An Analysis of Perceptual Errors in Reading Mammograms Using Quasi-Local Spatial Frequency Spectra

Claudia Mello-Thoms, Stanley M. Dunn, Calvin F. Nodine, and Harold L. Kundel

In this pilot study the authors examined areas on a mammogram that attracted the visual attention of experienced mammographers and mammography fellows, as well as areas that were reported to contain a malignant lesion, and, based on their spatial frequency spectrum, they characterized these areas by the type of decision outcome that they yielded: true-positives (TP), false-positives (FP), true-negatives (TN), and false-negatives (FN). Five 2-view (cranio-caudal and mediolateral oblique) mammogram cases were examined by 8 experienced observers, and the eye position of the observers was tracked. The observers were asked to report the location and nature of any malignant lesions present in the case. The authors analyzed each area in which either the observer made a decision or in which the observer had prolonged (>1,000 ms) visual dwell using wavelet packets, and characterized these areas in terms of the energy contents of each spatial frequency band. It was shown that each decision outcome is characterized by a specific profile in the spatial frequency domain, and that these profiles are significantly different from one another. As a consequence of these differences, the profiles can be used to determine which type of decision a given observer will make when examining the area. Computer-assisted perception correctly predicted up to 64% of the TP's made by the observers, 77% of the FP's, and 70% of the TN's. Copyright © 2001 by W.B. Saunders Company

KEY WORDS: computer-assisted perception, frequency spectra, wavelet packets, mammography, breast cancer detection.

Breast cancer is one of the leading causes of death among American women, and 46,000 women die from this disease each year. As with other types of cancer, early detection can significantly change the prognosis for a woman with this disease. Thus, renewed efforts have been made to develop accurate imaging techniques that can detect abnormalities of smaller and smaller sizes.

Nonetheless, a problem that usually is overlooked when considering such imaging techniques is the radiologist's ability to correctly interpret what is in the image. Studies have shown that 10% to 30% of all cancers in the breast are missed, and from these, approximately two thirds are seen in retrospect. The missing of these cancers is caused by a variety of factors, such as search errors (43%), interpretation errors (52%), and suboptimal technique (5%). Furthermore, in studies that examined how radiologists' search for cancerous lesions in the breast, using eye position monitoring, it has been shown that approximately 62% of the missed cancers are fixated with the high-resolution fovea.

However, image-derived factors are not the only ones involved in perception, also, factors that come from within the observer have just as much influence. Kundel showed that 3 factors seem to be involved in the decisions made by the radiologists when searching for chest nodules (1) the prevalence of cancer in the population from which the patient is drawn; (2) the cost of making an incorrect decision or incorrectly mistaking normal tissue as being cancerous; and (3) the structure of the image around the nodule and at a distance from it. The third factor, which is directly related to the image, has been shown to have significant impact in image perception. In a study in which nodules in the chest were displayed embedded in an uniformly distributed background and in a real anatomic background, the investigators found that the effects of the anatomic background, called "structured noise," were about 25 times higher than the effects of the variabilities in the image caused by the fluctuations in the number of x-ray photons reaching the receptors, called "quantum noise." Note that structured noise affects lesion detection either by masking the lesion or by creating artifacts that resemble lesions, thus taking attention away from the real lesion when one is present.

Furthermore, it has been shown that lesions can be classified based on their Fourier spectra, be-
cause different abnormalities will have a different signature in the spatial frequency space.\textsuperscript{7}

In this report we will take this argument a step further. Namely, we will consider the effects that different lesion and background spectra have on the observer's perception when reading mammograms. We will attempt to determine if there is a combination of image structures, the quasi-local combination of lesion and background, in the spatial frequency domain, in which lesion detection is facilitated, thus, leading to true-positives (TP) and to true-negatives (TN), or, where it is hindered, thus, yielding false-positives (FP) and false-negatives (FN).

**MATERIALS AND METHODS**

Eight experienced observers (3 mammographers from the staff of the Hospital of the University of Pennsylvania and 5 fellows undergoing training in Mammography at the same institution) read 5 2-view (cranio-caudal[CC] and medio-lateral oblique, [MLO]) mammogram cases (adding up to a total of 10 images). All cases had a malignant mass present; in 3 cases it was visible in both views, and in 1 case it was only visible in one view (CC). One case contained 2 malignant masses visible in both views.

These cases were obtained from the archives of the Hospital of the University of Pennsylvania. The films were digitized using a Lumiscan Model 100 digitizer (Lumisys Inc, Sunnyvale, CA), using a 100-μm spot size. The 2 views were displayed side-by-side on a single 19-inch, 2,048 × 2,048 gray scale monitor (GMA 201; Tektronix, Beaverton, OR), interfaced to a Sun Sparc computer (Sun Microsystems, Sunnyvale, CA).

The observers were instructed to search for malignancy and freely examine the cases until they felt confident to answer if a malignant lesion was present and, if so, where it was located. The eye position of the observers was monitored during search using an ASL 4000 SU eye-head-tracking device (Applied Science Laboratories, Bedford, MA), and it was used to determine the areas in the image that attracted the observers' visual attention. Details of this experiment have been published elsewhere.\textsuperscript{9}

Eye position was used because it is a good indicator of what in the image attracted the observer's visual attention. It has been shown that the observers dwell as long on lesions that were not reported (that is, FNs) as they do in the ones that were (TPs).\textsuperscript{2,10}

At the end of the experiment the eye positions of each observer, for each case, were superimposed to the 2-view mammogram examined as shown in Fig 1.

For each case and each observer, 10 regions were extracted from the 2-view mammogram displayed. These regions were based on the decisions made by the observer when reading the case and the areas where the observer had prolonged (>1,000 ms) visual dwell. In this way, 5 cases × 10 regions × 8 observers generated 400 regions. These regions were rectangular windows of 128 × 128 pixels, which corresponded to 5° of visual angle at 38 cm viewing distance. They were extracted and processed using a program written in IDL (Research Systems, Inc, Boulder, CO).

The extracted regions were labeled with the purpose of generating a truth table that later could be used to compute the

Fig 1. Example of eye-position monitoring when an expert is reading a mammogram case. The 2 larger circles correspond to the known location of a malignant mass. The smaller circles correspond to fixations (sequential dwells on areas of 0.5° of visual angle).