31.3: Experimental Methodology to Measure the Veiling Glare Limit for Detection Tasks in High-Dynamic-Range Displays

Mina Choi*[†♮]*, Diksha Sharma*[†]*, Fahad Zafar*[†♯]*, Wei-Chung Cheng*[†]*, Luigi Albani*[‡]*, Vesna Zderic*[♮]*,
***Aldo Badano*[†]**

[†]**Center for Devices and Radiological Health, FDA, Silver Spring, MD. ♮Department of Electrical and Computing Engineering, The George Washington University, Washington, DC. ♯Department of Computer Science and Engineering, University of Maryland, Baltimore County, Baltimore, MD. [‡]BARCO, Saronno, Italy.**

Abstract

We describe an experimental methodology for quantifying the effect of veiling glare in high-dynamic-range displays for simple detection tasks using a sensitivity experiment. A Gaussian spot was located on white noise image backgrounds indicated with dark hairline markers and a ring was added to the image as the veiling glare source. A double random staircase technique with one-image-at-a-time paradigm was used to estimate intensity thresholds using published methods. Observer gaze position was recorded in real-time during the experiments and used to provide auditory feedback to ensure fixation on the region where the signal might be present and minimize significant changes in adaptation that would affect the thresholds.

1. Introduction

High-dynamic-range (HDR) displays for medical imaging have gained interest in recent years because of the increased number of just-noticeable differences (JNDs) available for the display of DICOM images [1]. However, human observers typically miss details in the vicinity of bright regions due to scattering in the eye. In addition, the pixels surrounding bright areas are affected by light scattering in the device multiple layers. These deleterious effects are forms of veiling glare, generally defined as the scene-dependent, multiple scattering of light that reduces contrast in the acquisition, display, or visual perception of an image. Preliminary measurements on a HDR dual-layer liquid-crystal display (LCD) suggest that a veiling glare ratio of 0.1 can extend up to 1 cm. Many advances have been made to reduce veiling glare in acquisition, but still not much is understood about veiling glare in the display and human visual system. While HDR displays advertise the ability to display more contrast information, the bright areas in the scene may impede the viewers ability to detect another spot that is less bright. Figure 1 shows an example of this problem where a lesion might go unnoticed when near a bright region due to the veiling glare effect.

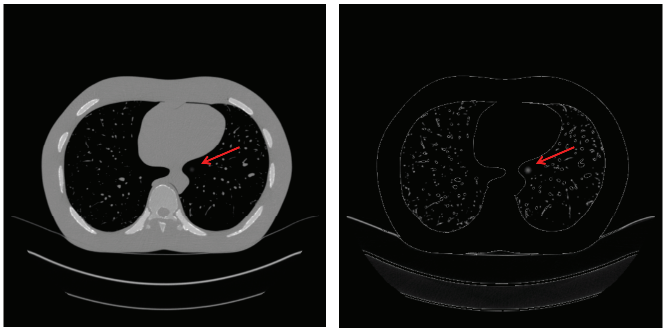

Fig. 1: (*left*) A chest CT image slice with a simulated nodule (see marker). (*right*) After clipping the bright structures in the CT, the simulated nodule becomes more conspicuous.

Previous work by Flynn and Badano reported an experimental technique to measure the degradation in image quality due to veiling glare in display devices such as film, monochrome monitors, and a color monitor with anti-reflective surface coating [2]. An image with a black spot was shown at the center of a white circle and the glare ratio, the maximum luminance (circle) over the minimum luminance (spot), was measured. The smaller glare ratio indicated a larger glare effect in the display. There has been recent interest in determining a systematic method to measuring reader performance in view of the expected technological improvements due to HDR [3, 4]. Tisdall *et al.* compared the detectability of a signal in an HDR LCD and a standard medical LCD. By using a low-resolution, 8-bit, rear back-light panel and a high-resolution, 8-bit, front panel, a 16-bit grayscale definition was achieved. Tisdall *et al.* were able to quantify the display quality by reader performance on a detection task with the display at both settings (standard LCD and HDR). Results showed that readers performed similarly in a detection task on the standard LCD and on an HDR display. This study provides some evidence that veiling glare caused by the HDR display might not affect detection performance, although further experiments are needed to verify this claim [1].

From the Division of Imaging and Applied Mathematics, Office of Science and Engineering Laboratories, Center for Devices and Radiological Health, U.S. Food and Drug Administration. 10903 New Hampshire Ave., Building 62, Room 3116, Silver Spring, MD 20993, phone 301-796-2534, email `aldo.badano@fda.hhs.gov`. MC is a M.Sc. student at GWU. FZ is a Ph.D. student at UMBC. The mention of commercial products herein is not to be construed as either an actual or implied endorsement of such products by the Department of Health and Human Services. This is a contribution of the Food and Drug Administration and is not subject to copyright.

Using camera calibration experiments, McCann and Rizzi found that even the multiple exposure technique [5] cannot reconstruct scene luminance beyond the veiling glare limitation of HDR display. In addition, they also found that intraocular scatter changes identical display luminance into different retinal luminances [6]. Stiehl suggests that the dynamic range of retinal luminance was approximately 30:1 while displays have ranges of 1000:1 [7]. In the experiment performed by McCann and Rizzi, observers were still able to discriminate the differences in luminance of the display even though the range was much larger. They attributed this to post-image processing that occurs in the brain based on spatial information of the scene [8]. Glare in human vision is caused by scattering of light in the cornea, lens, retina, and diffraction in the coherent cell structures on the outer radial areas of the lens. These effects results in ”bloom” and ”flare lines” that are perceived by observers around bright objects. Among the areas of interest of veiling glare, Spencer *et al.* proposed an algorithm to model human visual glare effects into digital images [9].

Veiling glare has been modelled as a static phenomenon until recently. Ritschel *et al.* found that humans use temporal properties of glare to increase the perceived brightness and produce realistic renderings of bright light sources. They developed a model to enable real-time simulation of dynamic glare effects on a GPU [10]. In addition, Issolio and Colombo conducted experiments on the effect of a transient glare source on the perceived brightness of a standard luminance patch as a function of the surround luminance [11]. Finally, Aguirre *et al.* looked at the effect of veiling glare on simple reaction time in the scenario of night-time driving and found that reaction time increases with decreasing contrast. The effects of glare on reaction time must be modelled by an equivalent glare luminance that depends on spatial frequency [12].

In this work, we present a methodology that can provide estimates of detection thresholds for a variety of veiling glare scenarios. This methodology can be used to explore the effects of veiling glare on more realistic medical image datasets. However, our initial experiments are focused on simple image backgrounds and targets in an effort to understand all the elements that contribute to the effect in a systematic manner.

2. Methods

The experiment was designed for a dual-layer LCD prototype. This technology makes use of a second LCD panel for the back-light, rather than the conventional LCD screens that use a low resolution light emitting diode (LED) or cold cathode fluorescent lamp (CCFL) panel, enabling the display of 16-bit images [3]. However, for the experiments reported in this paper, both front and back LCD layers were driven synchronously offering only 256 graylevels.

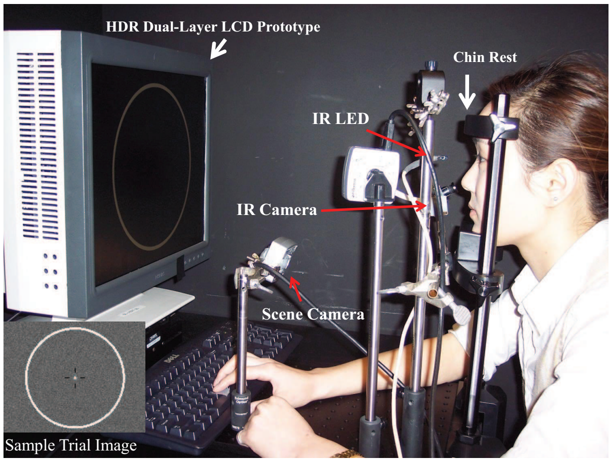

Fig. 2: Photo of the set-up with chin rest, dual-layer HDR prototype, eye-tracking module, and a sample image of a single trial. The amplitude of the target here is 255, however in the experiment the initial amplitude for the descending staircase was 10. Black hairlines (2 pixels wide and 40 pixels long) were included to help the observer determine the location of the target overlayed on white noise.

R_d (deg,pixel)	R_t (pixel)	R_i = 255, I (lx)	R_i = 200, I (lx)	$R_i = 0$, I (lx)
0.0117, 500	30	9.92	3.28	∼0.02
0.0065, 900	21	9.87	3.46	∼0.02

TABLE I: Veiling source parameters with three illuminance conditions and two ring diameters (R_d). Ring thickness (R_t) was set to give isoilluminant conditions for each ring diameter (R_d). R_i is ring intensity in an 8-bit scale. I is the measured illuminance at the view point (40 cm).

We used a double random staircase (DRS) proposed by Cornsweet [13] which incorporates one ascending and one descending staircase presented randomly in the same experiment. The two distinct starting stimuli are chosen to be relatively equidistant from the predicted threshold to minimize bias. Cornsweet argued that the DRS, not only minimizes the bias of starting from a particular stimulus intensity, but retains the efficiency of the single staircase (measured by how quickly the stimuli converges to the true threshold) and reduces interdependency of the responses. Optimal staircase techniques include a 1/1 ratio of number of yes or no responses needed to increment or decrement the succeeding stimulus and discarding first two reversals in the calculation of the estimate [14]. Typically, the length of the experiment should be as long as possible to attain a small variance.

Each experiment consisted of a binary decision on the presence of a target (a Gaussian spot with 10 pixels width corresponding to about 0.00013 degrees for the viewing distance of 40 cm) located in the center of the display screen. The background was populated with white noise with a mean value of 20 and a variance of 0.5 graylevels (on scale of 0 to 255). The initial stimulus of the descending staircase for the first experiment began with a target intensity of 10 graylevels, while the ascending began at 0. The proceeding experiment used the last values of the previous staircase for the initial stimulus.

Three observers with near 20/20 visual acuity and uncorrected vision were asked to perform the experiment in a single seating. The observers were adapted to the dark room environment for 15 minutes, were fully disclosed on the study, and performed a test run prior to the experiment. We use the data analysis of staircase methods described by García-Pérez, where the amplitudes of the target at every reversal in observer decision were averaged to find the threshold estimate (τ) [14]. After some preliminary experiments, García-Pérez found that any mistakes in early decisions largely skewed the calculated τ and error. For this reason, the first two reversals were excluded from the analysis. For the double staircases, the mean for the ascending and descending staircases were calculated separately then averaged together.

The veiling glare source in this experiment is a ring generated equidistant from the target spot. There are a total of 4 distinct rings, and a no ring control case. Table I shows the different parameters of the rings that give isoilluminant conditions at the mid-point between the eyes of the readers. To reduce adaptation effects that occur when the eye directly views a bright area, an eye-tracker is used to track the observer's gaze on the screen and provide audio feedback to notify the observer to return the gaze to the center position [15]. The eye-tracker data is used to document when the observer's gaze visits the ring.

3. Results

Figure 3 shows preliminary results of veiling glare effects over time as the veiling glare source (ring) is switched on and off. The observer threshold increased whenever the veiling glare was present to varying degrees. The top plot in Figure 3 shows the veiling glare conditions at 3 lx, and the bottom plot shows veiling glare condition at 10 lx. Our preliminary results suggest that as the distance between the veiling glare source and the target decreases the observer performance decreases. Also, as expected, when the illuminance of the veiling glare source is increased the performance decreases.

4. Discussion & Conclusion

This methodology allows for studying veiling glare effects due to light scattering in the display and perceptually. The eye-tracker module is a necessary tool used to minimize the adaptation effects which occur when the observer's gaze visits the ring area. Preliminary results show that there is a decrease in sensitivity (an increase in the threshold) when the veiling glare source, the ring, is turned on. A ring causing the same illuminance at the eye but with a smaller diameter diminishes observer performance further. This paper describes a technique to comprehensively study veiling glare in HDR displays and in the HVS. Using a DRS, visual detection thresholds with different ring veiling glare sources can be characterized. In a future, analogous experiment the veiling glare source, currently a ring, will be replaced with a lung CT image slice and a simulated nodule will be used to measure detectability thresholds. This study will inform models and algorithms to reduce the veiling glare effect locally and improve the display of HDR medical images.

5. Acknowledgements

The authors acknowledge useful discussions with G. Ramponi and G. Guarnieri (University of Trieste, Italy). This research is funded in part with a Cooperative Research and Development Agreement between FDA and BARCO.

References

[1] MD Tisdall, G Damberg, P Wighton, N Nguyen, Y Tan, MS Atkins, H Li, and H Seetzen. Comparing signal detection between novel high-luminance HDR and standard medical LCD displays. *Journal of Display Technology*, 4:398–409, 2008.

[2] MJ Flynn and A Badano. Image quality degradation by light scattering in display devices. *Journal of Digital Imaging*, 12:50–59, 1999.

[3] A Badano, G Guarnieri, G Ramponi, and L Albani. Quantization in medical imaging displays - initial observer results for a high-luminance-range, dual-layer LCD. *Proceedings of SID*, 39:923–926, 2009.

[4] A Badano, D Sharma, G Guarnieri, G Ramponi, and L Albani. Effect of case variability on the measurement of reader performance when comparing medical display technologies: application to the study of high-luminance-range displays. *Proceedings of IRDC*, 2009.

[5] CEK Mees. *The Fundamentals of Photography*. Kodak Research Laboratory, Rochester, 1920.

[6] JJ McCann and A Rizzi. Veiling glare: the dynamic range limit of HDR images. *Proceedings of SPIE*, 2007.

[7] WA Stiehl, JJ McCann, and RL Savoy. Influence of intraocular scattered light on lightness-scaling experiments. *Journal of the Optical Society of America*, 55:1303–1308, 1965.

[8] JJ McCann and A Rizzi. Retinal HDR images: Intraocular glare and object size. *Journal of the SID*, 17/11:913–920, 2009.

[9] G Spencer, P Shirley, Zimmerman, and DP Greenberg. Physically-based glare effects for digital images. *Proceedings of ACM*, pages 325–334, 1995.

[10] T Ritschel, M Ihrke, JR Frisvad, J Coppens, K Myszkowski, and HP Seidel. Temporal glare: Real-time dynamic simulation of the scattering in the human eye. *Eurographics*, 2009.

[11] L Issolio and EM Colombo. Brightness for different surround conditions: The effect of transient glare. *Psychonomic Society, Inc.*, pages 702–709, 2006.

[12] EM Colombo RC Aguirre and JF Barraza. Effect of glare on simple reaction time. *Optical Society of America*, 2008.

[13] TN Cornsweet. The staircase-method in psychophysics. *The American journal of psychology*, 75:485–491, 1962.

[14] MA García-Pérez. Yes-no staircases with fixed step sizes: Psychometric properties and optimal setup. *Optometry and Vision Science*, 78:1, 2001.

[15] WC Cheng and A Badano. A gaze-contingent high-dynamic range display for medical imaging applications. *Proceedings of SPIE*, 7627, 2010.

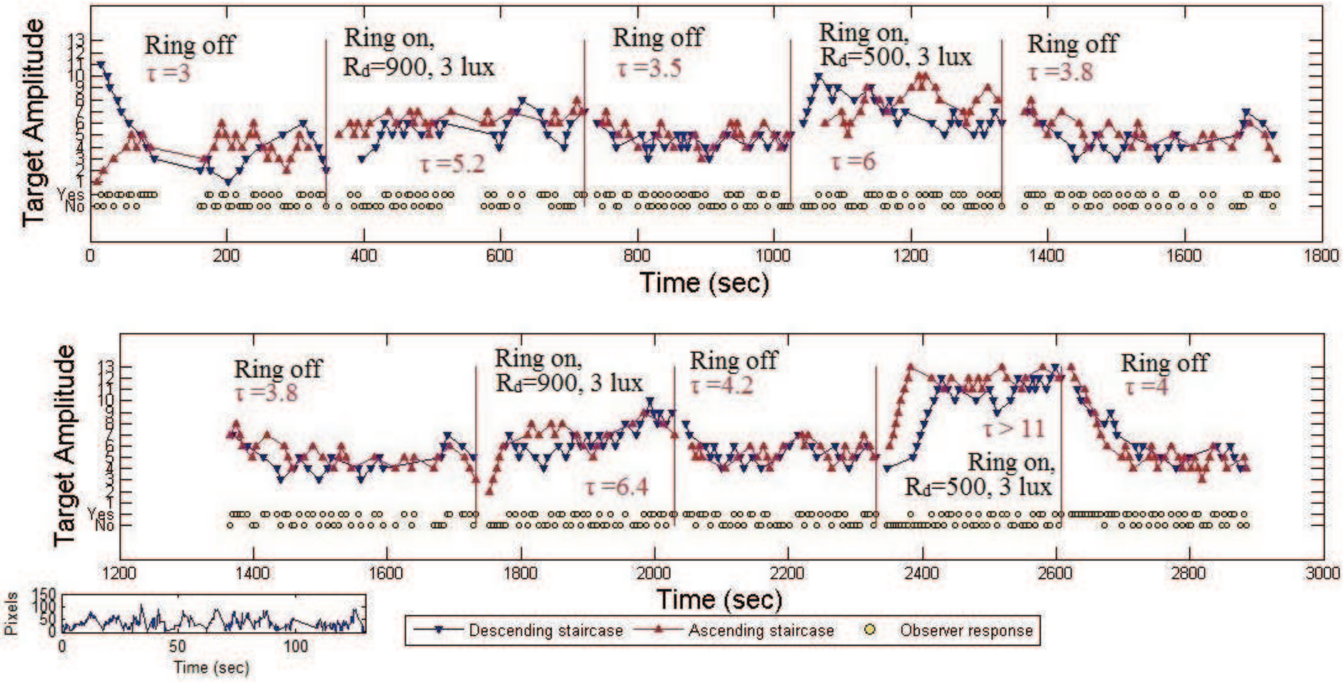

Fig. 3: Preliminary results of a complete experiment for two ring illuminances, two ring diameters, and no-ring conditions (control case), each with 50 observations. The last panel on the top figure is displayed again in the first panel of the bottom figure. *(bottom insert)* Typical real-time eye-tracking data (pixel separation between gaze location and center of the screen) corresponding to the first two minutes of the first experiment.