

## Full paper

### **Blurred digital mammography images: an analysis of technical recall and observer detection performance**

#### **Abstract**

5 Background: Blurred images in Full Field Digital Mammography (FFDM) are a problem in the UK Breast Screening Programme. Technical recalls may be due to blurring not being seen on lower resolution monitors used for review.

Objectives: This study assesses the visual detection of blurring on a 2.3 megapixel (MP) monitor and a 5 MP report grade monitor and proposes an observer standard for the visual detection of  
10 blurring on a 5 MP reporting grade monitor.

Method: Twenty-eight observers assessed 120 images for blurring; 20 had no blurring present whilst 100 had blurring imposed through mathematical simulation at 0.2, 0.4, 0.6, 0.8 and 1.0 mm levels of motion. Technical recall rate for both monitors and angular size at each level of motion were calculated. Chi-squared ( $X^2$ ) tests were used to test whether significant differences  
15 in blurring detection existed between 2.3 and 5 MP monitors.

Results: The technical recall rate for 2.3 and 5 MP monitors are 20.3 % and 9.1% respectively. Angular size for 0.2 to 1 mm motion varied from 55 to 275 arc seconds. The minimum amount of motion for visual detection of blurring in this study is 0.4 mm. For 0.2 mm simulated motion, there was no significant difference  $X^2 (1, N=1095) = 1.61, p=0.20$  in blurring detection between  
20 the 2.3 and 5 MP monitors.

Conclusion: According to this study monitors equal or below 2.3 MP are not suitable for technical review of FFDM images for the detection of blur.

Advances in knowledge: This research proposes the first observer standard for the visual  
25 detection of blurring.

Key words: Simulated motion; technical recall; monitor resolution; observer standard; blurring  
detection

## 1. Introduction

Image blurring due to motion unsharpness in full field digital mammography (FFDM) is a widely  
30 recognized problem in the UK and various explanations exist about how it occurs [1, 2]. One  
explanation is breast/paddle movement whilst the exposure is being made [1-4]. Other factors  
such as inadequate compression and patient movement together with long exposures may also  
cause blurring [5].

Blurring has the potential to increase false negative results as it may obscure small or low-  
35 density microcalcification cancers and larger lesions particularly in dense breast tissue. Technical  
repeat due to blurring increases client radiation dose, overall examination time and can raise  
client anxiety. Technical recall is necessary if blurring is not seen at the attendance time and it  
could add further to client and family anxiety [6], as unlike a technical repeat taken at the time of  
the initial examination the woman will have to wait several days for repeat imaging.

40 Little has been published about blurred mammography images. In 2000 Seddon et al. reported  
that over 90 % of their screening mammogram technical recalls were due to blurred images [5].  
More recently blurred images were found to be a major source of technical recall in Manchester,  
UK [7]. In an unpublished audit in one of our breast screening units we found that 0.86 % (40

out of 4650 FFDM examinations) of clients were recalled due to image blur; this contributed  
45 almost one third (29 %) of the 3 % maximum permissible recall rate in the National Health  
Breast Screening Programme (NHSBSP) [8]. For some of these images the blurring could only  
be detected when they were displayed on 5 MP reporting grade monitors at the time of reporting.  
In many instances blurring was missed when the images were checked for technical accuracy at  
the time of imaging. We believe this discrepancy could be due to the lower quality non-  
50 diagnostic quality monitors used in clinical rooms coupled with variable and also generally  
brighter ambient lighting when compared to reporting rooms. Interestingly, a good deal of  
research emphasis has been placed on the evaluation of reporting grade monitors and the  
environment in which they sit [9-11], but surprisingly little has been placed on the evaluation of  
technical review monitors used within mammography imaging rooms or X-ray imaging rooms  
55 generally. In the context of breast screening, only one study in 2016 by Kinnear and Mercer [12]  
was found which reported the ability of observers to visually detect image blurring in FFDM  
images on 5 MP and 1 MP monitors; the lower resolution monitor resulted in a lower visual  
detection rate for blurred images. Kinnear and Mercer's study represents an important first step  
and our study builds on this in various ways. First, our study has a much larger group of  
60 observers thereby enabling inter observer differences to be considered; second, simulation of  
blurring is used in which the exact amount of blurring is known; third, image selection went  
through a rigorous and carefully documented evidence-based approach; finally, the images were  
displayed in a room where the ambient lighting was controlled and standardized.

Aside monitor resolution, it is possible that observer ability to visually identify blur will also  
65 affect technical recall rates. Currently no performance data exists on observer ability to detect  
blur. However, early work by Ma et al [3] suggested that 0.4 mm of simulated blur can be

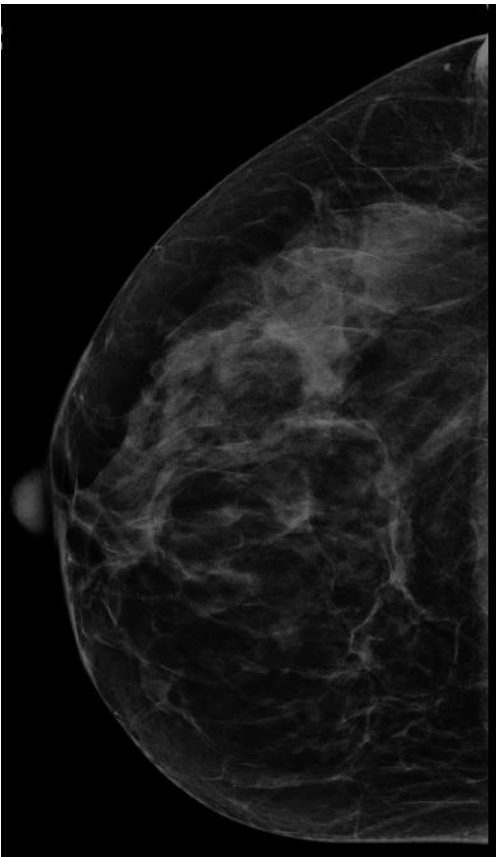
visually detected on 5 MP reporting grade monitors. Limitations of Ma et al's study relates to the low number of observers used and the observers being experienced image readers who are not representative of the practitioners who undertake mammography imaging.

70 Our study has two aims: to investigate whether there is a difference in the visual detection of blurring between a 2.3 MP technical review monitor and a 5 MP reporting grade monitor; to propose an observer standard for the visual detection of blurring on reporting grade 5 MP monitors.

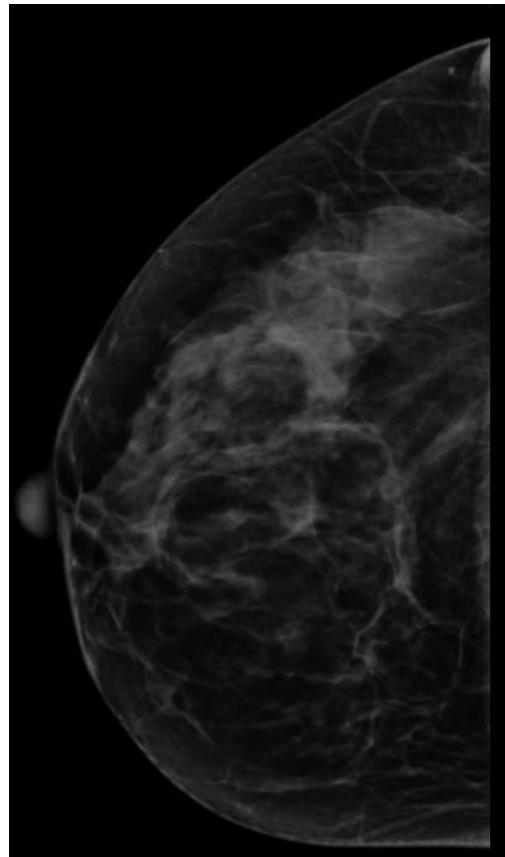
## **2. Materials and methods**

75 Mammography images were acquired in 2014 on a Selenia Dimensions FFDM unit (Hologic®, Bedford, MA) which has a 24 cm x 29 cm amorphous silicon (a-Si) thin-film transistor (TFT) image receptor with 70 micron pixel size and spatial resolution of 7.1 lp/mm [13] within the UK Breast Screening Programme. Two experienced image readers independently reviewed a number of images using published quality criteria [14] to identify twenty normal and artifact free FFDM  
80 images. These comprised of craniocaudal (CC) and mediolateral oblique (MLO) images. Mathematical simulation software [3] with a soft-edge mask was used to simulate the effect of motion in the 20 images. Soft-edge mask simulates motion by applying a mathematical algorithm known as convolution function based on a Gaussian distributed pixel under simulated motion [15, 16]. Motion blurring was added to the images by accumulating the pixel intensity of randomized  
85 microsteps within 1.5mm motion boundary [3]. The soft-edge mask method was chosen because it best represents the physical process that caused the blurring effect.

90 Simulated blurring was imposed to the 20 artifact free FFDM images from 0.2 to 1.0 mm at 0.2 mm increments. 120 images were available for use - 100 with five levels of simulated motion and 20 with no blur. Figures 1 and 2 show examples of FFDM images with and without simulated blur imposed.



*Figure 1: FFDM image with no blur*



*Figure 2: FFDM image with 1 mm simulated blur*

95 The 120 images were de-identified, randomized and displayed at full screen size on a 24 inch 2.3 MP monitor (NEC, Multisync 243wm) with 0.27 mm pixel pitch and 1920 x 1200 display resolution; and a 21.3 inch 5 MP monitor (NDS, Dome E5) with 0.17 mm pixel pitch and 2560 x 2048 display resolution. Both monitors were calibrated to the DICOM Grayscale Standard

Display Function [17]. Dimmed ambient lighting (less than 10 lux) was used for both monitor  
100 viewing sessions, being consistent with that employed in normal image reading conditions [14].  
Images were displayed using MediViewer (Schaeff Systemtechnik, Petersaurach, Germany). No  
interpolation method was used to map image pixels onto the display pixels. Observers were  
blinded to the type of monitor used as both monitors have similar dimensions and appearance;  
and information about the monitor was not displayed anywhere. Images were viewed on a  
105 blinded basis by 28 observers without knowing the amount of blurring. Window width and level  
was set to values agreed by consensus between two experienced FFDM image readers prior to  
the observers commencing the study; width and levels were set to give image appearances  
similar to those seen in routine practice.

In clinical practice distance between the monitor and observer's eye is not standardized or  
110 controlled. This is because observers constantly change the distance between their eye and the  
monitor when viewing images. Our study allows this variation of distance to be preserved by  
positioning the chair such that observers' eye to monitor distance would not exceed 75 cm. A  
viewing distance of 75 cm was chosen because it is within the viewing range (64 to 89 cm)  
which maintains the extraocular muscles in a more relaxed state and minimizes eye strain [18].  
115 However, we did not control or measure the distance from eyes to monitors as this was not the  
focus of our study. Two calculations on angular size will be performed, one at 30 cm and one at  
75 cm, as these are likely to be the extremes of distance that observers might view images.

Angular size is a measurement that describes how large an object appears from a given point of  
view, defining the distance between the two ends of an object. The capacity to identify blurring  
120 depends on the potentialities of the human visual system. To identify the minimum amount of

blurring that can be detected by the observer the angular size for each level of motion was calculated with the equation shown below [19]:

$$\text{Angular size in degree} = 57.3 \times \text{physical size/viewing distance}$$

125 Where physical size is the level of motion in mm.

Twenty-six radiographers qualified in mammography imaging and two radiologists ('observers') from two breast screening centres in the North West of England (UK) were invited to review the 120 images on the 2.3 MP technical review monitor and the 5 MP reporting grade monitor.

130 None of the observers reported visual pathologies and image evaluation was conducted with optical correction if glasses had been prescribed previously. The observers were approached individually and asked if they would be willing to participate; of those that agreed they were provided with written information about the research before conducting it. This study was classified as service evaluation in both breast screening centres; Clinical Audit Department  
135 permission was granted formally on this basis from both hospitals. Anonymity was provided by one coordinating staff member within each centre assigning a unique code to each observer; only the observer and coordinating staff member knew the code. Feedback was given only on an individual basis to each observer. Observers' age varied from 26 to 59 years (mean = 44.5, SD = 8.3 years). Mammography experience varied from 0.4 to 25 years (mean and median experience  
140 was 9.9 years and 10 years respectively, SD = 4.9 years, interquartile range = 7.5 years).

The observers were not permitted to magnify the images or adjust the window width and level. Image manipulation was not permitted due to the need to tightly control the viewing conditions to exclude sources of error [20-22]. If the observers were allowed to manipulate images based on

their personal preferences in display then the study could be comparing the ability of the  
145 observers to manipulate images as well as detect blurring on the two monitors.

For each image the observers had to indicate whether blurring was present or not, this was a  
binary decision (yes = 1, no = 0). As in Mucci et al's study [23], Fleiss' kappa analysis was  
carried out to determine the inter-observer variability [24]. To minimize fatigue, image review  
sessions did not exceed 30 minutes [25] and each monitor took approximately 1 hour to complete,  
150 therefore 4 viewing sessions were required (approximately 2 hours per observer was needed) to  
review the images on the 2.3 and 5 MP monitors. Due to clinical demands, data collection had to  
be conducted over an eight month period. Experimental conditions and observer training for the  
experiments were overseen and controlled/standardized by two members of staff – one in each  
clinical centre. Also, all observers underwent a training exercise to help them identify blurred  
155 and non-blurred images. This exercise was conducted by an experienced image reader using a 5  
MP reporting grade monitor; for this exercise clinical FFDM images were drawn from each of  
the two screening programmes to train the observers. These images contained blurred and non-  
blurred examples.

Blurring detection rate at each level of motion for 2.3 and 5 MP monitors was calculated. The  
160 equation for blurring detection rate (BD) is shown below.

$$BD = N_i/N_b$$

Where  $N_i$  is the number of blurred mammograms identified by the observers;  $N_b$  is the number  
of blurred mammograms.

Chi-squared ( $X^2$ ) test was used to determine whether significant differences in blurring detection  
165 rate existed between the 2.3 and 5 MP monitors. The influence of level of motion, monitor  
resolution, observers' experience and age on blurring detection was modeled in a logistical  
regression model.



Technical recall rate at each level of motion for 2.3 and 5 MP monitors was calculated according to the NHSBSP recommendations [26]. In this study, the number of mammograms required to repeat ( $N_r$ ) was estimated by the number of blurred mammograms missed by the observers ( $N_m$ ) which is equal to the difference between the number of blurred mammograms ( $N_b$ ) and the number of blurred mammograms identified by the observers ( $N_i$ ).

The equation for technical recall rate (TC) is shown below.

$$\begin{aligned}
 \text{TC} &= N_r/N_t \\
 &= N_m/N_t \\
 &= (N_b - N_i)/N_t
 \end{aligned}$$

Where TC is the technical recall rate;  $N_r$  is the number of mammograms required to repeat;  $N_t$  is the total number of mammograms taken;  $N_b$  is the number of blurred mammograms and  $N_i$  is the number of blurred mammograms identified by the observers.

The upper quartile for the blurring detection rate on the 5 MP monitor was calculated to develop the observer standard for the visual detection of blurring. The upper quartile was used to set the minimum standard for blur detection because it represents the highest 25 percent of the data. If the blurring detection rate is at 75th percentile it means 75 percent of the observers would perform the same as or less than this level and 25 percent would perform better than this level.

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### 3. Results

The average blurring detection rate for the 2.3 and 5 MP monitors are shown in Figure 3. All the non-motion images were identified correctly. As can be seen in Figure 3 the blurring detection rate increases with simulated motion and monitor resolution. The 5 MP monitor has a higher average blurring detection rate than the 2.3 MP monitor.

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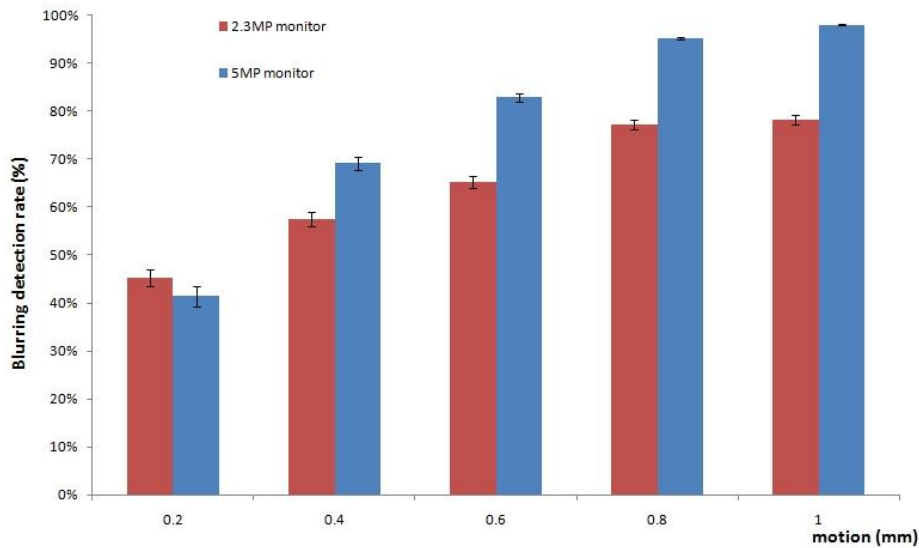


Figure 3. Blurring detection rate against level of motion, the error bars represent the standard errors.

Chi-Squared ( $X^2$ ) test revealed that there was no significant difference in blurring detection between the 2.3 and 5 MP monitors for 0.2 mm motion,  $X^2 (1, N=1095) = 1.61, p=0.20$ ). While there were significant differences in blurring detection between 2.3 and 5 MP monitors for 0.4 mm ( $X^2 (1, N=1095) = 17.50, p<0.001$ ), 0.6 mm ( $X^2 (1, N=1095) = 44.44, p<0.001$ ), 0.8 mm ( $X^2 (1, N=1095) = 75.26, p<0.001$ ) and 1 mm ( $X^2 (1, N=1095) = 108.32, p<0.001$ ) motion.

Fleiss' kappa for 5 MP and 2.3 MP monitors is 0.48 and 0.11 respectively and the mean kappa is 0.26. A kappa of 1 indicates perfect agreement where a kappa of 0 indicates agreement equal to chance [24].

Cohen's d was used to measure the effect size for factors in the logistical regression model. The Cohen's d values for level of motion, monitor resolution, observers' experience and age are 0.38, 0.35, 0.09 and 0.05 respectively. Cohen's d of 0.2 can be consider as "small" effect, around 0.5 as "medium" effect and larger than 0.8 as "large" effect [27].Therefore, the Cohen's d value

indicated that in this study observers' experience and age are not good predictors for blurring  
205 detection.

The angular size for each level of motion for viewing distances of 30 cm and 75 cm is  
summarized in Table 1. As can be seen, the angular size increases with the level of motion and it  
is bigger when the observers are closer to the monitor (30 cm). Individuals with 20/20 vision  
have the ability to recognize a pixel if the angular size is equal or larger than 60 arc seconds.  
210 The angular size for 0.2 mm motion at 75 cm is 55 arc seconds which is smaller than the  
threshold and such a small change cannot be identified by the human eye [27, 28]. With this in  
mind, we propose the minimum amount of motion required for visual detection of blurring in this  
study is 0.4 mm.

The technical recall rates for 2.3 and 5 MP monitors were calculated and summarized in Table 2.  
215 As can be seen in Table 2, the technical recall rate decreased with the level of motion and  
monitor resolution. The technical recall rate for the 2.3 MP monitor varies from 3.6 % to 7.1 %  
and for the 5 MP monitor it varies from 0.3 % to 5.1 %. The 2.3 MP monitor has a higher overall  
technical recall rate (20.3 %) compared to 5MP monitor (9.1 %). For example, at 1 mm motion  
the recall rate for 2.3 and 5 MP monitors are 3.6 % and 0.3 % respectively which means for 1000  
220 clients the number of recall would be 36 and 3 respectively.

The upper quartile for the blurring detection rates on the 5 MP monitor are summarized in Table  
3. The observer standard for the minimum standard of blurring detection at 0.4, 0.6, 0.8 and 1.00  
mm level of motion is 96 %, 100 %, 100 % and 100 % respectively.

#### **4. Discussion**

225 The results from the monitor comparison study confirm that a monitor with lower resolution (eg  
2.3 MP) would likely have a poorer visual detection rate for FFDM image blurring compared  
with a higher resolution reporting grade monitor (5 MP). The number of blurred images missed  
by the observers (Nm) for the lower resolution monitor is higher than the number in the higher  
resolution monitor, which leads to a higher technical recall rate for the lower resolution monitor.

230 In clinical practice as some technical review monitors have resolutions as low as 1 MP [12], we  
can confidently propose that such monitors would have even poorer blurred image visual  
detection rates than the one used in our study (2.3 MP). Further work is needed to determine the  
minimum specifications of a technical review monitor for use in imaging rooms for which  
technical recall rates could be suitably low for clinical purposes. It is worth noting that our data  
235 suggests that there is a 55 % reduction in the technical recall rate if a 5 MP reporting grade  
monitor is used for checking images in the clinical rooms. This would reduce the need for  
additional time slots for appointments as well as the cost of the administrative overhead for  
booking the appointments. Also it would minimize client/client family anxiety and costs for the  
re-attendance.

240 Resolution acuity refers to the smallest amount of spatial detail necessary to distinguish a  
difference between patterns or features in a visible target [28]. Individuals with 20/20 vision  
have the ability to recognize a minimal angle of resolution (MAR) subtended by the components  
of the stimulus, which has an angular size of 60 arc seconds [28, 29]. At 0.2 mm of simulated  
blurring there is no significant difference ( $X^2(1, N=1095) = 1.61, p=0.20$ ) in blurring detection  
245 between the 2.3 and 5.0 MP monitors. One of the possible explanations is that the human visual  
system is not able to resolve this level of detail at a distance of 75 cm as the angular size is less  
than 60 arc seconds.

Angular size calculations demonstrate that blur of 0.2 motion is not possible to identify if the viewing distance is increased to 75 cm, independently of the monitor used. The impact of the visual system on diagnostic decision-making is not well understood. However, it is known that  
250 visual acuity and accommodation accuracy get worse at the end of a long radiology workday [30, 31]. Variance in the viewing distance combined with visual fatigue and a low resolution monitor can be a potential risk factor for missing the detection of blur on 2.3 MP monitors.

The selection of the motion levels used in this study was related with the early work by Ma et al  
255 [3]. Detection performance between the limits of 30 cm and 75 cm was not tested for 0.3 mm. According with our current calculations of angular size for 0.3 mm of motion it could be argued that if 0.3 mm of blurring had been used the blurring would be identifiable by the observers at 75 cm (82 arc seconds). This warrants further research to determine threshold values for detection of blurring at different distances from the monitor.

260 Fleiss' kappa for 2.3 MP monitors is much lower than the 5 MP monitor which suggests that using the lower resolution monitor to see blurring is more difficult compared with the higher resolution monitor. On the other hand, the mean kappa in our study is 0.26 which indicates poor agreement between observers [24]. In observer studies it is very rare to achieve perfect agreement and a range of cognitive, visual and environmental factors can be used to explain this.  
265 Also, anecdotally we know that some people find the task of differentiating blurred from non blurred images very difficult, so this could be another explanation for poor agreement. One conclusion from this could be that observers who performed less well could need additional training. This poor level of agreement raises questions about the blur detection abilities between observers which is the second aim of this study. In view of this, the observer standard developed

270 in our study could be used to help inform the development of competence assessment standards of observers in training programmes and in routine practice.

Intra-observer variation and inter-observer variation across professional disciplines was not included into this study. As observers only viewed each image once it is not possible to calculate the intra-observer variation. For inter-observer variation across professional disciplines the  
275 sample size for radiologists is too small ( $n=2$ ) to conduct meaningful analysis. Further research is therefore warranted for intra- and inter-observer variability for different professional groups.

One of the limitations of our study is the use of motion simulation as this may not fully represent real blurring. For instance, the mathematical simulation used in our study blurs the whole image while real mammography image blurring may fully or partly affect the image. An updated  
280 version of our mathematical simulation has the ability to introduce regional blurring. Using this updated version further studies could be carried out to investigate the effect of regional blurring on observer and monitor blurring detection rates. Aside proposing an extension to our study using regional blurring it could be valuable to conduct a study using real blurred FFDM images. However, it should be noted that for real blurring it would be hard to control and identify the  
285 exact amount of blurring in the images.

Another limitation of our study is that the normal mammography screening environment might not be fully recreated in our study. For example, practitioners working in imaging rooms often do not work in levels of subdued light consistent with common reporting conditions and they probably do not have the same amount of time as image readers to scrutinize the image. Further  
290 studies could be carried out to investigate the effect of lighting and image viewing time on blurring detection rate for technical review monitors.

Finally, we did not take into account observers' previous activities. For example visual fatigue may occur if a radiologist or radiographer finished a reporting session and then immediately took part in the study. Further studies could be carried out to investigate the effect of visual fatigue on blurring detection rates and also other factors, as indicated earlier, which can impact upon observer performance.

## 5. Conclusions

According to our study monitors equal to or lower than 2.3 MP are not suitable for technical review of FFDM images for the detection of blur. The minimum amount of motion required for visual detection of blurring in our study is 0.4 mm and the observer standard for blur detection at 0.4, 0.6, 0.8 and 1 mm level of simulated blurring are 96 %, 100 %, 100 % and 100 % on a 5 MP monitor.

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*Table 1: Angular size for different levels of motion*

Level of motion (mm)	Angular size (degree)		Angular size (arc seconds)	
	30 cm	75 cm	30 cm	75 cm
0.2	0.0382	0.01528	138	55
0.4	0.0764	0.03056	275	110
0.6	0.1146	0.04584	413	165
0.8	0.1582	0.06112	550	220
1	0.1910	0.07640	688	275

395 *Table 2: Technical recall rate (TC) for 2.3MP and 5MP monitors*

Level of motion (mm)	0.4	0.6	0.8	1	Total
TC for 2.3MP monitor	7.1%	5.8%	3.8%	3.6%	20.3%
TC for 5MP monitor	5.1%	2.9%	0.8%	0.3%	9.1%

*Table 3: Observer standard for the minimum standard of blurring detection for 5 MP monitor*

Level of motion (mm)	0.4	0.6	0.8	1
Upper quartile (75 <sup>th</sup> percentile)	96%	100%	100%	100%