Evaluation of Human Contrast Sensitivity Functions Used in the Nonprewhitening Model Observer with Eye Filter

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Abstract. Model observers which can serve as surrogates for human observers could be valuable for the assessment of image quality. For this purpose, a good correlation between human and model observer is a prerequisite. The nonprewhitening model observer with eye filter (NPWE) is an example of such a model observer. The eye filter is a mathematical approximation of the human contrast sensitivity function (CSF) and is included to correct for the response of the human eye. In the literature several approximations of the human CSF were found. In this study the relation between human and NPWE observer performance using seven eye filters is evaluated in two-alternative-forced-choice (2-AFC) detection experiments involving disks of varying diameter and signal energy and two background types. The results show that the shape of the CSF has an impact on the correlation between human and model observer. The inclusion of a CSF may indeed improve the relation between human and model observer. However, we did not find an eye filter which is optimal in both backgrounds.

Keywords: model observers, image quality, NPWE, eye filter, contrast sensitivity.

1 Introduction

In general, image quality analysis and system optimization studies in full field digital mammography (FFDM) are performed using contrast detail analysis or linear system metrics like DQE and NEQ. The limitations of both approaches is the use of uniform backgrounds where quantum noise is dominating. Furthermore the pixel values must have a known relationship with entrance air kerma on the image receptor (like in unprocessed images), whereas for clinical images this relation might not be known due to (non-linear) processing. Furthermore, the radiological task is often dominated by

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anatomical structures rather than quantum noise. Statistical anthropomorphic model observers (model observers acting as human observers) use the image statistics to determine the detectability without the assumption of linearity or the assumption that quantum noise is dominating. Therefore statistical anthropomorphic model observers might be used for the assessment of image quality in clinical images.

Acceptance of anthropomorphic model observers for image quality assessment strongly depends on the relation between model and human observer. Rolland and Barrett [1] have investigated this using two different model observers: a pre- and a nonprewhitening matched filter (PW and NPW) and concluded that the NPW model observer fails to predict human observer performance in lumpy backgrounds. Burgess et al [2] subsequently demonstrated that the NPW model observer can predict the human response if a spatial frequency filter is included which mimics the contrast sensitivity function (CSF) of the human eye. This was followed by several studies where the NPWE (NPW eye) model observer was applied. In the literature several approximations of the human CSF can be found. The origin of these approximations varied from fitting experimental data to applied research in the field of human vision. The aim of this paper is to investigate the detection of a NPWE model observer using different eye filters compared with the detection of human observers. This has been studied by performing a two-alternative-forced-choice experiment (2-AFC) using simulated white noise backgrounds (WN), representing an ideal quantum noise limited system and clustered lumpy backgrounds (CLB), simulating clinical breast structures [3].

2 Method

The NPWE model observer correlates the signal template and the image after convolution with an eye filter. This means that the NPWE model observer only takes the signal template into account and does not incorporate background statistics. For an image g_n (with n = 1 (object absent) or 2 (object present)) the decision variable (T) of the NPWE model observer can be estimated using:

$$T(g_n) = [E^t \cdot E \cdot (\mathrm{B} \cdot s_2)]^t \cdot g_n \quad (1)$$

where t is the matrix transpose, B the imaging system blur, s_2 the signal template and E the eye filter which is defined in the spatial frequency domain and is assumed to be radially symmetric. The decision variable (T) is subsequently used to estimate a detectability index d' by:

$$d'_{NPWE} = \frac{\langle T\rangle_1 - \langle T\rangle_2}{\sqrt{\frac{1}{2}\sigma_1^2 + \frac{1}{2}\sigma_2^2}} \quad (2)$$

where $\langle T\rangle$ is the mean and σ the standard deviation of the decision variable T. In a 2-AFC experiment with normally distributed test statistics, d' is related to the fraction of correct response in the experiment (proportion correct, PC) by: