Foveated model observer predicts dissociation of signal detectability across 2D and 3D images

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RATIONALE

Model observers have been successful at predicting human observer performance for detection and search for signals in 2D noisy images. We argue that search in 3D images represents a paradigm shift in medical imaging because radiologists do not typically exhaustively scrutinize all regions of interest with the high-resolution fovea. Instead, for the detection of signals, observers must rely on peripheral retinal regions, and process the visual information with reduced spatial detail. We hypothesize that the peripheral processing can have important influences in the search of small signals in 3D images. These influences are not captured by current model observers or by the ideal observer for search. We propose foveated model observers that can correctly predict the search of small signals in 3D search.

METHODS

A 3D synthetic noisy background was generated using statistics similar to the x-ray mammograms (noise power spectrum = $1/f^{2.8}$). A mass and microcalcification-like signal were embedded in the 3D background. Human observers were instructed to find the signals in the 3D volume. In a separate condition, observers searched for the signals in a 2D slice. The signals were present with a 50% of probability. For the 2D case, we presented the central slice in which the signal appears. We quantified accuracy (yes/no task) in detecting each of the two signals in both 2D and 3D images. We implemented standard 2D/3D detection model observers including the Hotelling Observer (HOT), the Channleized Hotelling (CHO), the Non-Prewhitening model (NPW) and the NPW with eye filter (NPWE). In addition, we implemented an ideal observer for search. Finally, we implemented new foveated model observers (Foveated-Channelized Hotelling and Foveated NPWE) that take into account the varying spatial resolution across the visual field. Performance predictions were obtained for all models for the four experimental conditions.

RESULTS

Results showed that the small microcalcification-like signal is more highly detectable than a larger mass-like signal in 2D search, but its detectability largely decreases (relative to the larger signal) in the 3D search task. All standard detection model observers (HOT, CHO, NPW, NPWE) as well as the ideal observer for search did not predict the drastic decrease in microcalcification detectability in 3D search. The foveated model observers that take into account the varying resolution processing could predict the human experimental results.

CONCLUSION

The interaction of the properties of the visual periphery, the spatial frequency content of the signal and the observer search patterns have important influences on search in 3D images. Our findings show that these influences cannot be captured by current detection model observers nor by an ideal observer for search. In contrast, a new family of foveated model observers that account for the inhomogeneous visual processing across the retina might be important for assessment of medical image quality in 3D images.