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Abstract. Reducing dose increases noise impacting image quality but can be offset by increasing display luminance. Two contrast detail mammography images were obtained at 26 kV and the same distance between detectors, at 45 and 50 mAs resulting in entrance surface doses of 7.09 and 7.88 mGy, respectively. They were processed to make average gray level of the background independent of the dose level while maintaining original SNR. Eight radiologists viewed the images at 420, 1000 cd/m², and SpotView™ a tool that resulted in an average display luminance of 3138.8 cd/m². Percent correct (PC) for all three luminances was higher for high versus low dose. Performance was always higher with high dose no matter what the luminance. For low dose, PC was highest with SpotView™, and SpotView™ and 1000 cd/m² were significantly higher than 420 cd/m². At high dose, SpotView™ PC was significantly higher than both lower luminances. Average time per image was lower in high dose, and, at both doses, time decreased as luminance increased, with SpotView™ having significantly shorter times. Increasing luminance from 420 to 1000 cd/m² significantly increases target detection by ~3.0% and with SpotView™ by ~6.2%. Increasing display luminance with SpotView™ significantly decreases reading time by 16.0%. © 2018 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: [10.1117/1.JMI.5.3.035501](https://doi.org/10.1117/1.JMI.5.3.035501)]

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1 Introduction

Early papers summarizing the status of digital mammography^{1,2} often noted that one of the advantages of digital viewing was the ability to window/level, obviating the need for bright lighting (which was actually part of the American College of Radiology screening mammography guidelines).³ In fact, it has been noted that it often takes more time to manipulate digital images than it took to use a magnifying glass and bright light⁴ and that display workstations for full-field digital mammography (FFDM) should develop interfaces with bright light equivalents to make the two display modalities as equivalent as possible.⁵ Interestingly, although window/level functionality clearly became an integral part of all digital radiology workstations, the bright light concept did not. FFDM has done much to reduce radiation dose in screening mammography, but many women are still concerned with possible risks associated with annual exams and dose.^{6,7} Reducing dose increases noise impacting image quality. Noise can be dealt with at numerous points in the imaging chain, including the display on which the final presentation of images to the breast imager occurs. In this study, we hypothesized that the luminance of the display on which FFDM images are presented can maintain acceptable levels of target detection performance when radiation dose is reduced. Specifically, luminance differences were manipulated by the digital equivalent of a bright light, using display technology.

2 Materials and Methods

This study was approved by the Institutional Review Board at Emory University. All participants read and signed an approved consent form.

2.1 Processing and Selection of Images

Two different contrast detail mammography (CDMAM, Version 4.0) Phantom radiographs were used for this study. These were obtained with a mammography x-ray device (Senographe Essential version ADS_53.40, GE Medical systems, anode/filter Mo/Mo used) at the same voltage (26 kV) and the phantom was placed on top of a 2-cm-thick PMMA plate to keep a constant distance between phantom and detector for all radiographs (2 cm), but at different amperages (45 and 50 mAs) resulting in entrance surface doses of, respectively, 7.09 mGy (low) and 7.88 mGy (standard). The images were processed to make the average gray level of the background independent of the dose level while maintaining the original signal–noise ratio of the image. Of each CDMAM image, 30 tiles in the smaller size and lower contrast section were selected, which contain different disk sizes ranging from diameter 0.10 to 0.35 mm and from thickness 0.107 to 1.854 μ m, respectively. We used these size and contrast ranges to simulate more difficult targets. For training purposes, 20 different tiles in the same diameter and thickness ranges were chosen. Replicates of the various tiles (maximum two versions of each tile) are included with a randomly applied transformation (flipped and/or rotated by

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multiples of 90 deg) to avoid that the observer recognizes the same tile.

2.2 Study Setting

The sessions took place in a controlled environment with ambient room lighting of 45 lux. The monitor on which the images were displayed was a Barco Coronis Uniti 12 MP MDMC-12133. The display was DICOM Digital Imaging and Communications in Medicine Grayscale Standard Display Function calibrated taking into account the ambient light in the room, and compliance was verified prior to the study. During the sessions, the observers have kept their distance from the display constant at around 18 in. (or 45 cm). At this distance, the tiles were displayed at a size of 1.5×1.5 cm on the screen. Readers were not allowed to zoom/pan or adjust the window/level settings.

2.3 Reading Sessions

Eight radiologists participated as readers in this investigation. Each observer participated in two sessions in which the same images were read in a random order and with other transformations of the images. Three display settings were used alternately over six subparts per session: 420, 1000 cd/m^2 , and SpotView™, which resulted in an average display luminance of (3139 ± 30) cd/m^2 . We chose 420 cd/m^2 as the ACR-AAPM-SIIM⁸ recommend that the maximum luminance for primary interpretation should be at least 400 cd/m^2 . We chose 1000 cd/m^2 as most monitors for primary interpretation available today are capable of running at least this high. The images were displayed on a black background to allow for

dark adaptation, hence for best viewing conditions with regard to the relevant contents (Fig. 1).

The order in which the three settings were applied differed per session and per observer. Before starting the actual reading session, the observer performed a training session in which 20 tiles were read with random transformations in the three settings and the correct location of the gold disk was provided afterward. The training images differed from the ones used in the real study to avoid the influence of memory effects. The actual test session consists of reading the 60 CDMAM phantom tiles six times ($2 \text{ doses} \times 30 \text{ tiles/dose} \times 2 \text{ replicates/tile} \times 3 \text{ brightness settings}$). Between the images in each series of 60 tiles, the software provided a pause of a few seconds while indicating with a countdown timer when the next image would appear. Among the six different parts, participants were able to take a break when needed. For each tile, the observer had to perform a four-alternative forced choice task by determining which of one of the four corner quadrants contained the target disk. They did not have to indicate anything about the center disk as it is always there. The assessment and the time spent per image by the observer were automatically registered by the study software.

2.4 Description SpotView™ Feature

The Barco SpotView™ display feature allows focusing on a circular region of interest in an image, by boosting the display's backlight such that the maximum luminance is provided inside the region of interest (Fig. 2). SpotView™ also enables focused observation during readings by dimming images outside the region of interest and increasing the contrast in this region. During the readings with this feature, the spot was only focused on the images. The readers could not control the size, position, or relative luminance of the spot. All of the readers were familiar with the concept and use of a bright light, even those more recently trained.

2.5 Statistical Analyses

Percentages correct (PC) was calculated for each dose under the different settings by comparing the indicated gold disk position of the observer with the actual position. For each observer, the total PC and the PC per dose were statistically compared for the three display settings by means of Friedman tests ($\alpha = 5\%$). Confidence intervals were bootstrapped for the PCs of all observers under the same settings. Average time spent per image was calculated under the different settings per observer and per radiation dose. The settings were statistically compared

Fig. 1 Example of the user interface and one of the displayed test tiles.

Fig. 2 Example of an FFDM image using the SpotView™ display feature.

on the 5% significance level using repeated measures analysis of variance and protected least squares difference posthoc tests.

3 Results

3.1 Accuracy

The results from the pooled data are shown in Fig. 3. In the low dose condition, PC was highest with SpotView™ (mean = 86.88%, sd = 4.17) and SpotView™ and 1000 cd/m² (mean = 84.90%, sd = 4.66) were significantly higher ($Q = 13.00$, $p = 0.002$) than 420 cd/m² (mean = 79.48%, sd = 5.40). In the standard dose condition, SpotView™ PC (96.04%, sd = 1.98) was significantly higher ($Q = 12.00$, $p = 0.002$) than both of the lower luminances (mean 1000 cd/m² = 91.67%, sd = 2.67; mean 420 cd/m² = 91.04%, sd = 3.93). Overall (total), SpotView™ PC (91.46%, sd = 2.64) was significantly higher ($Q = 15.06$, $p = 0.002$) than both of the lower luminances (mean 1000 cd/m² = 88.28%, sd = 3.44; mean 420 cd/m² = 85.26%, sd = 4.32) and 1000 cd/m² was significantly higher than 420 cd/m². For all but one observer, results were highest with SpotView™ compared with both lower luminances (those for the last reader were equivalent for SpotView™ and 1000 cd/m²), and, for four of them, differences were significant.

Fig. 3 PC for the three different conditions calculated on the pooled data over all observers and split up in low and high exposures dose of the CDMAM phantoms, corresponding with, respectively, 7.093 and 7.880 mGy. Differences on the 5% significance level compared with the lowest luminance level 420 cd/m² are indicated with stars (*), while those compared with the luminance level 1000 cd/m² are highlighted with circles (deg). Error bars represent the confidence levels obtained by bootstrapping.

Fig. 4 Relationship between accuracy as a function of dose [entrance surface dose/correct answer (mGy)] and luminance.

Fig. 5 Average time (in seconds) spent per image for the three different conditions calculated on the pooled data over all observers and split up in low and high exposures dose of the CDMAM phantoms, corresponding with, respectively, 7.093 and 7.880 mGy. Differences on the 5% significance level compared with the lowest luminance level 420 cd/m² are indicated with stars (*), while those compared with the luminance level 1000 cd/m² are highlighted with circles (deg). Error bars represent the calculated standard errors.

Figure 4 shows the relationship between accuracy as a function of dose [entrance surface dose/% correct answers (mGy)] and luminance. Higher entrance surface dose/% correct answer indicates worse accuracy, and it appears the relationship with luminance is best characterized by a power function.

3.2 Efficiency

Observer efficiency pooled results are summarized in Fig. 5. Average time spent per image was lower in the standard dose compared with low dose condition, and at both dose levels time decreased as luminance increased, with SpotView™ have significantly ($F = 36.78$, $p < 0.0001$) shorter times overall (total) than 420 and 1000 cd/m². The same was true for low dose ($F = 24.13$, $p < 0.0001$) with all conditions significantly different, and high dose ($F = 15.37$, $p < 0.0001$) although in this condition 420 and 1000 cd/m² did not differ significantly. For six of the eight observers, viewing time was lowest (significantly) with SpotView™, and, for the other two, it was equivalent for all three luminance levels.

4 Summary and Discussion

Increasing display luminance from 420 to 1000 cd/m² significantly increases target detection accuracy (PC) by ~3.0%. Use of SpotView™ significantly increases target detection accuracy by ~6.2%. Increasing display luminance from 420 to 1000 cd/m² significantly decreases reading time by ~6.0%. Use of SpotView™ significantly decreases reading time with ~16.0%. It is important to also note that luminance alone is only half the picture. As seen in Fig. 3, accuracy with the highest luminance at low dose was still not as good as in the lowest luminance at standard dose and decision times were longer as well. Both display luminance and adequate radiation dose are required for accurate and efficient interpretation.

Although the current study follows the classic paradigm of testing image quality and observer performance hypotheses using validated phantoms, it is limited by the fact that it is phantom-based. The target shape is essentially always known and constant, although its size and contrast differ; the background lacks anatomic noise; and there is very little search (beyond looking in the four corners) as one would need to do with a real mammographic image. For SpotView™ to work in the clinic, there are two possible scenarios. In the first scenario, the reader views a case without SpotView™ and if something

suspicious is noted SpotView™ could be turned on to enhance visibility. This is the more likely scenario but one could also foresee someone using SpotView™ almost like a flashlight and systematically passing it over the image until something attracts their attention. This obviously would take more time and thus the tool is less likely to be used in this way. Therefore, further research is required to verify these results using clinical images and getting feedback about the most effective use strategy.

These results confirm what has been demonstrated in prior studies that have assessed the impact of increasing the overall luminance of the entire digital display for radiographic images.^{9–11} However, what is new is the validation that a user-controlled high-luminance “bright light” can also be used to improve reader efficacy and efficiency. Why is this important? As radiologists spend a significant number of hours reading high volumes of cases from digital displays, there is increasing concern regarding visual and physical fatigue and their impact not only on radiologists’ well-being but also their diagnostic performance.^{12–15} Long hours spent reviewing radiographic images on workstation displays reduces radiologists’ ability to accommodate (focus), increases subjective feelings of fatigue and strain, and most importantly reduces diagnostic accuracy. The root cause of this visual fatigue is in large part likely due to the digital monitors themselves. There is a large body of evidence surrounding the phenomenon of “computer vision syndrome,”^{16,17} which is characterized by changes in accommodation and vergence (both related to the ability to focus) that occur after even a few hours of working at an electronic display monitor. This is compounded with the rather intense visual nature of the task of the radiologist and the increasing number and types of complex images radiologists view for hours on end each day.

There is a significant need, and indeed an urgent call, to address fatigue and errors caused by fatigue in radiology.^{18–23} Clearly fatigue can be addressed in a variety of ways, and optimizing the reading environment and the tools used to interpret images is a fundamental and very direct way to do so. With film, the “bright light” was used only when necessary to increase the visibility of subtle structures and potential lesions. Otherwise lightboxes were masked to avoid the bright backlight overwhelming the viewer’s eyes (and hence negatively impacting dark adaptation and the ability to discriminate subtle, low-contrast lesions from their background). The SpotView™ tool that has been developed may in fact be one way to accomplish the same thing in the digital reading environment.

This study demonstrates the potential of SpotView™ to enhance accuracy and efficiency in interpreting FFDM images. It is, however, limited by the fact that this was a phantom-based study. Next steps are to conduct a similar study using clinical FFDM images in a receiver operating characteristic (FFDM) study, measuring accuracy and efficiency. We could also investigate the hypothesis that with clinical images, higher dose and luminance speed up the reading process and reduce fatigue.

Disclosures

The author has no relevant financial interests in the paper and no other potential conflicts of interest to disclose.

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