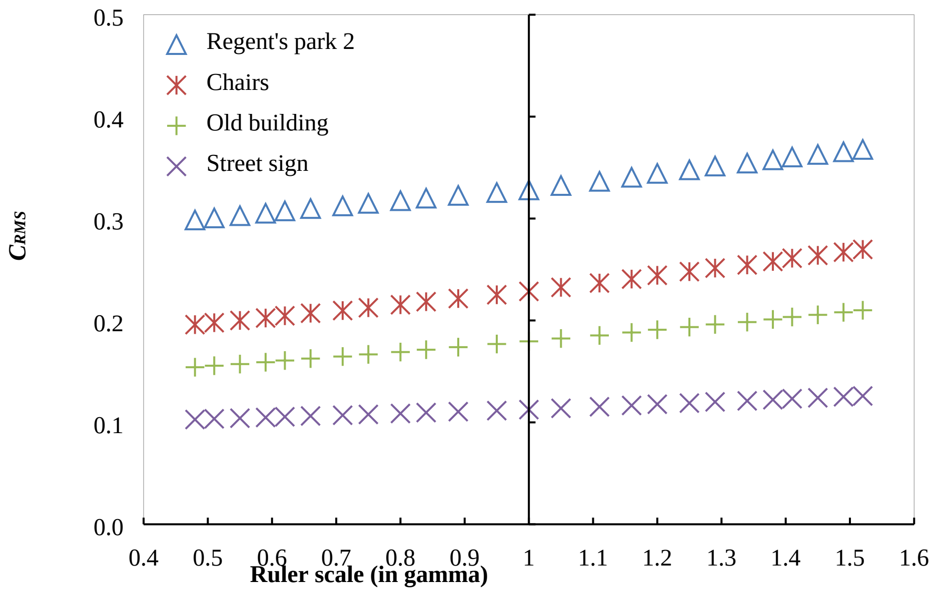

Figure 3. C_{RMS} of four selected scenes at a different ruler scale.

In addition, the effect of bi-cubic interpolation on the measured image contrast was investigated. C_{RMS} of all test images at five different sizes was measured. The effect of bi-cubic interpolation on C_{RMS} was not evident. C_{RMS} of the filtered 'Regent's Park 2' scene at various image sizes is shown in Figure 4.

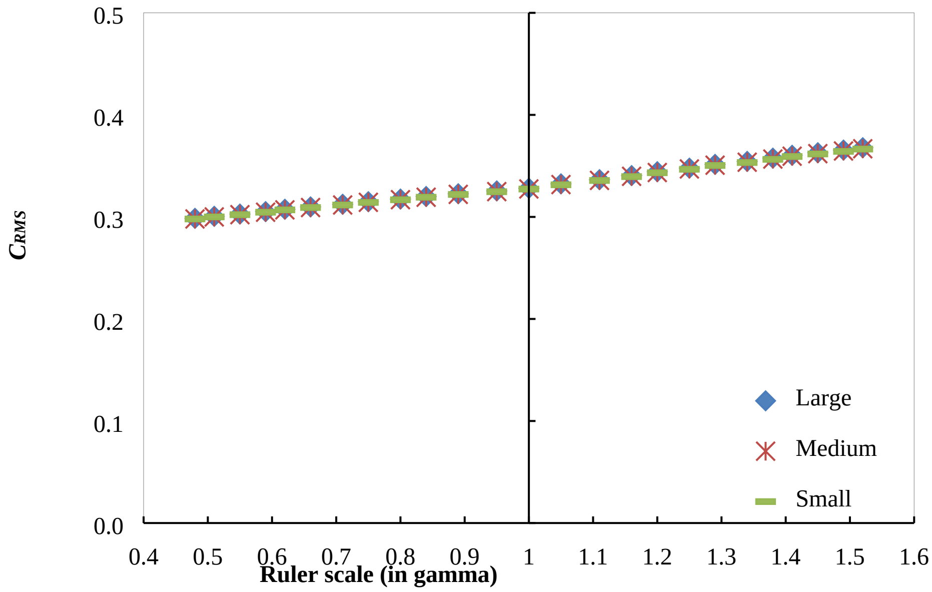

Figure 4. C_{RMS} of 'Regent's Park 2' at a different ruler scale in 3 different image sizes.

3. PSYCHOPHYSICAL INVESTIGATION

3.1 Calibration and settings of the system

The EIZO ColorEdge 245W LCD, driven by a Dell® Optiplex 760 computer with an ATI Radeon HD 3450 graphics controller, was used in the psychophysical investigation. The LCD has a native spatial resolution of 1,920 x 1,200 pixels and a tonal resolution of 24 bits (with a DVI connector). The system was set to a white point luminance of 120 cd/m^2, a gamma of 2.2 and a color temperature of D_{65}, using the GretagMacbeth Eye-One Pro with Profilemaker5. Daily calibration was carried out using the built-in calibration sensor.

3.2 Software preparation and interface design

The application employed in the contrast matching experiment was written in PHP, HTML and CSS, and the user interface was controlled using JavaScript. It was tested and optimized in Mozilla Firefox v5.0 web browser [19]. A mid-grey background in luminance (pixel value of R=G=B=186, at a gamma of 2.2) was selected. The application gathered some personal information provided by the observers before the experiments started. Each test image was displayed simultaneously in two different sizes. The test images were displayed in random order and display sides, adjacently placed on the left and right side of the display. Observers used a slider, controlled by the computer mouse, which simulated changes in the image contrast in response to changes in the slider position, by replacing the image frame with the appropriate ruler image. The display interface is illustrated in Figure 5.

Figure 5. Graphical user interface of the contrast matching experiment.

3.3 Contrast matching

Contrast matching tests were conducted in a totally dark environment. Although the reference sRGB display viewing conditions were dim (ambient illuminance of 64 lux, and veiling glare of $0.2cd/m^2$), the advantage of conducting experiments in such an environment was that the display was free from veiling glare, which is known to decrease perceived contrast and color saturation [20]. Observers were seated on a comfortable seat with a chin rest to hold the observation distance at 60cm from the display and were requested to move their eyes from side to side only. During the tests, a randomly selected test image was displayed simultaneously at two different sizes on the LCD. The test images were displayed with random display position, one on the left side and the other on the right side of the display. The observers were asked to match the perceived image contrast of the smaller 'test' images to that of the larger 'standard' images using a slider. The application automatically wrote the observation data and saved them in a CSV file.

The experiment consisted of four matching contrast sessions: small image size to large image size, medium-small image size to large image size, medium image size to large image size, and large-medium image size to large image size. The observers completed the experiment in four separate sessions. Each observation took less than one hour per session; one session was conducted per day to avoid fatigue. A total of twenty observers, with normal visual acuity, participated. Their age ranged between 20 and 40 years old: all of them had imaging and design backgrounds.

4. RESULTS AND DISCUSSION

4.1 Results from the psychophysical tests

The mean, μ, and standard error of the mean (SEM) were calculated for each scene and size pairs. Results from the contrast matching experiment showed that perceived contrast was increased when image size was decreased and were consistent with results from the sharpness matching experiment [7]. Observations from matching the contrast of the small version image to that of the large version image, resulted in an average change in tone reproduction of 0.087 gamma (or 2.0 steps in the gamma scale), with an average standard error of mean (SEM) of 0.030. The range of change for all scenes was from -0.04 to 0.19. The changes for each scene, along with standard error, are plotted in Figure 6(a). From the experiment of the medium-small against large pairs of images, the average change was 0.050 gamma with an average SEM of 0.027. The range of change was from -0.08 to 0.14. From the medium version against the large version image, the average change was 0.043 gamma with an average SEM of 0.022. The range of change was from -0.02 to 0.13. And the large-medium version against the large version matching experiment showed that the average change was 0.036 gamma with an average SEM of 0.023. The range of change was from -0.054 to 0.096. The results are plotted in Figure 6 (b) to 6(d).

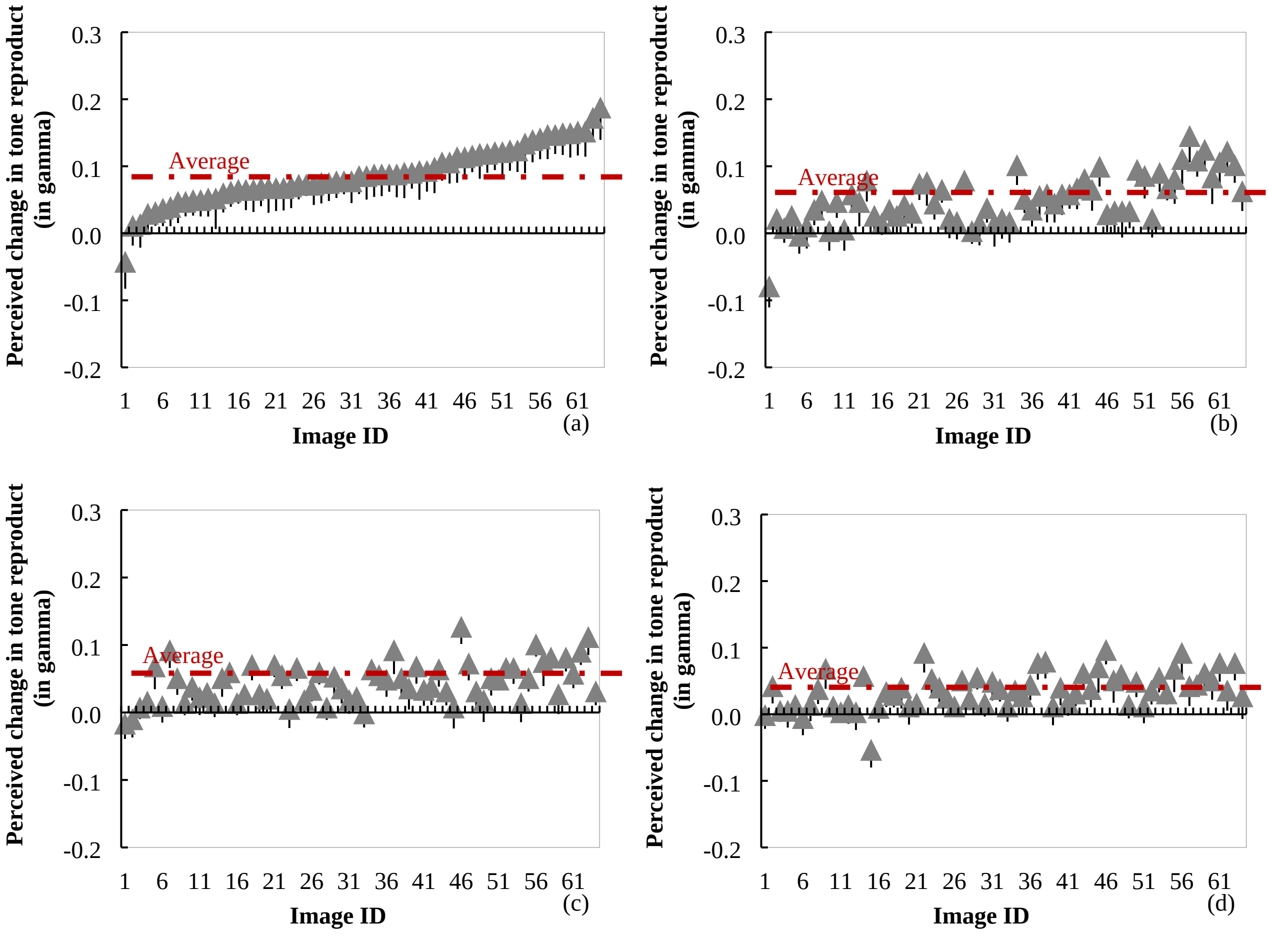

Figure 6. Average perceived change in tone reproduction (in gamma) with SEM. (a) small vs. large, (b) medium-small vs. large, (c) medium vs. large, (d) large-medium vs. large.

In addition to results in Figure 6, the average changes in perceived tone reproduction in gamma from all four experiments were plotted as a function of displayed image size in Figure 7. The figure clearly illustrates that the perceived contrast was proportionally affected by the changes in displayed image size. Smaller version images were perceived as having a higher contrast than that of the larger version. Similar results were found by recent research conducted by Haun *et al* [21]. The authors found that magnified video is perceived as having lower contrast than original video. Therefore, mirrored data at zero point has also been estimated by extrapolation and plotted as a linear function to predict change in perceived contrast when images may be displayed at larger scales. This assumes that the relationship remains linear. The linear trend line showed the relationship as: y = -0.001x+0.000 with R^2 = 0.983.

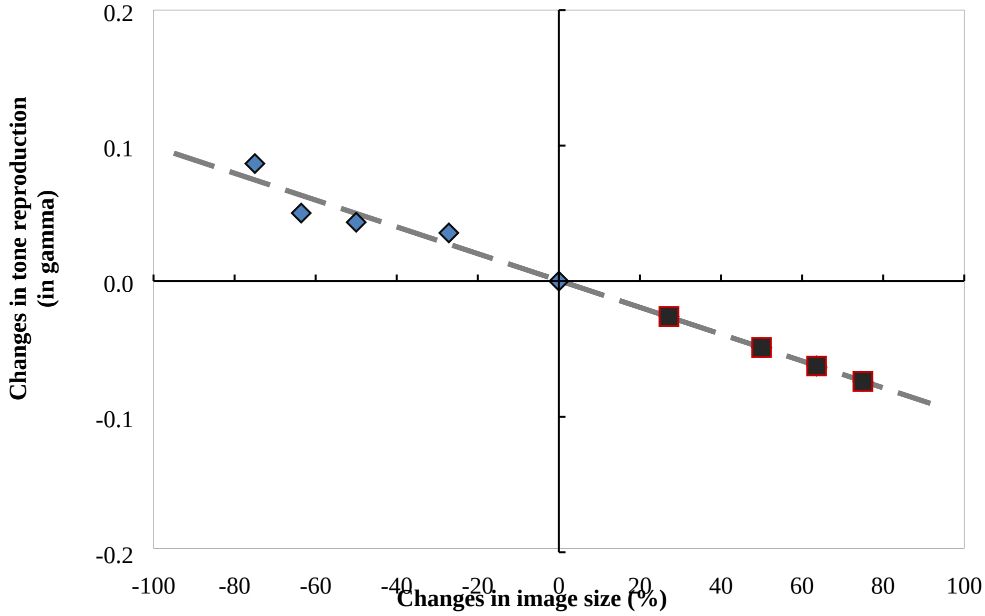

Figure 7. Perceived changes in tone reproduction with respect to the changes in displayed image size (blue) and extrapolated changes (dark gray) in non-calibrated relative image quality gamma scale.

4.2 Validation of the results

A psychophysical experiment to validate the results obtained from the contrast matching experiments was conducted under the environmental condition described in Section 3.3. A total of sixteen large size average scenes [22] and their corresponding smaller versions, one unmodified and one contrast modified version according to previous finding, were used. Observers were asked to asked to rate the test image pair in terms of their appearance matching (from 10 being the most matching to 1 being the least matching). A total of 7 average observers took part in the experiment.

Only in a few images, unmodified version images were perceived to be closer matching to the large original. However, majority of the contrast modified small versions were perceived to be closer matching to the large original than the unmodified small versions, as shown in Figure 8.The large original and contrast modified small version image pairs rated superior, $\mu = 4.90$, compared with the large original and small unmodified image pairs, $\mu = 4.62$.

However, in some cases the error bars overlap, making it unclear whether the contrast modified small images were clearly better than the unmodified originals or not. Nevertheless, the overall trends indicate that in general the contrast modification to compensate for image size modification is probably a worth-while operation, especially since it is not computationally expensive. Further work is needed to identify the original contrast characteristics of the scenes with close results.

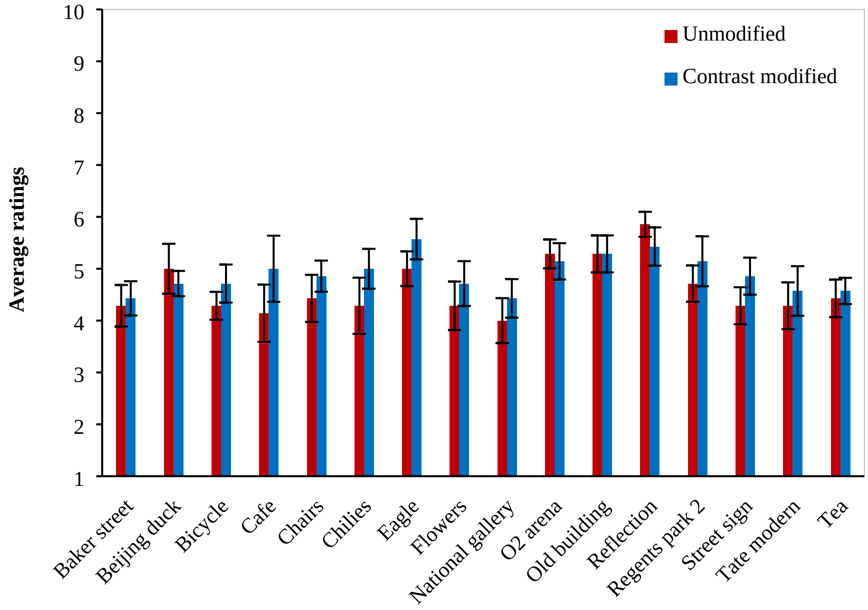

Figure 8. Average ratings for the contrast modified and unmodified image pairs.

4.3 Validation of step intervals and calibration in JND scale

A series of paired comparison experiments were conducted using all sixty-four scenes. For the step interval evaluation, only the central region of the scale (original ± 6 steps) was used, as most of the appearance changes were found within the range. A new set of filters with smaller intervals (half of the intervals used for contrast matching) was created for contrast enhancements to increase accuracy. Three male expert observers participated to a total of 192 sessions. Each observation took less than 10 minutes per session and a maximum of 10 sessions per day was conducted to avoid fatigue.

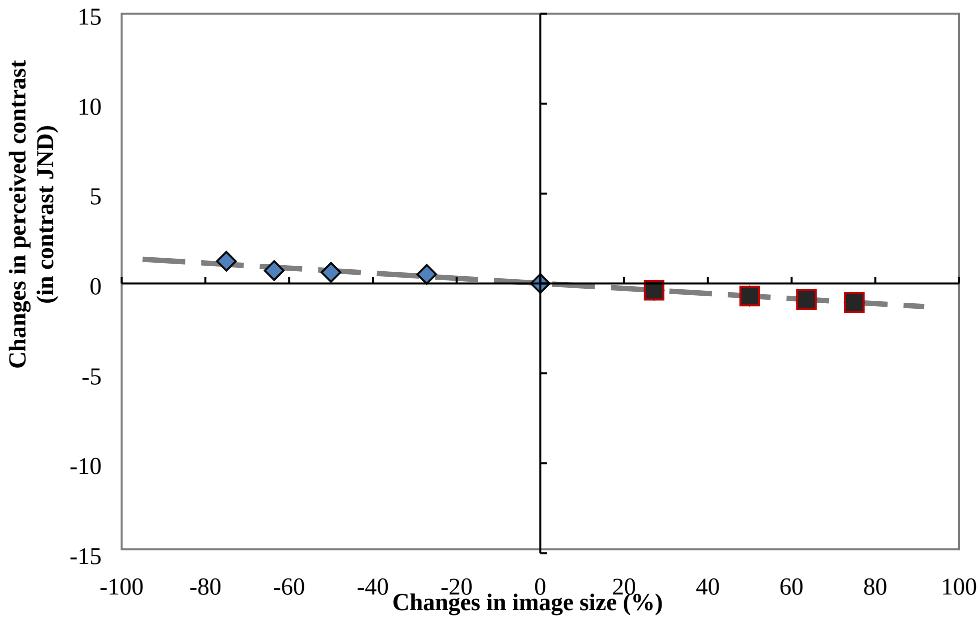

Figure 9. Changes in perceived contrast with respect to the changes in displayed image size (blue) and extrapolated changes (dark gray) in contrast JND scale.

An average of 0.070 gamma (or 1.614 steps) in the ruler scale was found to be 1 JND in perceived contrast. The outcome was used to calibrate the results obtained in Section 4.1 into contrast JND scales, plotted in Figure 9. The linear trend line showed the relationship as: y = -0.014x+0.006 with R^2 = 0.983. The change in perceived contrast was approximately 1 JND with a 75% change in the displayed image size.

4.4 Changes in perceived contrast vs changes in perceived sharpness

Results from a sharpness matching experiment to define perceived sharpness changes with changes in displayed image size have been previous published [1]. They are presented in Figure 10, calibrated in a sharpness JND scale [22]. The linear trend line shows the relationship as: y = -0.159x-0.069 with R^2 = 0.995. Figures 9 and 10 allow a comparison between JNDs in sharpness changes versus JND in contrast changes, with similar changes in the display image size. The change in perceived sharpness was as much as 12 JNDs with a 75% change in the displayed image size, where as the equivalent change in perceived contrast was 1 JND. Sharpness and contrast were previously identified to be the two most affected image attributes with respect to changes in displayed image size [7], but perceived sharpness is shown in this study to be affected more severely compared to perceived contrast.

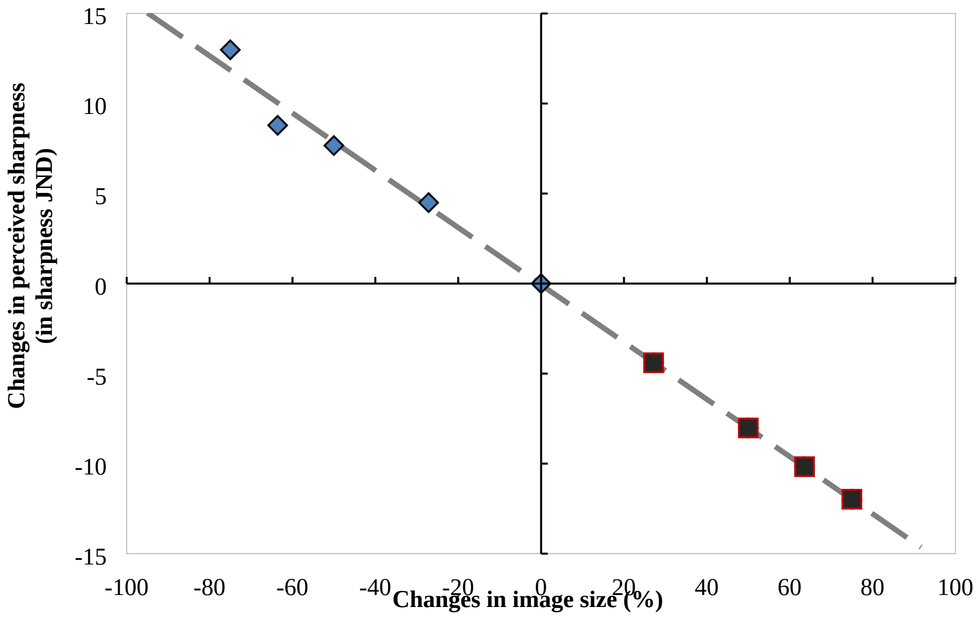

Figure 10. Changes in perceived sharpness with respect to the changes in displayed image size (blue) and extrapolated changes (dark gray) in contrast JND scale.

5. SUMMARY AND CONCLUSIONS

A series of psychophysical experiments were carried out to investigate the changes in perceived image contrast when images are viewed at different displayed sizes on an LCD device. A total of 64 natural scenes with various scene contents were selected for the purpose. The images were resized to generate five different sizes: small, medium-small, medium, large-medium, and large using bi-cubic interpolation. For the smaller versions of the test images, a set of 25 images of varying image contrast with an equal quality interval were created, using S-shape filters applied in the spatial domain.

For the range of image sizes we studied, no significant effect of the bi-cubic interpolation on image contrast was found. Results from the psychophysical matching experiments indicated that the perceived contrast was affected by changes in displayed image size. For the majority of the test images, smaller versions were judged as having a higher perceived contrast compared with the perceived contrast of the larger versions.

REFERENCES

[1] Park, J. Y., Triantaphillidou, S., Jacobson, R. E. and Gupta, G., "Evaluation of perceived image sharpness with changes in the displayed image size, " SPIE/IS&T Electronic Imaging, 82930J-82930J (2012).
[2] Choi, S. Y., Luo, M. R. and Pointer, M. R., "Colour appearance change of a large size display under various illumination conditions," Electronic Imaging 2007, 649308-649308-9 (2007).
[3] Nezamabadi, M. and Berns, R. S., "Effect of image size on the color appearance of image reproductions using colorimetrically calibrated LCD and DLP displays, " Journal of the Society for Information Display 14(9), 773-783 (2006).
[4] Nezamabadi, M., Montag, E. D. and Berns, R. S., "An investigation of the effect of image size on the color appearance of softcopy reproductions using a contrast matching technique," SPIE/IS&T Electronic Imaging, 6493091-6493099 (2007).
[5] Xiao, K., Luo, M. R., Li, C. and Hong, G., "Colour appearance of room colours," Color Research & Application 35(4), 284-293 (2010).
[6] Xiao, K., Luo, M. R., Li, C., Cui, G. and Park, D., "Investigation of colour size effect for colour appearance assessment," Color Research & Application 36(3), 201-209 (2011).
[7] Park, J. Y., Triantaphillidou, S. and Jacobson, R. E., "Identification of image attributes that are most affected with changes in displayed image size," SPIE/IS&T Electronic Imaging, 724210 (2009).
[8] Wang, Z. and Hardeberg, J. Y., "Development of an adaptive bilateral filter for evaluating color image difference," Journal of Electronic Imaging 21(2), 023021-1-023021-10 (2012).
[9] Moulden, B., Kingdom, F. and Gatley, L. F., "The standard deviation of luminance as a metric for contrast in random dot images," Perception 19(1), 79-101 (1990).
[10] Tiippana, K., Näsänen, R. and Rovamo, J., "Contrast matching of two-dimensional compound gratings," Vision Res. 34(9), 1157-1163 (1994).
[11] Bex, P. J. and Makous, W., "Spatial frequency, phase, and the contrast of natural images," Journal of the Optical Society of America 19, 1096-1106 (2002).
[12] Triantaphillidou, S., Jarvis, J. and Gupta, G., "Contrast sensitivity and discrimination of complex scenes," Proc. Image Quality and System Performance X, 8653, San Francisco, USA (2013), 86530C-86530C (2013).
[13] Bilissi, E., Jacobson, R. E. and Attridge, G. G., "Just noticeable gamma differences and acceptability of sRGB images displayed on a CRT monitor," Imaging Science Journal, The 56(4), 189-200 (2008).
[14] Braun, G. J. and Fairchild, M. D., "Image lightness rescaling using sigmoidal contrast enhancement functions," Journal of Electronic Imaging 8(4), 380-393 (1999).
[15] Hassan, N. and Akamatsu, N., "A new approach for contrast enhancement using sigmoid function," the international arab journal of information technology 1(2), 221-225 (2004).
[16] Oakdale Engineering, "Oakdale Engineering DataFit, " 2007(11/25).
[17] Peli, E., "Contrast in complex images," JOSA A 7(10), 2032-2040 (1990).
[18] Frazor, R. A. and Geisler, W. S., "Local luminance and contrast in natural images, " Vision Res. 46(10), 1585-1598 (2006).
[19] Mozilla, "Mozilla Firefox," 2008(08/13) (2013).
[20] Hunt, R. W. G., "Light and Dark Adaptation and the Perception of Color," J. Opt. Soc. Am. 42, 190-199 (1952).
[21] Haun, A. M., Woods, R. L. and Peli, E., "Perceived contrast of electronically magnified video," Proc. SPIE, 21 (2011).
[22] Park, J. Y., "Evaluation of changes in image appearance with changes in displayed image size," Ph.D. thesis, University of Westminster (2014).