The Digital Reading Room and its Impact on the Radiologist

a report by
Elizabeth A Krupinski, PhD
Research Professor, University of Arizona

Over the past 20 years radiology has undergone a major transformation, moving from analog to digital acquisition and display and creating a very different working environment for radiologists. Picture archiving and communications systems (PACS) have significantly changed the workflow in radiology. Imaging studies can now be routed to the most qualified sub-specialist available without delay, either within the hospital setting or from remote sites via teleradiology. Overall radiologist productivity has improved by more than 50% according to some studies. This increase can be attributed to fewer interruptions, better workload sharing, reduced time waiting for images, increased and faster access to old reports and images and improved (and even customised) hanging protocols with tailored pre-fetch strategies. However, digital acquisition and advances in technology (e.g. helical computed tomography (CT) scanning) have also resulted in many more images per study and an increased number of studies being requested (often in modalities such as CT where images are already numerous).

There is some evidence that the use of PACS itself may even increase the number of images per study in certain modalities and types of examinations due to the increased use of image enhancement protocols, such as color flow Doppler in ultrasound studies, and added views such as the addition of the posterior fossa in neonatal head studies. The increase is both a function of the added information the radiologist obtains and the ease with which additional studies can be acquired.

The digital radiology reading room is increasing efficiency and productivity, but it is also becoming more demanding for radiologists. The time needed to read the increased volume of imaging examinations has led to more studies being read after hours or by on-call radiologists. This is particularly true for CT and magnetic resonance imaging (MRI). Helical CT now produces even more images, in the range of five times as many images per study compared with traditional CT. According to one study, CT, MR, and ultrasound studies increased by 59%, 51%, and 30%, respectively, during traditional hours between 1998 and 2002 and up to 15% for on-call volume. Teleradiology and second-opinion services also contribute to increased examination volume, often without commensurate increases in staffing. Studies suggest that this increased workload may even contribute to radiologists’ job discontent.

The move to the digital reading environment has significantly affected the way radiologists interpret images. It is becoming less common to view hard-copy film on light boxes and much more common to read soft-copy images on digital displays. Owing to the fact that images are acquired.

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that the display is the final link in the imaging chain between the radiologist and the image data, it is important to understand the interaction in order to optimise the viewing environment. To this end, there have been a number of studies conducted to measure reader performance in order to investigate the perceptual and cognitive mechanisms underlying the interpretation of medical images in the new digital environment. The goal is to optimise the diagnostic information being displayed so that the radiologist can render a correct decision in the most efficient and timely manner.

Over the past 10 years a series of studies have been conducted to determine what digital properties display in the radiologist’s interpretation behaviors. The investigations typically measure two aspects of observer performance, both of which are felt to be critical for optimising interpretation and workflow. The first component of the studies is a measure of diagnostic accuracy, typically using receiver operating characteristic (ROC) techniques as the metric of diagnostic accuracy. The second component is a measure of interpretation efficiency. For this aspect of the investigation, the eye position of the radiologist is tracked as they scan the images during the interpretation process (see Figure 1). Examining the visual search strategies of radiologists is not new, and has yielded important information regarding the nature of errors in the interpretation process and the role of reader experience.

One of the key problems that arose in the move to digital technology was image quality and, in particular, images that looked the same no matter what system they were being displayed on and optimising the display by taking into account the capabilities of the

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human visual system. The problem was addressed by the development of the Digital Imaging and Communications in Medicine (DICOM)-14 grayscale display function standard.25

In order to confirm that calibrating a digital display to the DICOM standard does influence performance, radiologists viewed a series of 50 mammograms on a cathode ray tube (CRT) display that was either perceptually linearised (calibrated to the DICOM-14 standard) or non-perceptually linearised (calibrated to the Society of Motion Picture and Television Engineers (SMPTE) pattern).26 Perceptual linearisation optimises the display by producing a tone scale in which equal changes in driving level yield changes in luminance that are perceptually equivalent across the entire luminance range.

It was found that diagnostic performance was significantly higher (t=5.42; df=5; p<0.001) with the perceptually linearised display compared with the non-perceptually linearised display (mean ROC Az=0.94 versus 0.88). Using the eye–position recording techniques it was found that viewing time was shorter for the perceptually linearised display and visual search was more efficient, as reflected by shorter decision dwell times and fewer fixation clusters, compared with the non-perceptually linearised display.

Similar studies have been performed and it was concluded that, in terms of both diagnostic accuracy and visual search efficiency, higher luminance27 displays are the best, monochrome is better than color,28 and liquid crystal displays (LCDs) are equivalent to CRTs as long as they are viewed on axis (off-axis viewing of LCDs results in lower performance).29

The physical characteristics of the display are crucial and there has been a significant amount of work in the development of display standards and characterisation techniques for digital radiology.30–32

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search of the image as the readers accessed the image processing and manipulation tools/menus, but approximately half were generated sporadically during a search of the image and were rarely associated with actual use of the menu items being fixated. The radiologists were essentially distracted from their interpretation task by a user interface that was not optimised for efficient viewing.

While the imaging task of the radiologist becomes more complicated as they view more images, and as multimodality displays are developed, it is imperative that attention is paid to the design of the user interface to optimise the extraction of information from the display during the interpretation process.

A further twist on information in the digital world comes into play when image processing, image analysis, and decision aids are added. Many of the images that reach the radiologist’s workstation have already been pre-processed to some extent by software associated with the acquisition device. The goal is to present the radiologist with the best image possible in the default or initial view, and studies comparing pre-processed with unprocessed images have shown that the diagnostic quality of the pre-processed images is better.34

It has also been shown that workflow is improved with the pre-processed images because the radiologists do not have to adjust window/level as much as with the unprocessed images.35 From a perceptual point of view this makes considerable sense. Radiologists are capable of perceiving and processing a significant amount of information in the first few milliseconds of an image being displayed, even to the point of being able to detect some lesions before fixated. The more the initial image the radiologist sees on the soft-copy display is optimised, the more likely it is that performance will be optimal.

In addition to tools to process the image, computer-aided detection (CAD) tools are beginning to have a significant impact in radiology in such diverse applications as mammography, breast MRI, chest imaging (CR, digital radiography (DR) and CT) and colonoscopy, generally resulting in increased detection performance, better discrimination of benign versus malignant lesions, and even reduced viewing times.36–41 CAD will become even more important in years to come as radiologists have to search through larger datasets of images, while still being required to interpret an increasing number of cases.

It is important to remember that even though CAD is designed to aid the radiologist, it is yet another source of information that must be integrated into the display. In addition to improving the CAD schemes that already exist (i.e. increasing the true positive and decreasing the false positive rates) and expanding them to different disease entities, it is therefore also necessary to improve the understanding of how prompts should best be presented to the radiologist and how the perceptual and cognitive mechanisms of the radiologist are being affected.

The future of digital radiology is exciting and will hopefully bring improved detection and diagnosis of diseases. It is clear that current CRT and LCD displays are bound to be replaced by even more sophisticated displays that include color, stereoscopic, and possibly even true three-dimensional (3-D) visualisation techniques.

While these technologies are developed and introduced into the reading room, it is crucial to continue evaluation of how and why they impact the perceptual and cognitive systems of the radiologist during the interpretation process. The digital workstation and the radiologist do not exist in isolation from one another, so the complex ways in which they interact in the broader scope of the digital reading environment must be understood and appreciated.