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RADIOLOGICAL EDUCATION

The use of lower resolution viewing devices for mammographic interpretation: implications for education and training

Yan Chen [1] · Jonathan J. James [2] · Anne E. Turnbull [3] · Alastair G. Gale [1]

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Abstract
Aims To establish whether lower resolution, lower cost viewing devices have the potential to deliver mammographic interpretation training.
Methods On three occasions over eight months, fourteen consultant radiologists and reporting radiographers read forty challenging digital mammography screening cases on three different displays: a digital mammography workstation, a standard LCD monitor, and a smartphone. Standard image manipulation software was available for use on all three devices. Receiver operating characteristic (ROC) analysis and ANOVA (Analysis of Variance) were used to determine the significance of differences in performance between the viewing devices with/without the application of image manipulation software. The effect of reader's experience was also assessed.
Results Performance was significantly higher ($p<.05$) on the mammography workstation compared to the other two viewing devices. When image manipulation software was applied to images viewed on the standard LCD monitor, performance improved to mirror levels seen on the mammography workstation with no significant difference between the two. Image interpretation on the smartphone was uniformly poor. Film reader experience had no significant effect on performance across all three viewing devices.
Conclusion Lower resolution standard LCD monitors combined with appropriate image manipulation software are capable of displaying mammographic pathology, and are potentially suitable for delivering mammographic interpretation training.
Key points
- *This study investigates potential devices for training in mammography interpretation.*
- *Lower resolution standard LCD monitors are potentially suitable for mammographic interpretation training.*
- *The effect of image manipulation tools on mammography workstation viewing is insignificant.*
- *Reader experience had no significant effect on performance in all viewing devices.*
- *Smart phones are not suitable for displaying mammograms.*

Keywords Mammographic interpretation training · Observer Performance · Tele-radiology · Experimental Investigations · Jackknife free-response ROC (JAFROC)

✉ Yan Chen
y.chen@lboro.ac.uk

[1] PERFORMS, Department of Computer Science, Loughborough University, Loughborough, UK

[2] Nottingham Breast Institute, Nottingham City Hospital, Nottingham City, UK

[3] Breast Unit, Royal Derby Hospital, Derby, UK

Introduction

Digital radiological images can potentially be viewed on a wide range of devices from high-resolution workstations available in a radiology department to much lower resolution handheld computers or smartphones [1–5]. Interpreting digital mammograms has always challenged the available technology. Digital mammograms typically have matrix sizes in excess of 4800×6400 pixels compared to a CT image where the resolution of a single slice would typically be 512×512 pixels. The ability to perceive mammographic details is a function of screen resolution, contrast ratio, and grey scale depth.

High-resolution dual monitor PACS workstations with 5 megapixel resolution and 12-bit grey scale display approved for mammographic interpretation are expensive and so availability in many departments is limited. The NHS Breast Screening Programme performs mammograms on more than 2 million women annually with all the mammograms double reported by two mammographic image readers [6]. Delivery of high quality training and education to the next generation is crucial to maintain the quality of the programme. Continuing education is also important to maintain skills. The availability and cost of high-resolution workstations has implications for delivering film reader training and education [7].

Lower resolution monitors such as a standard office PC monitor or handheld computing devices are significantly cheaper and widely available. Little is known about the adequacy of lower resolution viewing devices in delivering teaching and training of mammographic interpretation. The aims of this study were to see, if by combining less sophisticated viewers with appropriate image manipulation software such as zoom, pan, and window level/width adjustment, mammographic interpretation was at all possible, and to compare performance with a standard high-resolution PACS workstation approved for mammographic reporting. Being able to perceive mammographic details suitably on a monitor is a function of screen resolution, its contrast ratio, and appropriate grey scale depth. Mammographic displays typically have a 5 megapixel resolution, high contrast ratio, and 12-bit grey scale displays.

Materials and methods

Fourteen consultant radiologists and reporting radiographers from two breast screening centres in the UK took part in this study. There were nine consultant radiologists and five reporting radiographers, with experience in film reading ranging from 6 – 19 years (M=10.6 years; Mdn=9 years). Both screening centres had used digital mammography equipment for at least seven years and all participants had experience of soft copy reporting.

Forty challenging digital mammography screening cases were selected by an experienced breast radiologist. Each case included both the medio-lateral oblique [MLO] and the cranio-caudal [CC] projections for each breast. There were 22 malignant and 18 normal cases. The malignant cases include examples of masses lesions, microcalcifications, and architectural distortions confirmed by biopsy. All images were available as DICOM files.

Three viewing devices were investigated (Fig. 1). The first was a digital mammography workstation (with 5 megapixel dual monitors; resolution 2048×2560 pixels each) (GE Medical). The second was a standard (1.8 megapixel) LCD monitor (screen size 21.5”, resolution: 1050×1680 pixels), with the images displayed by means of a DICOM viewer running on a laptop. The third device was an iPhone 3 (Apple Inc.) (screen size 3.5”, resolution: 480×320 pixels) chosen as an example of a low-resolution handheld device; images were displayed using Osirix DICOM viewing software. The image files shown on each modality were identical. The experiment was carried out in darkened radiological reporting rooms with controlled ambient lighting levels of approximately 22 lux. The equipment used, room set up, and lighting levels were identical in the two centres.

Over an eight-month period each participant viewed all 40 cases on each of the three devices. There was a gap of at least two months between the read on each of the three devices. At each read the 40 cases were divided into two sets. The number of normal and abnormal cases, the type of mammographic feature, and the degree of difficulty of each set was judged to be equivalent by the experienced radiologist who selected the cases for the study. One set of 20 cases was viewed with access to image manipulation software (zoom, pan, and window width/level adjustment) and one set of 20 cases was viewed without image manipulation tools. The order of viewing the two image sets and the order of viewing conditions were counter balanced across all 14 participants using a Latin Square Design. Each case was first presented as two MLO views followed by two CC views reflecting a standard hanging protocol. On the mammography workstation and standard LCD monitor, the images filled the displays. On the iPhone small ‘thumb nails’ had to be tapped for the relevant images to have a large display. Application of the image manipulation software was by a dedicated workstation key pad (GE Medical) for the mammography workstation and a ‘mouse’ for the LCD monitor. Image manipulation interaction of the iPhone was via the touch sensitive screen with two fingers required to zoom and a single finger used to pan and adjust window settings. For the standard LCD monitor and iPhone reads, participants first practised using the relevant DICOM viewing software.

For each case, the participant classified the case, using a six-point scale of normal, benign, probably benign, indeterminate, probably malignant, or malignant. The location of any mammographic feature (mass, microcalcifications, or architecture distortion) was recorded on a paper proforma, and the participants were asked to rate their confidence that the abnormality was present.

The results were analysed according to the viewing device used and whether image manipulation tools were applied. The effect of reader experience was also considered; the performance of participants with more than ten years film reading experience was compared to those with less than ten years of experience. Participants' overall performance data were firstly examined by performing a JAFROC analysis for each individual [8, 9]. ANOVA and Bonferroni post hoc tests were used to determine the significance of any differences between

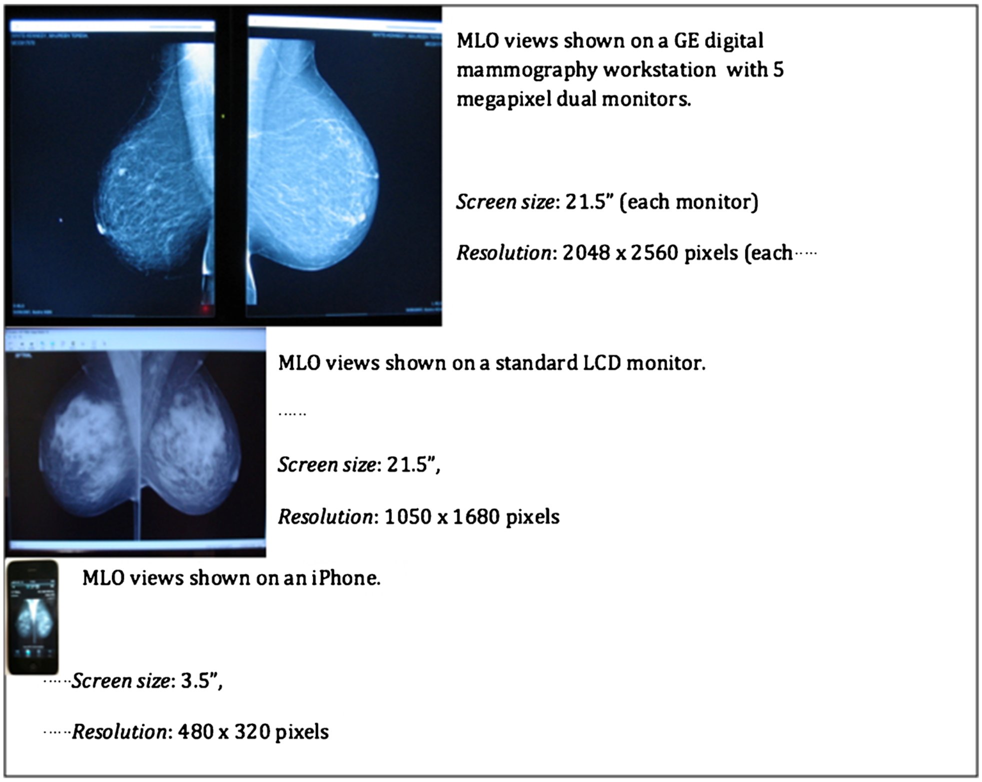

Fig. 1 Illustration of the relative sizes of the three viewing devices

the groups analysed with a *p* value of <0.05 considered significant.

The study was deemed to be audited by the chair of the local NHS ethics committee and so Central Office for Research and Ethics Committees (COREC) approval was not required.

Results

The viewing device used and the application of image manipulation software had a significant effect on film reader performance ($F(2,20)=27.489$, $r=0.76$, $p<0.001$). Figure 2 shows the overall performance across all three viewing devices. Performance was significantly higher ($p<0.05$) on the mammography workstation compared to the standard LCD monitor, and the performance on both was significantly higher than on the iPhone ($p<0.05$). Figure 3 shows the performance on all three viewing devices with and without the application of image manipulation software. On the mammography workstation the application of image manipulation software had no significant effect on performance, in fact there was a small decrease in performance when image manipulation software was used, although this did not reach statistical significance ($p>0.05$). When image manipulation software was applied to images viewed on the standard LCD monitor, then performance improved to mirror levels seen on the mammography workstation with no significant difference ($p>0.05$) demonstrated between the two. Image manipulation software improved performance on the iPhone, although performance remained significantly lower than on the mammography workstation and standard LCD monitor ($p<0.05$).

Figure 4 shows the effect of participants' experience on performance. For the purpose of analysis, the participants were divided into two groups – those with less than 10 years experience in mammographic interpretation ($M=6.5$ years; $Mdn=7$ years) and those with more than ten years ($M=14.5$ years; $Mdn=12$ years). There was a trend for the more experienced group of readers to perform better on all three viewing devices, although this did not reach statistical significance. Figure 4 also demonstrates the significantly poorer performance of both groups on the iPhone compared to the other viewing devices ($p<0.05$).

Discussion

Delivering training in mammography interpretation in a filmless digital department presents a challenge to those who provide education to radiologists and reporting radiographers. Mammography interpretation in a clinical setting necessitates the use of high-resolution workstations. A PACS workstation approved for mammography would typically be dual screen with each having a resolution of 2048×2560 pixels (5 megapixels). A standard PACS workstation has a 3 megapixel display (1536×2048 pixels), and it has been suggested that

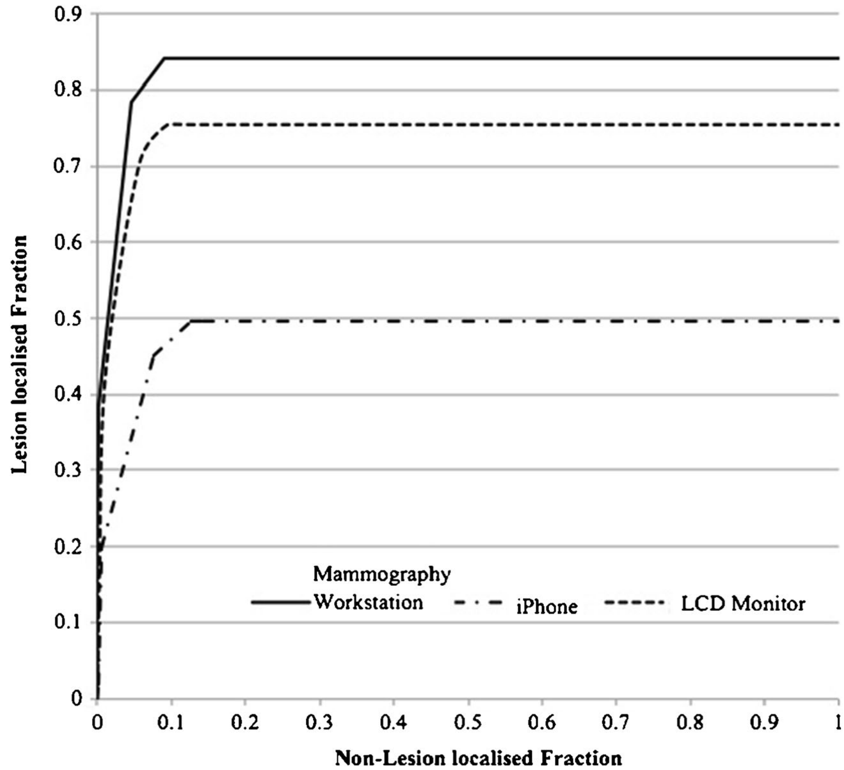

Fig. 2 Overall performance across all 40 cases for the mammography workstation, standard LCD monitor, and iPhone

comparable performance can be achieved when mammograms are viewed on these lower resolution workstations [10]. PACS workstations are expensive, so numbers are limited and are heavily utilised for clinical work with little spare capacity for teaching and training. Lower resolution handheld devices have been used successfully to interpret

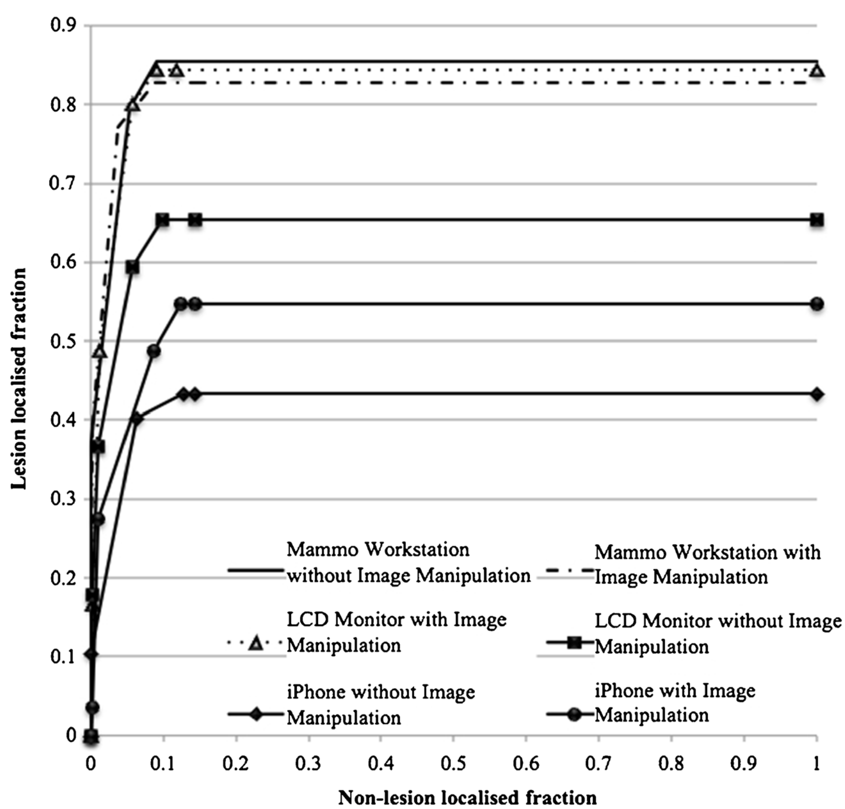

Fig. 3 The effect of the application of image manipulation software on performance on the mammography workstation, standard LCD monitor, and iPhone

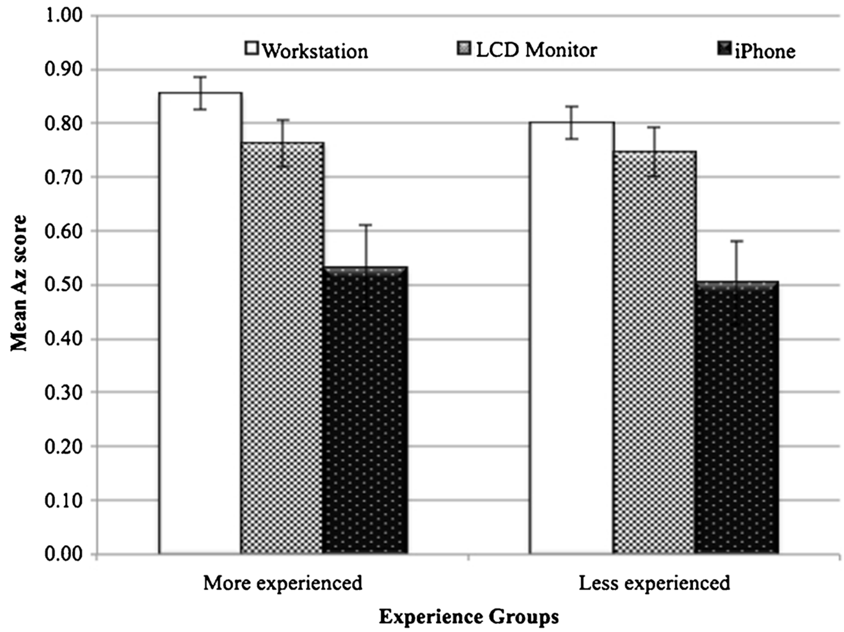

Fig. 4 The effect of participants' film reading experience on performance on each viewing device

low-resolution CT images [1–5], but little is known about the adequacy of lower resolution viewing devices below 3 megapixels for mammographic interpretation. The LCD monitor used here had a 1.8 megapixel display (1050×1680 pixels) and the iPhone had a 0.15 megapixel display (480×320 pixels).

In this study, the high-resolution mammography workstation performed the best of all three viewing devices. It is unsurprising that overall performance on the mammography workstation was very high as participants were essentially reporting as they would do in clinical practice. When the lower resolution (1.8 megapixels) LCD monitor was used, there was no significant difference in performance as long as the image manipulation software was used to aid interpretation. This implies that the pathological features on the mammogram can be perceived as long as the reader is able to magnify the image to an appropriate level using a pan/zoom function. This suggests that using a standard LCD monitor with appropriate image manipulation software could be a useful tool for training and education purposes.

Delivering training to groups rather than individuals is widely used and cost effective. Classroom based teaching using lower resolution monitors, like the standard LCD monitor in this study, is commonly used for the interpretation of lower resolution examinations such as radiographs, CT, and MRI studies. Group education may also involve projecting images, but subtle mammographic abnormalities such as microcalcifications, distortions, and small mass lesions can be difficult to perceive. Informal feedback from mammography training courses suggests that attendees would like to be able to view images themselves on workstations as part of the training process [7]. Centres involved in mammographic interpretation training have to balance the problems of delivering high quality training with the availability of high- resolution mammography approved workstations, which is a particular issue in the setting of group or classroom based teaching. Using lower resolution standard LCD monitors with image manipulation software may provide a cost effective and pertinent solution.

Adequate image manipulation software is crucial to successful image interpretation when the lower resolution (1.8 megapixels) standard LCD monitor is used. The use of image manipulation software on the mammography workstation with a 5 megapixel display had no significant effect on performance, and, in fact, there was a slight trend for performance to decrease when image manipulation was used. It may be that when images are already displayed at optimal resolution on a mammography workstation, the use of image manipulation software becomes a distraction, potentially impacting adversely on reader performance. The use of image manipulation software has the potential to increase the interpretation time, increasing fatigue, and so adversely affecting performance. It is a limitation of our study that interpretation time was not measured, and, thus, further work in this area is needed.

There has been interest in utilising even lower resolution handheld devices in radiology. The iPhone is representative of a growing number of handheld devices. In the past, the focus has been on using these devices to increase the efficiency of workflow and improve communication rather than supporting image interpretation [11, 12]. In some recent studies, lower resolution handhold devices have been successfully shown to support the interpretation of CT brain images, whose small physical size and resolution is adequately handled by these lower resolution screens [3]. Here the performance on the iPhone using the Osirix software was uniformly poor. Clearly there is a screen resolution below which mammography interpretation is no longer possible even with appropriate image manipulation software, as zooming can 'pixelate' the image without enhancing the quality of the information displayed.

The performance of one participant on the iPhone was particularly interesting as they correctly identified all the small microcalcification clusters on the iPhone image. This suggests that the pan/zoom function implemented in the Osirix software on the iPhone was capable of displaying many of the small mammographic features. However, it is very hard for a reader to ensure that the whole image has been completely viewed when panning and zooming on such a small display. Poor performance on the lowest resolution screen probably relates to a combination of factors with participants not being able to navigate appropriately around the zoomed image to ensure that all parts of the image have been properly assessed as well as the 'pixilation' phenomenon making subtle features uninterpretable.

As one might expect, there was a trend for the more experienced readers to perform better on all three viewing devices. Reassuringly from a training perspective, there was no suggestion that less experienced readers were more likely to be at great disadvantage to their more experienced colleagues when reporting from the lower resolution viewing devices. However, the least experienced reader in this study already had six years of experience, so more work is needed with novice readers.

For clinical work, dedicated high-resolution mammography workstations are crucial to accurate mammography interpretation. There is a screen resolution below which accurate mammography is not possible, but this study suggests that lower resolution (1.8 megapixel) standard LCD monitors when combined with appropriate image manipulation software are capable of displaying mammographic pathology, suggesting that these cheaper more widely available viewers are suitable for delivering mammographic interpretation training.

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No study subjects or cohorts have been previously reported. Methodology: prospective, experimental, multicenter study.

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