Neural Transfer Functions from Interferometric Measurements

A. J. Ahumada
NASA Ames Research Center
al.ahumada@nasa.gov
and
N. J. Coletta
New England College of Optometry
ColettaN@neco.edu

Abstract

Williams (JOSAA, 1985) and Coletta and Sharma (JOSAA, 1995) measured the contrast sensitivity function (CSF) for interference fringes as a function of spatial frequency. They added varying amounts of incoherent light to the background and found that as the proportion of coherent light decreased, the contrast sensitivity increased. This increase was attributed to the loss of masking by laser speckle. We have used a simple additive model to estimate from their data both the CSF in the absence of noise speckle (the neural transfer function or NTF) and the shape of the speckle noise spectrum. NTFs enable the prediction of the effects of optical variables on visual discriminations.

The Williams (1985) experiment

Williams (1985) used the basic interference fringe technique of Campbell and Green (1965) to bypass the optics of the eye to measure the NTF. In addition to measuring the threshold for the interference fringe on the coherent light background, he added incoherent light to the background to reduce the masking effects of laser speckle. Figure 1 shows contrast sensitivity at 2 spatial frequencies 10 and 50 cpd as a function of the proportion of coherent light in the background. As the proportion of coherent light decreases, the contrast sensitivity increases as the speckle noise is diluted, but unfortunately we cannot measure the case with no speckle because then there is no signal. We use a model that assumes the speckle noise and the equivalent noise of the NTF are additive to estimate the limiting NTF.

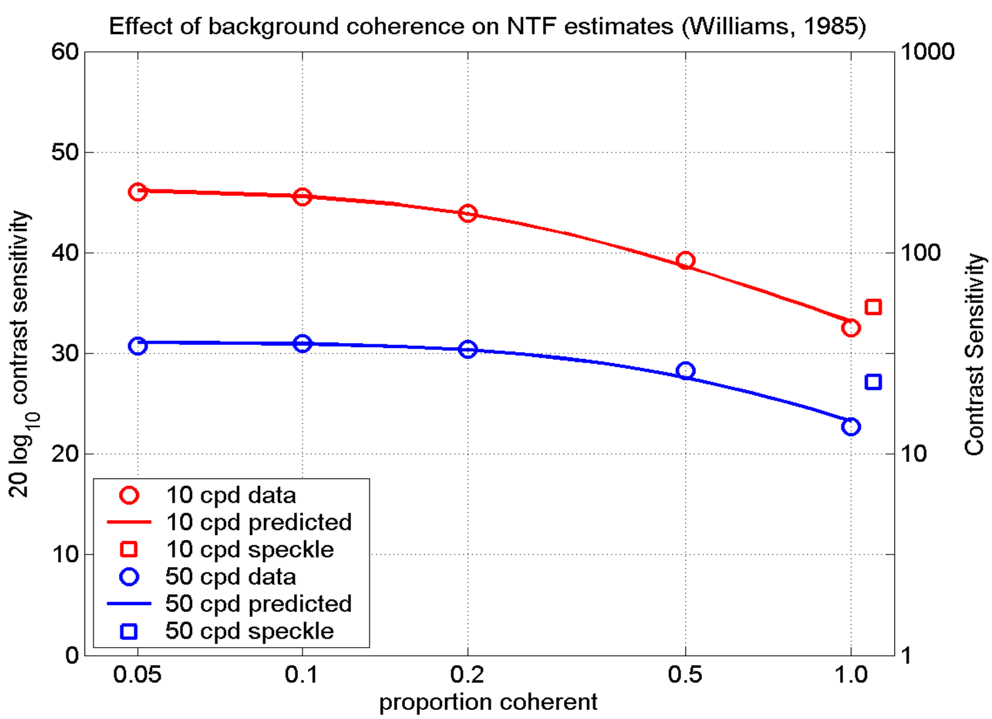

Figure 1. NTF estimates from Williams (1985, Fig.3) for spatial frequencies of 10 and 50 cpd. . The lines are the predictions of the additivity model and the squares indicate the contrast sensitivity limited only by speckle.

The Additive Model

The model assumes two noises are masking the signal, the speckle noise and the observer's internal noise referred to the signal contrast domain (Ahumada & Watson, 1985). In the absence of speckle, the internal noise spectrum is responsible for the NTF. The amplitude of speckle contrast noise is assumed to be proportional to the proportion of coherent light in the background. The masking of the combined noises is assumed to be proportional to the sum of the noise powers at each frequency. We will report our results in terms of contrast sensitivity. The NTF contrast sensitivity CN(f) is the NTF. CS(f) is the contrast sensitivity that would occur if P=1 and there were no internal noise. Notice that like the standard contrast sensitivity functions, these functions are low when the noise is high. The contrast sensitivity CP(f) for a proportion P of coherent background is given by

$$1/CP(f)^2 = 1/CN(f)^2 + P^2/CS(f)^2 .$$

Estimates of CN(f) and CS(f) minimize the squared error of prediction in log contrast. Figure 1 illustrates the fit of the model to Williams (1985) data from his Figure 3. The RMS errors corrected for the two estimated parameters are 0.52 dB and 0.57 dB for the 10 and 50 cpd curves, respectively. In his Figure 2, Williams (1985) shows NTF estimates for two observers at two proportions of coherence, 10% and 100%. These data are plotted in our Figure 2.

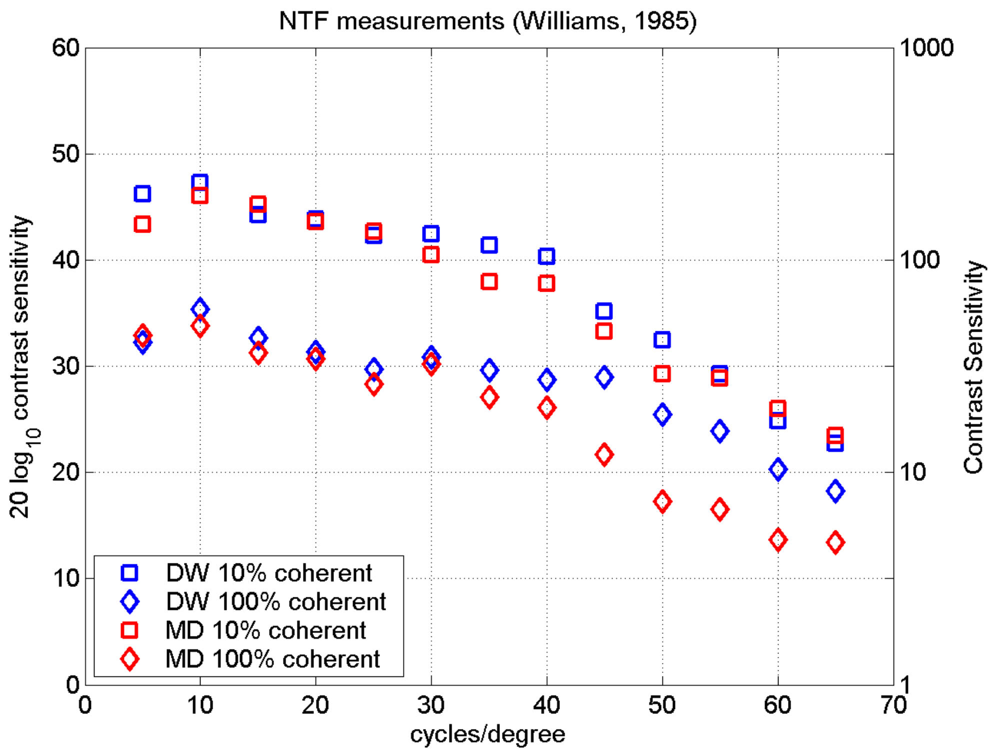

Figure 2: Contrast sensitivity data for two observers at two levels of coherence from Williams (1985, Figure 2). The observer DW is the observer from Figure 1.

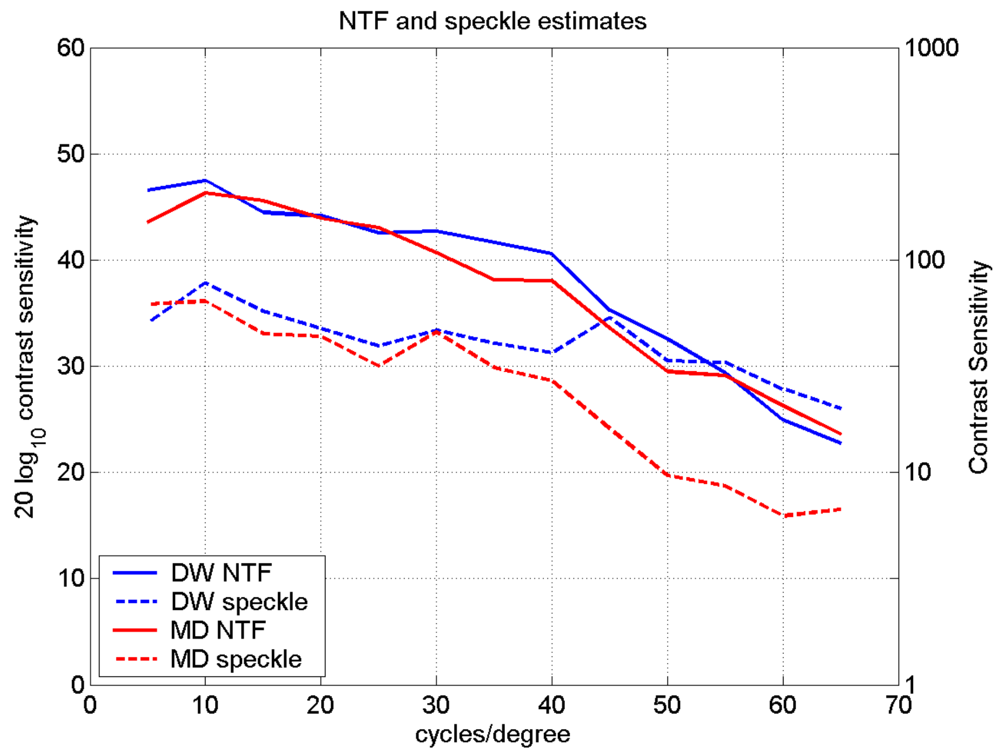

Figure 3: The data of Figure 2 converted by the model into estimates of NTFs (solid lines) and contrast sensitivity for the speckle noise alone (dashed lines).

The model supports Williams (1985) conclusion that the 10% curves were NTF estimates not contaminated by speckle for the good observers, but suggests that measurements at 2 different coherence levels could have provided more objective NTF estimates for those observers whose contrast sensitivity fell below 10 at high spatial frequencies.

The Coletta and Sharma (1995) experiment

Coletta and Sharma (1995) measured the CSF for interference fringes for a range of intensities, 0.3, 3, 30 and, 300 trolands (close to Williams (1985) 500 trolands) and for coherence proportions (0.1, 0.2, 0.5, 1.0). The thin lines in Figure 4 show the measurements of the study for observers NC and VS. The 300 trolands measurements are similar to the Williams (1985) results. At lower light levels, the masking effect diminishes as the sensitivity decreases and the functions become low-pass. The thick solid lines of Figure 4 are the model estimates of the NTF under the assumption that the speckle spectrum is the same as the illuminance varies. The RMS error corrected for the number of parameters was 2.0 dB for NC and 2.1 dB for VS. Figure 5 shows the speckle-only contrast sensitivity estimates for the two observers. They are clearly band-pass, indicating high speckle spectrum levels at low and high spatial frequencies.

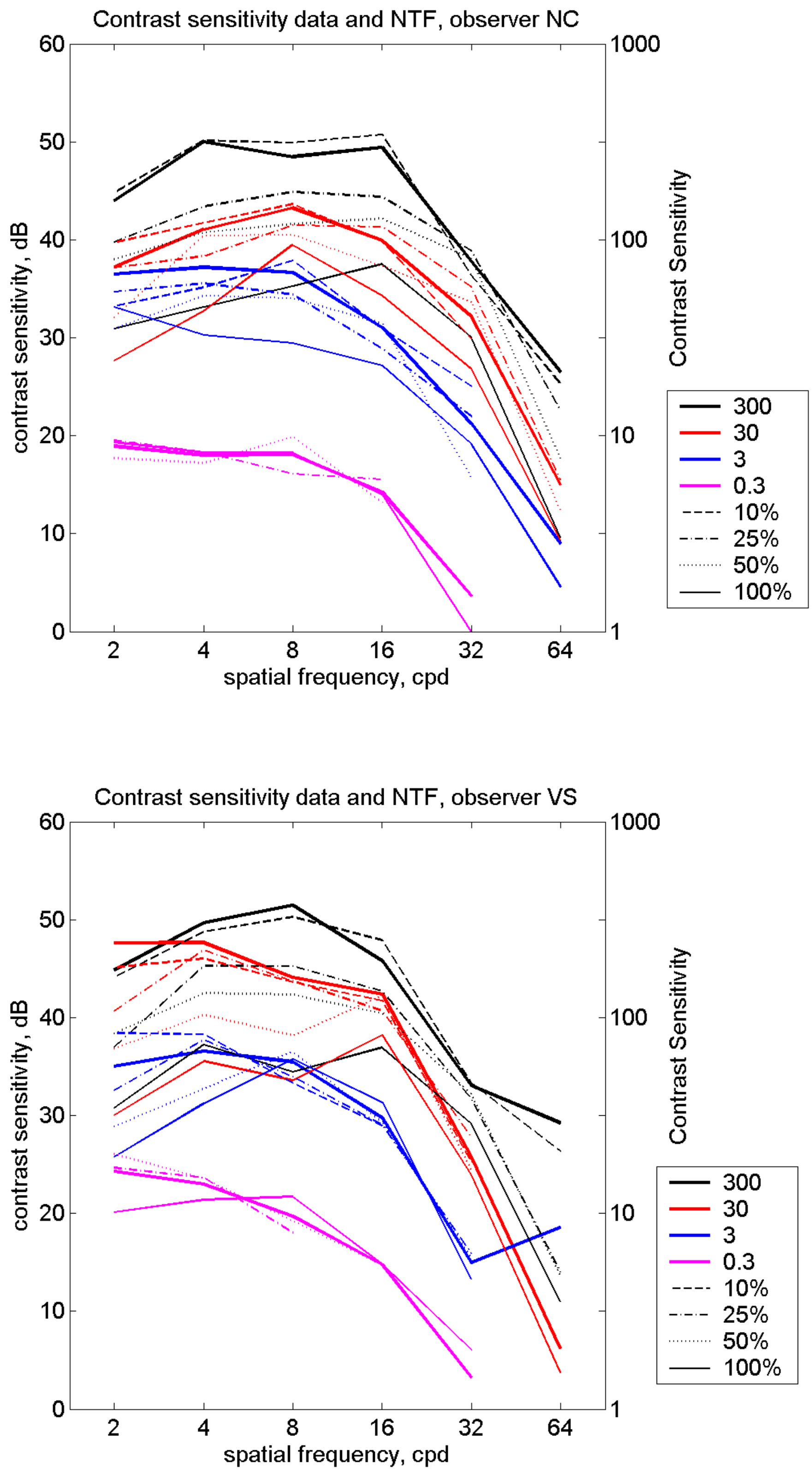

Figure 4. The thin lines show the contrast sensitivity measurements for observers NC (above) and VS (below). The colors indicate the illumination level in trolands. The thick solid lines are the model estimates of the NTF.

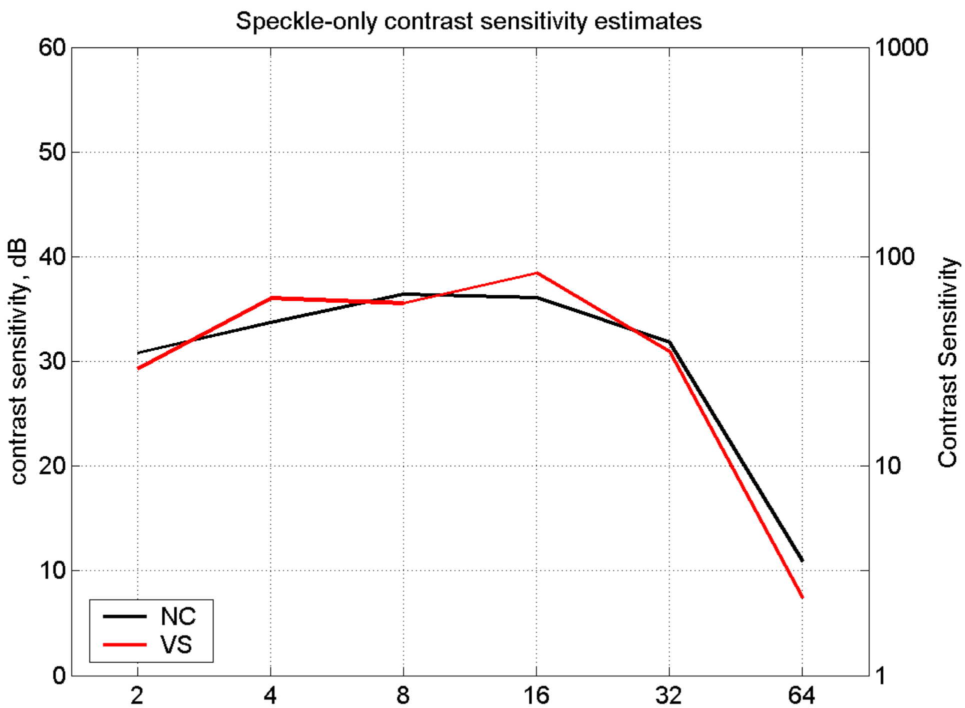

Figure 5. Speckle-only contrast sensitivity estimates for the two observers.

Discussion

Williams (1985) attributed the high frequency falloff in the NTF to neural integration. This paper preceded the work of Curcio, Sloan, Packer, Hendrickson, & Kalina (1987) showing that there can be significant variation of cone density within the fovea. The high-frequency fall-off might be the result of the integration area for the high frequencies being reduced to only the sub-Nyquist region. A reduction in area results in a decrease in contrast sensitivity which our model interprets as an increase in the speckle spectrum. If we assume the falling side of the speckle CSF represents the integration area reduction and add it back to the NTF, we obtain estimates that are relatively flat in the high frequency region as shown by Figures 6 and 7.

References

Ahumada & Watson (1985) J. Opt. Soc. Am. A 2, 1087-1093
Campbell & Green (1965) J. Physiol. (London) 181, 576–593.
Coletta & Sharma (1995), J. Opt. Soc. Am. A 12, 2244-2251.
Curcio, Sloan, Packer, Hendrickson, & Kalina (1987) Science, 236, 579-582.
van Nes & Bouman (1967) J. Opt. Soc. Am. 57, 401-406.
Williams, D. R. (1985) J. Opt. Soc. Am. A 2, 1087-1093.

Acknowledgements

Support provided by NASA Aerospace Systems and the U. S. Navy.

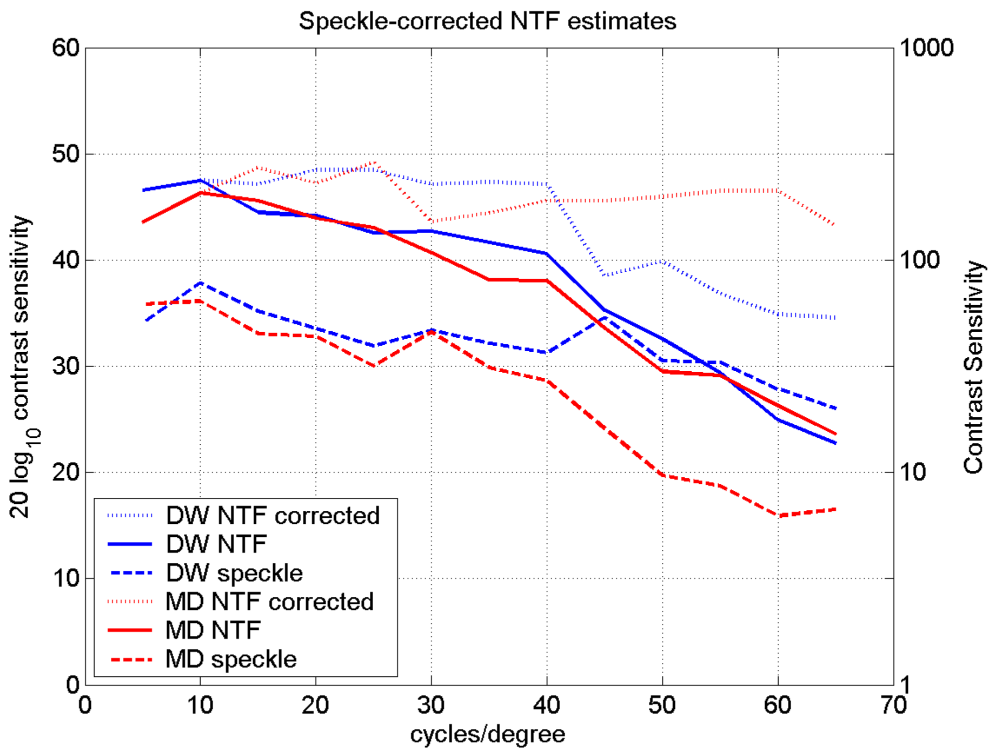

Figure 6.The dotted lines show the NTF estimates of Figure 3 corrected by the falling slope of the speckle-only CSF.

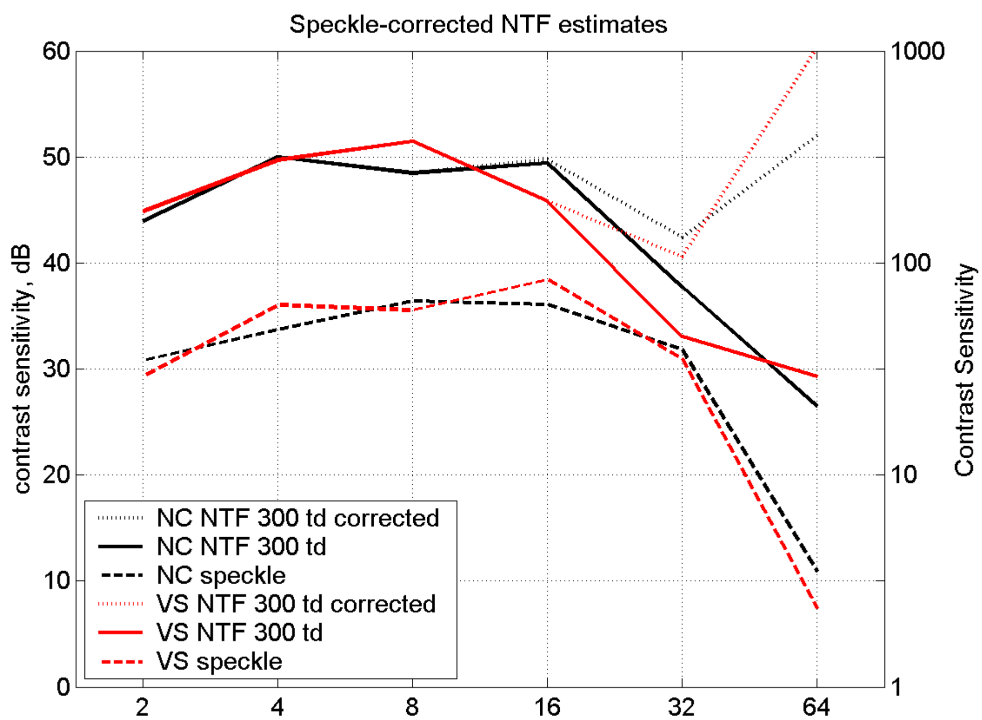

Figure 7.The dotted lines show the 300 troland NTF estimates of Figure 4 corrected by the falling slope of the speckle-only CSFs in Figure 5.