Radiography 31 (2025) 131–136

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

The impact of technical and environmental conditions on the quality assessment in mammography

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ARTICLE INFO

Article history:
Received 1 July 2024
Received in revised form
30 September 2024
Accepted 16 October 2024

Keywords:
Quality assessment
Mammography
Environmental conditions
Quality control
Image quality
Breast imaging

ABSTRACT

Introduction: Mammography requires optimal image quality and that should be ensured during quality assurance. This study investigates the impact of environmental conditions and monitor specifications on quality control procedures within image acquisition rooms in breast imaging departments.
Methods: During this study, nine TORMAM test object images acquired under different conditions were evaluated by 16 observers in 12 different environmental conditions (low, medium, and high illumination level, white and grey wall colour and 2 monitors with high and low technical characteristics). Visibility of structures was the key criteria.
Results: The number of visible structures per image was dependent on the different environmental conditions, with large variations observed. The wall colour and the illumination level have a statistically significant effect on the number of visible structures. It was statistically proven that the grey wall colour had a positive effect on the visibility of low contrast detail discs.
Conclusion: Low ambient light, with a grey wall colour and monitors with high specification allow greatest structure visibility. On the contrary, white wall colour around the monitor and high ambient light had a negative impact on technical evaluation of the images during quality control procedures.
Implications for practice: Better standardization of the environmental condition is required in acquisition rooms. Specifically, this research points to the benefit of using a low reflectance wall colour and low illumination level around the monitors.

Introduction

Mammography is a technically demanding x-ray examination that requires optimal image quality to help formulate a confident and accurate final diagnosis. The evaluation of the image quality and image interpretation are two distinct tasks. Image interpretation consists of a cognitive process based on the visualization of structures within an image, with a range of factors, such as expertise and fatigue that influence this process.[1] On the other hand, the review of technical image quality relies on a known input and the quality of this process helps ensure that the images are optimal for image interpretation. Both tasks are influenced by monitor display characteristics, illumination levels and the design of reporting and acquisition rooms.[2,3]

Sub-optimal environmental conditions, such as high ambient light levels, reflections from the surface of the walls or other objects in the room, and poorly positioned windows and doors can lead to unwanted reflections on the display surface of monitors.[4,5] According to literature the coefficient of reflection and the direction of the light should be carefully evaluated in acquisition rooms in order to establish the best environment where every monitor can be operated without overly compromising the luminance from the monitor and the contrast threshold.[4] This has the potential to influence both the technical review of image quality and image interpretation.[5]

The specification of monitors used for image interpretation can vary within and between different screening units, although minimum requirements should be met.[5–9] Regulations and guidelines exist on monitor specifications and illumination levels to ensure

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https://doi.org/10.1016/j.radi.2024.10.013

optimal conditions for diagnosis, and these are summarized in Table 1. On the other hand, the viewing conditions for assessment of technical image quality (in the acquisition rooms) are not driven by guidelines and are subject to significant variation.[10]

Monitors with poor technical specifications may (i) prevent the detection of technical problems at the point of care, and (ii) interfere with diagnosis during image interpretation where small or low-density micro calcifications or even larger lesions may be obscured.[3,6,14] Consequently, it can be inferred that the review of technical image quality may also be compromised by poor monitor specification and sub-optimal environmental conditions.

Previous work has identified that monitors in acquisition rooms are typically lower specification.[10] It is important that technical image quality can be confidently assessed at the point of care to avoid a technical recall and maintain a good client and patient experience.

The overall aim of this study is to evaluate the impact of sub-optimal technical and environmental conditions on the technical assessment of image quality in mammography.

Methods

Institutional ethical approval was obtained for this study (HSR1819-122). Test object images were evaluated under different combinations of monitor specification, ambient light, and wall colour. The study operated within a controlled environment such that the impact of the experimental conditions (i.e. monitor specifications, ambient lighting level) can be assessed in isolation of compounding variables (i.e. additional influences on ambient light, such as door, windows and light source position). The controlled environment was created with the use of room dividers around the monitors.

During this experiment, nine different TORMAM phantom images (Fig. 1) were evaluated by 16 participants. The aim for this research was to recruit more than 14 participants for good statistical power.[15] This would help with the generalizability of the results and account for inter-observer variation. All participants were registered radiographers with 2–15 years experience in mammography. Those who agreed to take part received a participant information sheet and signed a consent from; they could withdraw consent at any time during the experiment and the data would not be used. Images were produced with different target/filter combinations (Mo/Mo; Mo/Rh; W/Rh) with automatic exposure control. Different thicknesses of poly-methyl methacrylate (PMMA) (20, 45 and 67 mm) were used to ensure the AECs produced the images with a variation in subject contrast (range of 24–29 kVp and 73–163 mAs) for the human observer task. The images were classified from the highest subject contrast to the lowest according to literature.[16,17]

Table 1
Summary of the regulatory bodies' criteria.

Professional Body/Guidance	Criteria
IPEM[9]	>15 lux ambient light
AAPM[6]	2–10 lux (the use of matt wall paint is recommended) Monitor in acquisition room: 1,2 MP Monitor in reporting room: 3,4–5 MP
EUREF (2006)[11]	<10 lux ambient light Monitor in acquisition room: 3 MP Monitor in reporting room: 5 MP
NHSBSP[12]	Recommends that high levels of ambient light should be avoided Monitor in acquisition room: 1 MP Monitor in reporting room: 5 M
IAEA[5]	20–40 lux, 75–100 lux can be acceptable under conditions Monitor in acquisition room: 3 MP Monitor in reporting room: 5 MP
RCR[8]	15 lux ambient light Monitor in acquisition room: 2 MP Monitor in reporting room: 5 MP
EUREF (2013)[7]	≤20 lux for LCD monitors and ≤10 lux for CRT monitors
ACR[13]	25–50 lux ambient light Monitor in acquisition room: 3 MP Monitor in reporting room: 5 MP

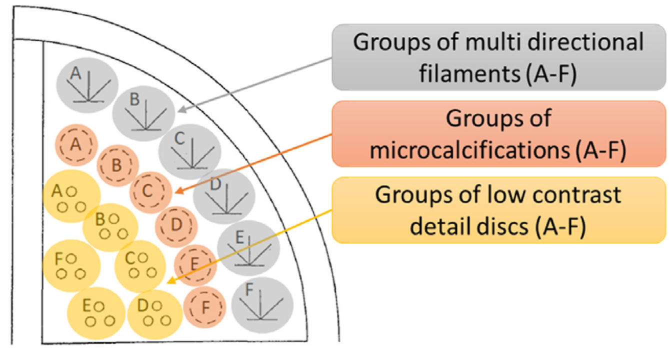

Figure 1. Schematic representation of a TORMAM phantom image. Representation of the different structures within the test object image.

Two monitors were used during this experiment (Table 2). For ease of reference, the two monitors will be labelled according to their technical specifications. The Philips Brilliance C272P4 will be labelled as ‘High specification monitor’ and the NEC MultiSync EA243WM as ‘Low specification monitor’. Ambient light was measured with a Raysafe X2 Lux meter and controlled by a Bluetooth Smart LED Light Bulb.

The ambient light levels (25, 75 and 500 lux) and the different wall colours (white and grey) under investigation, were based on previous work.[10]

The immediate environment around the monitors was isolated with mobile office partitions as a form of experimental control. These room dividers were covered with matt grey or white paper in order to mimic different wall colours identified in a previous survey of acquisition rooms.[10]

During the experiment the participants had to perform a technical image evaluation of the top half of the TORMAM image (Fig. 1) under three different illumination levels (25, 75, 500 lux), with grey (reflectance value 30 %) and white (reflectance value 87 %) wall colours and on both monitors. Each colour has a characteristic reflectance value which is the total quantity of visible light reflected by a surface.[18,19] They were required to identify only the structures they could see in their entirety; (i) all elements of the multi-directional filaments, (ii) the microcalcification clusters, and (ii) all three low contrast objects in each group (Fig. 1). Participants recorded data manually in a data collection sheet.

In total the participants evaluated 9 images under 3 different ambient light levels, 2 different monitors and 2 different wall colours. In total each participant made 108 evaluations. The observations were made without time limit.

Table 2
Monitors within the experimental study and their specifications. Both monitors are reflective of monitors used in mammography departments in clinical environments.

Model	Philips Brilliance C272P4	NEC MultiSync EA243WM
Resolution	2560 × 1440	1920 × 1200
Panel size	27″	24″
Luminance	300 cd/m^2	250 cd/m^2
Contrast ratio	1000:1	1000:1
Pixel pitch	0.23 mm	0.27 mm

Statistical analysis

A two-way repeated measures ANOVA analysis test was performed to evaluate whether the results from the experiment were statistically significant and to determine whether there are any statistically significant differences between the means of independent groups. This statistical test is appropriate for these types of data because the dependent variable (the same group of participants) has been measured repeatedly. Bonferroni multiple-comparison correction was performed to minimize the Type I familywise error due to multiple comparisons. During this correction, the significance level of ‘a’ is divided by the number of performed analyses. For these statistical analysis 6 comparisons were performed and consequently the corrected p-value is 0.008.

The comparison of monitors was performed separately since the main objective was to investigate the impact of environmental conditions (ambient lighting and wall colour).

Results

The results from this experiment revealed that different environmental conditions lead to large variations in the number of visible of structures on the TORMAM images for both monitors (Fig. 2). A white wall colour and the brightest ambient light (500 lux) lead to a statistically significant reduction in the number of structures that were visible. The results of this experiment showed that the different ambient light level is a statistically significant factor ($p < 0.001$) for structure visibility in the TORMAM phantom. Table 3 presents this result.

At the same time, the different wall colour appeared to be statistically significant factor in some structures within the TORMAM images used in the experiment. Table 4 presents this outcome.

Groups of multi directional filaments

The visibility of the multi-directional filaments reduced from group A (highest structure contrast) to group F (lowest structure contrast). All the multi directional filaments in group A were visible to all participants in all nine images. As the inherent contrast reduced, moving through group B to F the number of visible structures reduced among all participants. The image with the most visible structures was the image obtained by Mo/Mo target filter combination and 20 mm PMMA thickness. This image had the highest structure contrast. Statistical analysis of the results from both monitors with high and low specifications indicate that the different ambient light levels ($p < 0.001$) among 25, 75 and 500 lux and the different wall colours ($p < 0.001$) were statistically significant factors for the visualisation of the multi directional filaments.

Less groups of multi directional filaments were visible when the PMMA thickness of the test phantom was increased. The image with the fewest visible structures was obtained with a W/Rh target–filter combination and 67 mm PMMA thickness ($p = 0.208$)

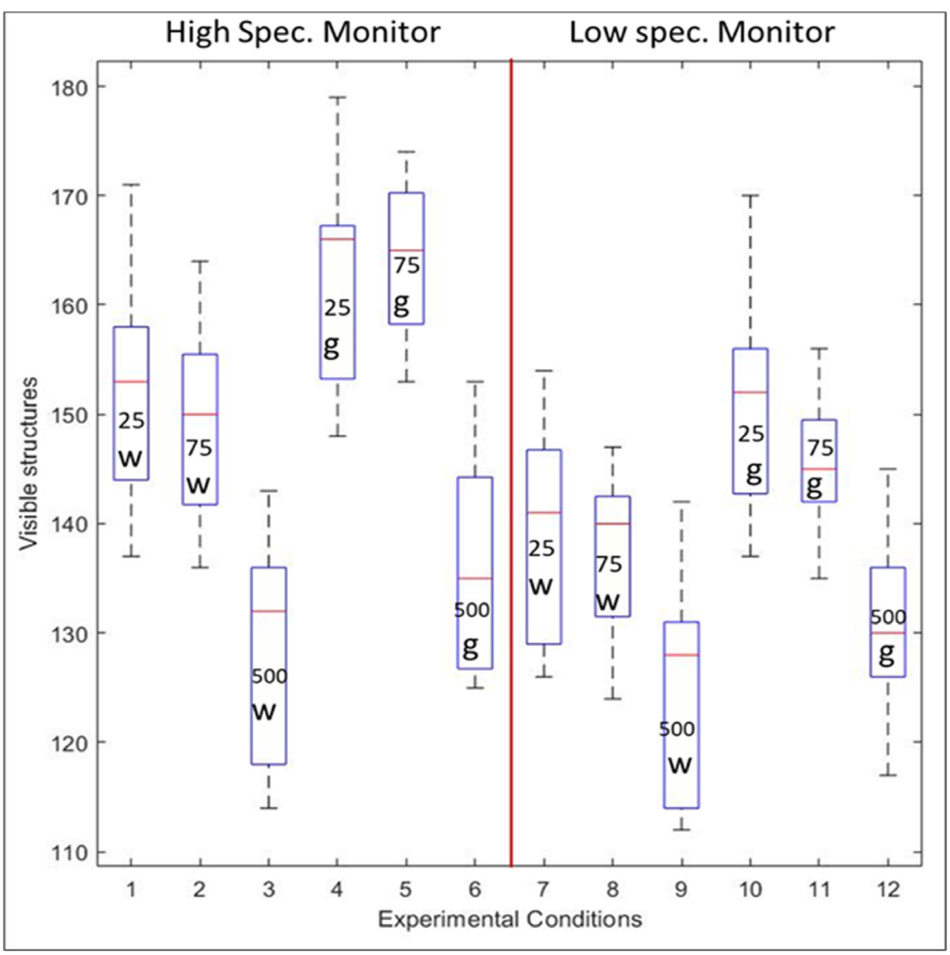

Figure 2. Experimental conditions are shown on the x-axis; for all ambient light levels and wall colours, for each monitor (HRM and LRM specification). The number of all visible structures was fewer at an ambient light of 500 lux compared to both 25 and 75 lux. In addition, structure visibility was better with a grey wall colour at all ambient light levels. Paired comparison between monitors showed better structure visibility on the high specification monitor for all condition. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Classification of the images from the image with the highest subject contrast to the lowest. Description of where the ambient light level was found to be a statistically significant factor for the visibility of structures within each TORMAM image. HRM: High resolution monitor, LRM: Low resolution monitor, + indicates the areas where the statistical analysis showed that the different ambient light level composes a significant factor in terms of visibility of all structures.

Images (Target-Filter, PMMA thickness)	Low contrast discs		Group of Microcalcifications		Group of Filaments	
	HRM	LRM	HRM	LRM	HRM	LRM
Mo–Mo, 20 mm	+	+	+	+	+	+
Mo–Mo, 45 mm	+	+	+		+	+
Mo–Rh, 20 mm	+	+		+	+	+
W–Rh, 20 mm		+	+	+	+	
Mo–Rh, 45 mm	+	+	+	+	+	+
W–Rh, 45 mm						
Mo–Rh, 67 mm	+	+			+	+
Mo–Mo 67 mm	+	+				
W–Rh, 67 mm						

for the different ambient light levels and (p = 0.048) for the different wall colours with the HRM SPEC and (p = 0.509) for the three different ambient light levels around the LRM and a p = 0.061 for the different wall colours for the LRM.

Groups of microcalcifications

The visibility of the groups of microcalcifications reduced from group A (highest structure contrast) to group F (lowest structure contrast). As with the multi-directional filaments, all the groups of microcalcifications were visible to the participants in group A for all nine images. The image with the most visible groups of microcalcifications was the image obtained by Mo/Mo target filter combinations and 20 mm PMMA thickness. The results from the statistical analysis for the High spec. Monitor indicate a p = 0.000 for the different ambient light levels and a p = 0.041 for the different wall colours. Additionally, for the LRM spec. Monitor the statistical analysis presented a p = 0.000 for the three different ambient light levels and a p = 0.007 for the different wall colours.

The image obtained with a W/Rh target–filter combination and 67 mm PMMA thickness has the fewest visible structures; this was expected due to variations in structure contrast. All tables showing the number of observers who highlighted each group of microcalcifications under the twelve conditions of the experiment. The results from the statistical analysis for these structures and the HRM SPEC. monitor indicate a p = 0.109 for the different ambient light levels and a p = 0.038 for the different wall colours. Additionally, for the LRM SPEC. monitor the statistical analysis indicated a p = 0.314 for the three different ambient light levels and a p = 0.003 for the different wall colours.

Groups of low contrast detail discs

When reporting the visibility of the low contrast detail discs the ambient lighting and wall colour has a statistically significant impact, where there was again better visibility with a grey wall colour and low ambient light levels, with similar visibility in each of the different images acquired with different target–filter combinations and thickness of PMMA. For all nine images, similar results were noted. It appeared from the experiment that the participants at 25 and 75 lux managed to highlight more low contrast detail discs rather than when the ambient light was set at 500 lux. The differences were significant between 25 and 500 lux. Although, it seems that the low contrast detail discs in images with Mo/Mo target filter combination, were more visible to the participants. The observers seemed to evaluate more low contrast discs with the images from 20 mm PMMA thickness. An interesting finding is that low contrast discs that were located higher in the TORMAM image (physical position on the monitor) were less visible to the participants. It is unclear if this is due to the position of the light source relative to the monitor and this would need further investigation.

Discussion

This study investigated the impact of different environmental conditions that may be found in breast imaging departments. The study was designed to assess the visibility of different structures in the TORMAM phantom, with the images acquired over a range of target–filter combinations and PMMA thickness to simulate the range of image quality that may be experienced in different breast imaging departments. The results of this study demonstrated a significant impact on structure visibility when there was a high ambient light level and when the environment contained a white wall colour, which has a higher coefficient of reflection than when a grey wall colour provided the background.

The lack of clear guidelines for acquisition rooms leads to a lack of standardization of the environment where the proper image evaluation and object detectability can be decreased significantly. This experiment demonstrated that the white wall colour and the high ambient light level around the monitors had statistically significant negative impact on the test object detectability including the number of multi directional filaments, microcalcifications and low contrast detail discs visualized by the participants.

At a high ambient light level (500 lux), the visibility of different structures was reduced, with a significant difference to the lower ambient light levels (25 and 75 lux). There was a smaller difference in structure visibility between these two lower levels which may suggest that a small degree of variation in ambient light may not be detrimental to the technical review of image quality, so long as the environment is kept consistent. When the wall colour was white rather than grey the structure visibility was also reduced. A potential reason for this difficulty was the increased reflections due to the white wall colour.[18,19]

The reflections pose an important role in eyestrain and have a significant effect on contrast ratio of the display.[5] According to the regulatory bodies summarized in Tables 1, it appears that the acceptable contrast ratio of a monitor should be $\geq$ 250:1 (the ratio of the luminance of the brightest white to the darkest black in an image).[5] At the same time, the reflected luminance from a monitor screen toward the eyes of the observer should be considerably less than 1/250 of the maximum luminance. In this way the contrast ratio of a monitor will not be compromised and the object detectability will not be affected.[5] High illumination levels (>100 lux) are associated with reflections from the faceplate of the monitors.[5,6] These reflections can produce an uniform luminance that decreases the contrast between the displayed image and its

Table 4
Description of where the different wall colour was found to bea statistically significant factor for the visibility of structures within each TORMAM image. HRM: High resolution monitor, LRM: Low resolution monitor, + indicates the areas where the statistical analysis showed that the different wall colour composes a significant factor in terms of visibility of all structures.

Images (Target-Filter, PMMA thickness)	Low contrast discs		Group of Microcalcifications		Group of Filaments	
	HRM	LRM	HRM	LRM	HRM	LRM
Mo–Mo, 20 mm	+			+	+	+
Mo–Mo, 45 mm						+
Mo–Rh, 20 mm						
W–Rh, 20 mm						
Mo–Rh, 45 mm						
W–Rh, 45 mm	+		+		+	+
Mo–Rh, 67 mm					+	
Mo–Mo 67 mm	+				+	
W–Rh, 67 mm	+			+		

background.[22] Patterns of high contrast next to the monitor are common sources of reflected features and indicate improper illumination level and monitor placement in the room.[6]

As a result, it appears that the ambient light within the room and the occurred reflections are factors which can affect the assessment of a mammogram or a test object image. For both monitors, the visibility of the groups of low contrast discs was reduced most by the changing ambient light level and the white wall colour. Visibility decreased significantly when the ambient light was increased from 25 lux to 75 lux and then from 75 lux to 500 lux in both white and grey wall colours. This difficulty on highlighting low contrast structures has parallels to clinical diagnostic tasks, where missing subtle image characteristics can occur due to sub optimal conditions.[5]

The visibility of microcalcifications was least affected by the change in ambient light, and this is most likely because of high contrast of the structure with the background. [(20-2120)] On the other hand, the multi directional filaments and the low density discs are subtle structures[20,21] and low contrast structures and can be difficult to visualise when the conditions are not optimal and the level of reflections is high.[3,5]

The results from this experimental study demonstrated that the target/filter combination appears to be a determining factor for the quality of the formatted image. The results revealed that the combination of the target and the filter has an important role on the visibility of structures in the images.

The contrast of the images was different and relevant to the target filter combination. According to literature the images acquired from Mo/Mo combination have higher contrast in relation to the images acquired with W/Rh.[16] Additionally, the breast equivalent material thickness or phantom thickness contribute to the increase or decrease of the subject contrast of the image. Within the literature we can see that the images with Mo/Mo target filter combination can have the highest contrast. The second-best target filter combination in contrast metrics can be the Mo/Rh. The combination with the lowest contrast was the Rh/Rh.

Consequently, the images of the experimental study could be categorized from the image with the highest to the lowest contrast according to their target filter combination and phantom thickness. In general, the visibility of structures and the number of structures identified by the participants, was consistent with the inherent contrast in the images produced by different target–filter combinations and thickness of PMMA. This gives good validation of the outcomes generated by the participants.

Although not a primary aim of the study, it was an interesting finding that the low contrast discs located in the upper part of the TORMAM image (appearing higher on the display screen of the monitor) were less visible to the participants. This may have been caused by the direction and the position of the light source that was used to control the ambient light in the room, as this was positioned above the monitor. This could have a potential clinical impact, considering the fact that a microcalcification or a mass in that area of the image (position on the monitor) may have been missed due to reflections. As such, the position of the light sources in acquisition and reporting rooms should be a consideration in design.

Finally with regards to future work, the position of the light bulbs in several angles relative to the faceplate of the monitor in order to simulate different directions of light source in relation to observer's and monitor's location should be investigated. The misplacement of the monitors can lead to increased reflections that are responsible for loss of image quality and artefacts.[5,6] Although according to the Papathanasiou et al. study, in the majority of the acquisition rooms (24/29) a light bulb was placed above the monitor.[11] As a result, this location was selected in the methodology for this experimental study.

A limitation of this work is related to the lack of assumptions such as normality or homogeneity of variance of the tests used during the statistical analysis.

Conclusion

The choice of wall colour around and the ambient light in acquisition rooms can have a detrimental impact on the technical review of image quality. This seems in part to be due to the influence of screen reflection caused by these environmental variables. This work indicated need for better standardization and optimization of the environment in acquisition rooms, to ensure consistency.

Conflict of interest statement

None.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radi.2024.10.013.

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