

The Effects of Ambient Lighting in Chest Radiology Reading Rooms

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Abstract Under typical dark chest radiography reading room conditions, a radiologist's pupils contract and dilate as their visual focus intermittently shifts between the high luminance monitor and the darker background wall, resulting in increased visual fatigue and degradation of diagnostic performance. A controlled increase of ambient lighting may minimize these visual adjustments and potentially improve

comfort and accuracy. This study was designed to determine the effect of a controlled increase of ambient lighting on chest radiologist nodule detection performance. Four chest radiologists read 100 radiographs (50 normal and 50 containing a subtle nodule) under low ($E=1$ lx) and elevated ($E=50$ lx) ambient lighting levels on a DICOM-calibrated, medical-grade liquid crystal display. Radiologists were asked to identify nodule locations and rate their detection confidence. A receiver operating characteristic (ROC) analysis of radiologist results was performed and area under ROC curve (AUC) values calculated for each ambient lighting level. Additionally, radiologist selection times under both illuminance conditions were determined. Average AUC values did not significantly differ ($p>0.05$) between ambient lighting levels (estimated mean difference= -0.03 ; 95% CI, $(-0.08, 0.03)$). Average selection times decreased or remained constant with increased illuminance. The most considerable decreases occurred for false positive identification times (35.4 ± 18.8 to 26.2 ± 14.9 s) and true positive identification times (29.7 ± 18.3 to 24.5 ± 15.5 s). No performance differences were statistically significant. Study findings suggest that a controlled increase of ambient lighting within darkly lit chest radiology reading rooms, to a level more suitable for performance of common radiological tasks, does not appear to have a statistically significant effect on nodule detection performance.

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Introduction

The introduction of liquid crystal displays (LCDs) to diagnostic radiology has rapidly transformed the reading room

environment. While the reading room was once the exclusive domain of hard-copy film displays, many imaging facilities have transitioned to almost entirely digital acquisition and interpretation of radiographs. While optimal reading conditions have been established for conventional radiographic interpretation, they have not yet been determined for digital radiographs. One condition, ambient lighting, is known to play an important role in image perception and radiologist comfort. Conventionally, it has been thought that ambient lighting should be minimized in reading rooms to maintain perceived image contrast [1, 2]. The validity of this convention is supported by studies utilizing film and cathode ray tube (CRT) displays which demonstrated a generally negative effect of increased ambient lighting on chest radiologist performance [3, 4].

Although perceived image contrast is maintained under low ambient lighting, these minimal levels likely cause radiologists to suffer visual fatigue and lead to performance degradation [5]. This fatigue may occur as a result of a radiologist's pupils contracting and dilating as the visual focus intermittently shifts between reading the high luminance image (L_{adp}) and the low luminance surrounding background (L_s) [2, 6]. It has been hypothesized that an ambient lighting increase may reduce pupillary action by minimizing the discrepancy between L_s and L_{adp} levels [5]. In contrast to film and CRTs, modern calibration-capable LCDs, with intrinsically low diffuse reflection coefficients and high luminance ratios may permit a moderate increase of ambient lighting without image quality degradation [7]. Following this assumption, theoretical, and psychophysical studies have provided preliminary evidence that radiologist performance should not degrade, and may improve, under a controlled ambient lighting increase [5, 8, 9].

This study was designed to determine the effect of a controlled increase of reading room ambient lighting, such that the difference between L_{adp} and L_s luminance levels was minimized, on the nodule detection performance of chest radiologists.

Materials and Methods

Image Data

One hundred posterior–anterior erect chest radiographs were selected from a database of 300 anonymous, digitized radiographs previously acquired with institutional review board approval [10, 11]. The radiographs were digitized with 12-bit luminance resolution and a pixel size of approximately 170 μm using a laser scanner (Lumiscan model 75; Lumisys, Sunnyvale, CA). Each radiograph was initially identified as suspicious for the presence of a pulmonary nodule and further evaluated using fluoroscopy or CT. Fifty

of the radiographs utilized in the study contained a solitary, subtle, non-calcified nodule, while 50 had no confirmed nodules. The nodule cases represented subtle nodule appearances and most had diameters between 5 and 15 mm (average of 9.2 ± 2.6 mm). Images with lung nodules were utilized primarily because they are so important in the initial diagnosis of lung cancer.

Each image was windowed, leveled, and filtered using a medical image editing program to match a physician-approved (by PM) clinical radiograph appearance [12]. Although the vertical dimension of the images ($2,048 \times 2,048$ pixels) was shorter than that of the LCD ($2,048 \times 2,560$ pixels), the images were not resized. Instead, to avoid the introduction of any resizing artifacts, the images were centered within a uniform 12 cd/m^2 background. Figure 1 shows a few examples of utilized images.

Illuminance Levels

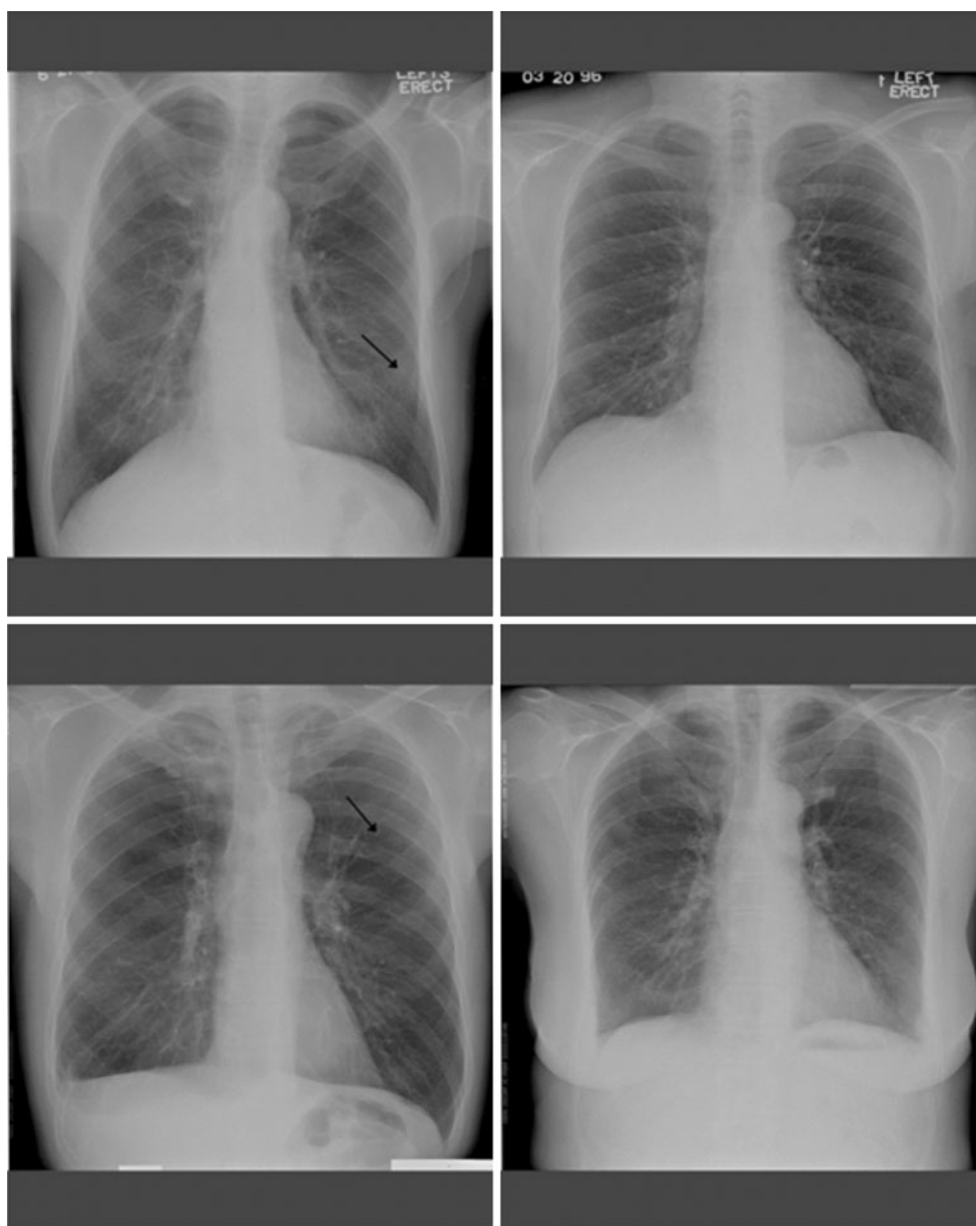
The study was conducted under low ($E=1 \text{ lx}$) and elevated ($E=50 \text{ lx}$) ambient lighting conditions. The elevated ambient lighting level was selected based on two criteria. First, it was important to ensure that the diffusely reflected luminance from the surrounding background (L_s) was near the previously estimated L_{adp} range of typical radiographs displayed on a LCD (approximately $12\text{--}20 \text{ cd/m}^2$) [5, 13, 14]. A reduction of the discrepancy between L_s and L_{adp} levels was expected to moderate pupillary action, and could easily be achieved by increasing ambient lighting to 50–80 lx (based on a measured surrounding background diffuse reflection coefficient (R_s) of 0.24 sr^{-1}) [5]. Second, the specific lighting level (50 lx) was selected because it was sufficiently luminous to perform many tasks that might be required of a radiologist (e.g., viewing charts/reports, answering calls, or interfacing with equipment), while also low enough to limit the deleterious effect of specular reflection on image contrast [7].

Display System

A five-megapixel monochrome LCD (model-GS510, Eizo Nanao Technologies, Cypress, CA, USA) with 10-bit luminance resolution was utilized in the study. The study purposefully employed a five-megapixel pixel display instead of a two- or three-megapixel display that is generally considered sufficient for chest radiography. The reason was to provide sufficient pixel density to display the $2,048 \times 2,048$ image at full resolution while also representing clinical situations when a single display is used to view images of various matrix sizes.

An important aspect of the study was the proper digital imaging and communications in medicine (DICOM) calibration of the display. A previous measurement indicated

Fig. 1 Sample chest radiographs used in the study. Observers were required to identify subtle lung lesions under a dark room condition ($E=1$ lx) and increased ambient lighting level ($E=50$ lx). Two radiographs contain nodules (indicated by *arrows*)



that the display had a diffuse reflection coefficient (R_d) of 0.007 sr^{-1} [5]. Under darkroom conditions, the diffusely reflected luminance (L_{amb}) from the display was nearly negligible; however, under the elevated ambient lighting level (50 lx), the L_{amb} value was 0.35 cd/m^2 . These L_{amb} values were utilized to generate lookup tables that maintained display luminance output levels corresponding to the DICOM GSDF luminance curve under the elevated ambient lighting condition [15]. The additional precaution allowed precise display calibration from a minimum effective luminance (L'_{min}) of 1.10 cd/m^2 to a maximum effective luminance (L'_{max}) of 450.35 cd/m^2 , resulting in an effective luminance ratio (LR') of 409 under both ambient lighting conditions.

Images were displayed with full 10-bit resolution on the LCD using a custom graphical user interface (GUI) designed

specifically for the study. The GUI allowed the radiologists to select suspicious image locations and rate their detection confidence, while also recording the time required for the radiologist to perform these actions. A mouse was utilized to select the suspicious locations and advance the images, while a keyboard was used for numerical input of detection confidence levels. To avoid artificially altering the luminance of the radiographic image, only a small selection box and numerical digits representing confidence levels were displayed after selection of a potential nodule.

Observer Study

The 100 chest radiographs were read by four chest radiologists with an average of 12.5 years of reading experience (10, 11,

15, and 14 years, including residency and fellowship training). Each radiologist attended reading sessions under a darkroom condition ($E=1$ lx) and a moderately elevated ($E=50$ lx) ambient lighting level. The ambient lighting level of the initial reading session was alternated among radiologists. As an additional precaution to minimize recall bias, all repeat reading sessions were separated by two weeks or more.

Each reading session was conducted in the same viewing room and in a single sitting. Care was taken to ensure that the room lighting did not directly illuminate the display. Before beginning a session, each radiologist participated in a training exercise. The exercise utilized ten images of a similar quality and appearance as those used in the study, and was designed to familiarize the observers with the GUI software. After completing this training, the radiologists were informed that many of the images they would view were normal, while many contained a very subtle, solitary nodule. The radiologists were asked to identify, if present, the location of the most likely nodule within each randomly displayed image and to rate their detection confidence on a 1–100 scale (1=no nodule present, 100=a nodule most certainly present). If no abnormal nodules were identified, the radiologist was instructed to rate the radiograph as normal. Although radiologists were not informed, the selection times were recorded. Total observing time for each session was approximately 45–60 min.

Performance Evaluation

Four basic decision categories (true positive fraction, false positive fraction, true negative fraction, and false negative fraction) were determined for each radiologist under both lighting levels. Selection of an image location, if a nodule was present in the image, was considered a true positive image identification. To compare the detection performance of the radiologists, a receiver operating characteristic (ROC) curve analysis based on the multiple reader multiple case (MRMC) method developed by Dorfman, Berbaum, and Metz and implemented in the software DBM MRMC 2.2 was used [16–22]. The analysis considered readers as fixed effects and the cases as random effects.

The times required for a radiologist to either select a potential nodule or to decide that no nodule was present were also recorded and compared based upon the corresponding decision category and ambient lighting level. A two-tailed paired *t* test was used to compare the differences between radiologist selection times under both ambient lighting levels. A selection time difference with a *p* value <0.05 was considered statistically significant. The statistical analysis was performed with standard software packages [23, 24].

Results

Average radiologist area under ROC curve (AUC) values did not significantly differ ($p>0.05$) between ambient lighting at 1 lx and at 50 lx (estimated mean difference=-0.03; 95% CI on difference in mean AUCs, (-0.08, 0.03); Table 1). Individual radiologist performance differences were not statistically significant ($p>0.05$), but no radiologist performed better under increased ambient lighting. The average radiologist ROC curves were visually similar for both lighting levels (Fig. 2). Although differences were minor, at the higher sensitivity zone of the ROC radiologist sensitivity was improved under increased illuminance, while at the higher specificity zone, sensitivity decreased.

Although no selection time differences were statistically significant, average radiologist selection times generally decreased under the elevated ambient lighting condition (Fig. 3). The selection times for every decision category remained constant or decreased with elevated illuminance for three of the radiologists. Radiologist 2, however, was slower when making true negative and false negative selections. Overall average selection times decreased for all decision categories. The most considerable time decrease, approximately 9 s, was associated with a false positive selection. Additionally, the average true positive selection time decreased by approximately 5.3 s, while true negative and false negative selection times stayed approximately constant, only decreasing by 0.3 and 1.8 s, respectively. Summing all decision categories (i.e., true positive, false positive, true negative, and false negative), the total selection

Table 1 Average observer AUC values at low and elevated ambient lighting levels

Radiologist	Ambient light level		Difference (50–1 lx)	Standard Error	95% Confidence interval	
	1 lx	50 lx				
1	0.606	0.585	-0.021	0.060	-0.141	0.099
2	0.665	0.634	-0.031	0.044	-0.118	0.057
3	0.563	0.552	-0.010	0.047	-0.104	0.083
4	0.597	0.553	-0.044	0.053	-0.150	0.062
Average	0.608	0.581	-0.027	0.028	-0.0813	0.028

Observers 1 and 4 initially read under low ambient lighting ($E=1$ lx), while observers 2 and 3 first read under increased lighting ($E=50$ lx)

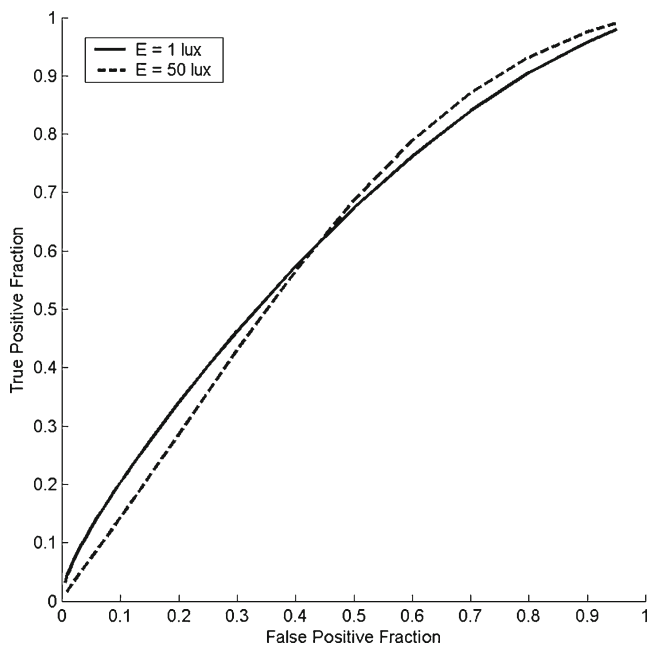


Fig. 2 Average observer ROC curves at low (*solid line*) and elevated (*dashed line*) ambient lighting levels. Curves created with ROCKIT 0.9B for illustrative purposes

time declined from approximately 51.9 ± 9.4 min to 44.7 ± 11.7 min with elevated illuminance.

Discussion

Image contrast is an especially important aspect of radiograph interpretation. Attributes of both the display system and the reading room environment directly affect perceived image contrast. While precisely defined display output expectations and rigorous quality control through TG-18 have led to maximized contrast performance [7, 15], the role of ambient lighting has not been thoroughly elucidated. The importance of ambient lighting should not be underestimated, however, as it is known to directly influence visual adaptation, diagnostic quality, and efficiency. This study was designed to develop a greater understanding of the effect of ambient lighting on the detection performance and interpretation throughput of chest radiologists when reading radiographs on a DICOM-calibrated medical-grade LCD.

The results provide evidence that chest radiologist performance will not be adversely affected by a controlled increase of ambient lighting. Although average radiologist detection performance for solitary pulmonary nodules declined slightly under increased ambient lighting, the decline was statistically insignificant and of the same order of magnitude of interobserver variability. Additionally, nodule detection time showed a considerable, but statistically insignificant, decrease.

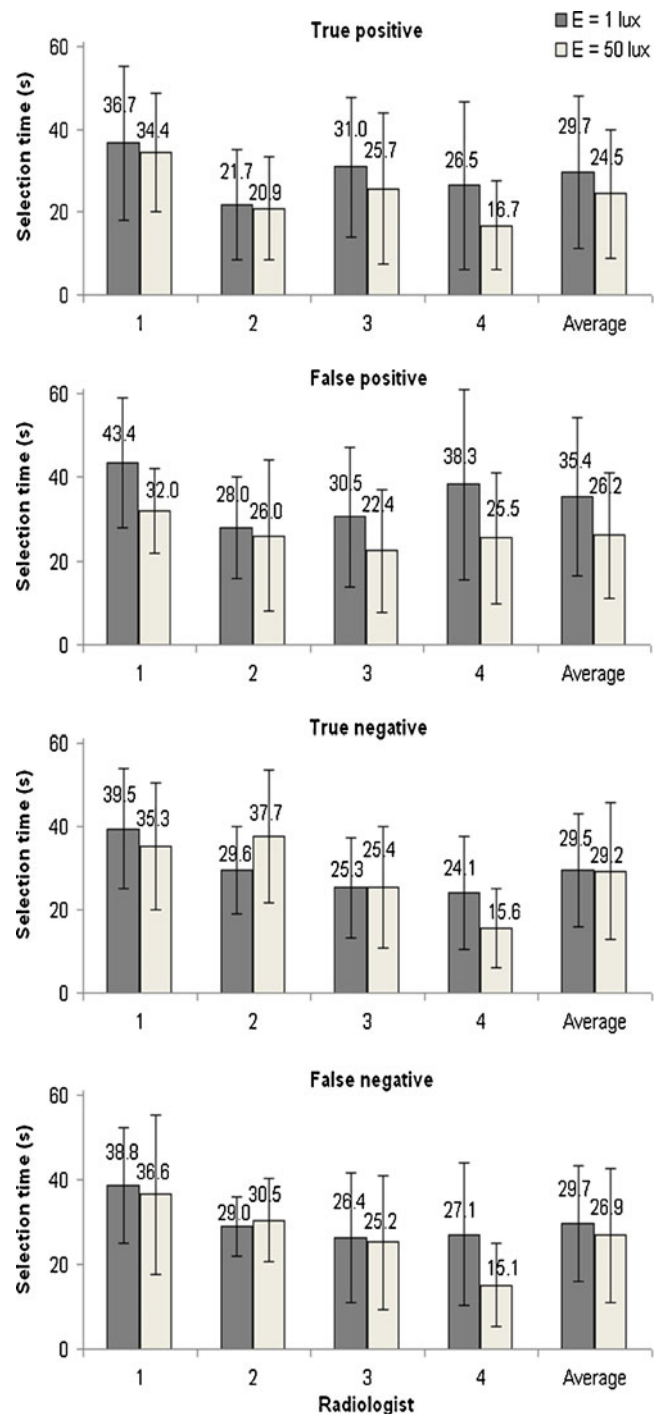


Fig. 3 Observer average selection times based on decision category. Observers 1 and 4 initially read under low ambient lighting ($E=1$ lx), while observers 2 and 3 first read under increased ambient lighting ($E=50$ lx). The average represents the pooled average

As might be expected, most radiologists were slightly more cautious in the identification of potential nodules under increased ambient lighting. Three of the four radiologists identified fewer possible nodules under elevated ambient lighting. The increased discretion was likely due to the difference

between the elevated lighting condition and the more subdued lighting condition used by the radiologists in his/her usual working environment. Although accustomed to reading under low illuminance, the only radiologist (2) who did not follow this trend had previous reading experience under a similar elevated ambient lighting condition.

To our knowledge these are the first reported results assessing the effect of moderately elevated ambient lighting on the interpretation of chest radiographs viewed on a LCD display. The study results, however, support and advance findings from previous studies that suggested an increase of ambient lighting will not degrade detection performance. Several studies using both simulated images and clinical radiographs have shown that moderate levels of ambient lighting (40–50 lx) should not degrade, and may improve, observer detection performance [5, 8, 9, 25]. In contrast to the current study, however, the previous studies utilized observers who either had no radiology reading experience or were accustomed to reading images under elevated ambient lighting levels. This difference in observer background may explain the lack of detection performance improvement seen in the current study, while providing evidence that radiologist experience and preference should be taken into consideration before altering reading room ambient lighting levels.

Although the results suggest observer performance differences were minor and statistically insignificant, some study limitations were evident. One limitation was the recall bias inherent to viewing images more than once. Although this bias can be seen in some individual observer results, the effect on average performance was moderated by alternating the ambient lighting level of the initial reading sessions. Additionally, the bias effect was reduced through the randomization of the radiograph display order and the separation of reading sessions by at least 14 days. A second limitation was that the study examined only radiologist detection of solitary pulmonary nodules. Although nodule detection is an extremely important aspect of chest radiology, many different detection tasks exist that may be influenced by ambient lighting (e.g., detection of interstitial lung disease or pneumothoraces). Finally, only four experienced radiologists participated in the study, thereby limiting the conclusions of the work.

Conclusion

Although sample size was limited, study findings suggest that a controlled increase of ambient lighting within darkly lit chest radiology reading rooms, to a level more suitable for common radiological tasks, will not significantly degrade nodule detection performance. It is important to realize, however, that these findings are based on the

performance of four experienced radiologists, and apply only when a DICOM-calibrated, medical-grade LCD is utilized. Although further research is advised, these results build upon previous studies and provide evidence in support of an ambient lighting increase in chest radiology reading rooms of up to 50 lx.

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