Internal and external noise contributions to classification templates: A double pass analysis

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INTRODUCTION

Graham & Nachmias (1972) found minimal subthreshold summation of a 1st plus 3rd harmonic sinewave gratings, strongly supporting a multiple channel model against an ideal observer template model. However there is mounting evidence for a template model in the suprathreshold regime. Levi, et al. (Vision Res. 2000) found that a template model explained observers behavior on spatial frequency tuning vernier task better than a standard multi-scale filter model.

We repeated the Graham and Nachmias experiment in the presence of noise with the goals of determining: **(i) the observer's template or classification image, (ii) whether an ideal observer or a multiple channel model was operating for these suprathreshold stimuli, and (iii) the ratio of internal systematic noise (such as produced by a fixed mismatched template) vs. random noise (such as produced by a variable mismatched template) .**

METHODS

Six cosine phase test patterns were used: the 2nd harmonic (of a 1 c/deg grating), the 6th harmonic, 2nd + 6th, 2nd - 6th, 2nd - (1/3)6th and 2nd + (3/4)6th. Short (0.75 & .5 sec) and long (2.0 & 1.5 sec) presentation durations were used to manipulate scrutiny. A small white mark was presented to the side of each stimuli at its midpoint to assist subjects in centering their template. Observers were able to refresh their memory of the appearance of the zero noise template while in the middle of a run

$$Stim(x) = c_2*(\cos(2\pi*2x) + c_6*\cos(2\pi*6x) + [n_j(\cos(2\pi j)) + m_j (\cos(2\pi j))]$$

For example the 3rd test pattern without noise was $stim(x)=\cos(2\pi*2x) + .75*\cos(2\pi*6x)$. The noise was the sum of 1st through 7th harmonics of the same 1 c/deg grating. The contrast of each noise harmonic n_j and m_j were generated randomly and had a mean of zero and had a 4% Gaussian standard deviation in both sine and cosine phases.

We used the method of constant stimuli with 4 test contrast levels (0, 1, 2 and 3 times a base contrast) and 4 responses. We used three subjects, two experienced in psychophysical experiments and one naive. Two of the subjects were kept naïve about the specific nature of the experiment. Auditory feedback based on the ideal observer's response rather than the pre-noise stimulus was given after each trial to help subjects refine their template and their response criterion. There were 200 trials per run and 2-4 runs were performed by each subject. Half of the runs used identical random seeds to allow for later doublepass analysis.

i) Classification images were recovered from the coefficients of the subject's weights for each frequency.

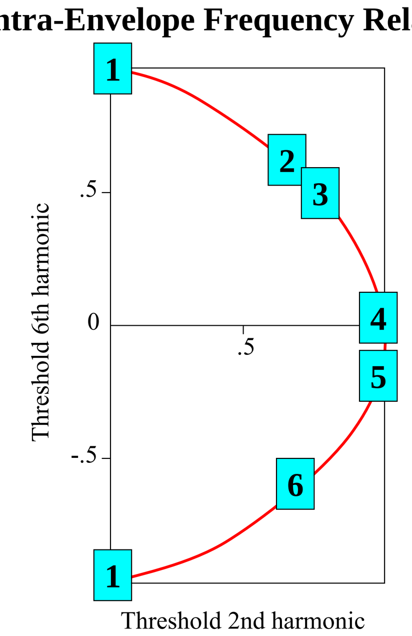
ii) The threshold for each envelope was calculated at d prime =1

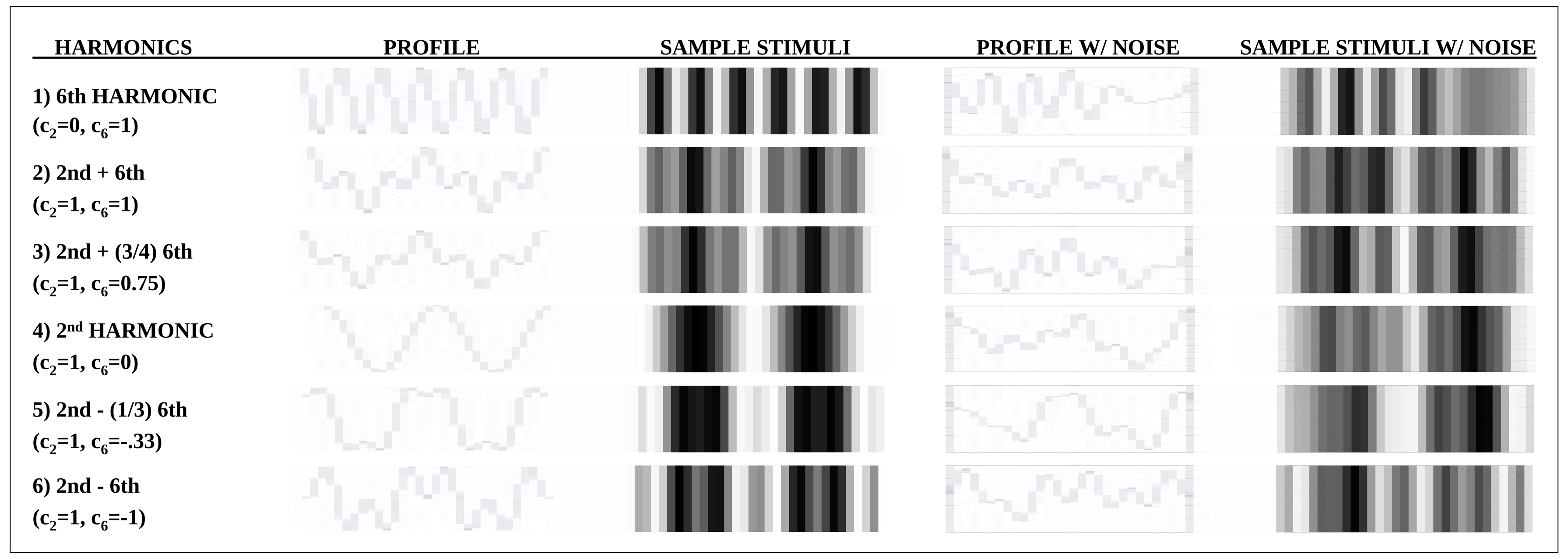
iii) The ratio of random to systematic noise was calculated in two ways: First, a double pass method was used. For each of the four stimulus levels, the covariance, R, of the Pass 1 and Pass 2 responses from the two identical randseed runs was calculated for each response (0-3). This was done by fitting ellipses to the response data taking into account the criteria for each run. A weighted average was then calculated to find a single R value for each pattern. Second, the ratio of the d-prime of the human to the d-prime of the ideal observer using the classification image template reveals the proportions of random noise to systematic noise using the formula:

$$R = (d' \text{ template}/d' \text{ human})^2 - 1)^{1/2}$$

For R values greater than 1, random noise is the dominant contributor to errors. R values less than 1 means systematic noise is the primary cause.

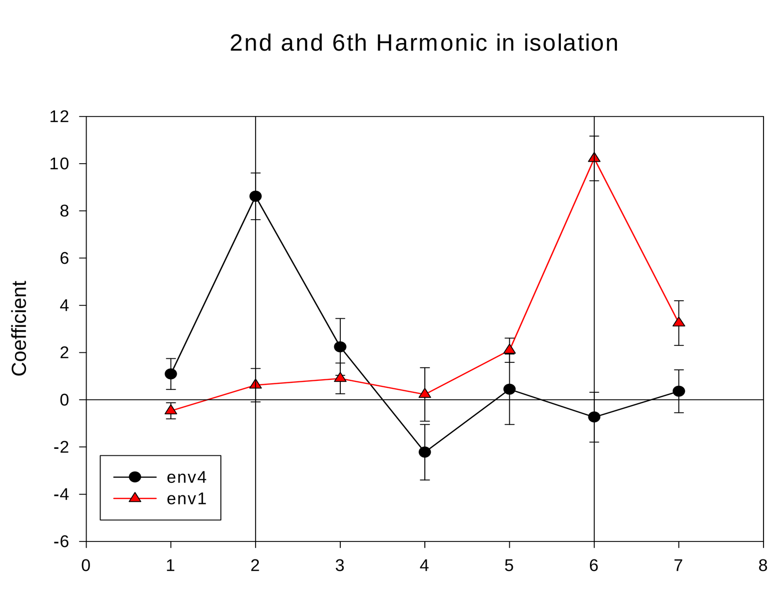
Intra-Envelope Frequency Relationships

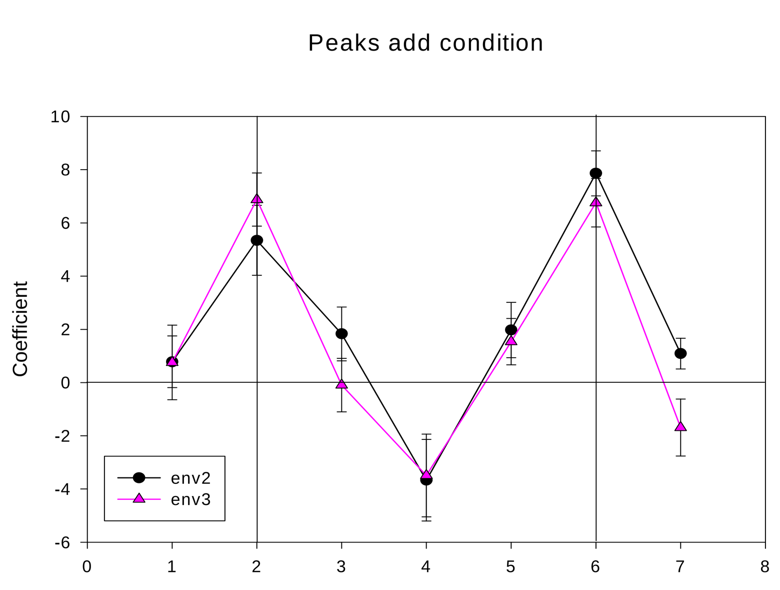


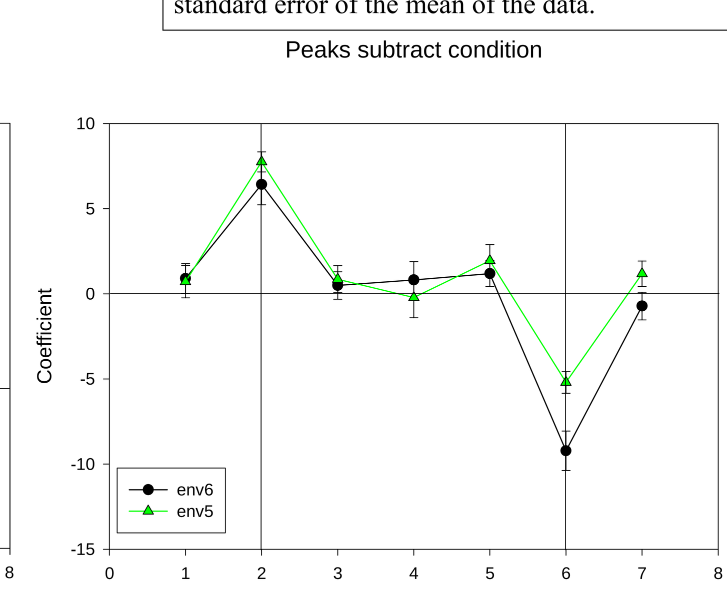


(i) Classification Images

NOTE: **error bars** represent the within subject standard error of the mean of the data.

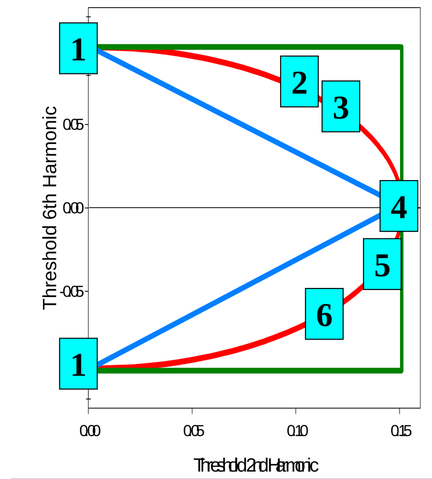






(ii) Possible models

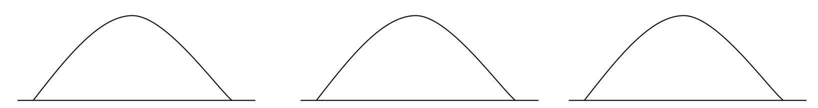
A wide variety of models can be summarized by the Minkowski summation relationship: $(c_2/Th_2)^n + (c_6/Th_6)^n = 1$ where n is the pooling exponent, c_2 & c_6 are the contrasts and Th_2 & Th_6 are the thresholds of the 2 and 6 c/deg components. For this experiment we considered three possible models.



Predictions of models, with markers for where each envelope should fall for template model

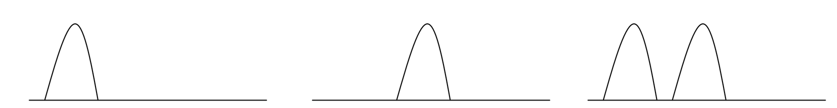
SAMPLE STIMLULI

"Single Channel/ Linear Summation"



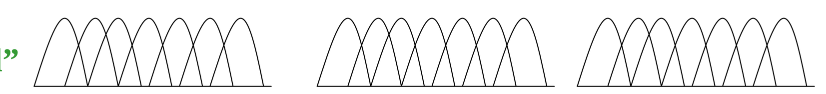
Subject uses one channel (an unvarying template) to respond to all stimuli, regardless of target. This model predicts linear summation with a **pooling exponent of n=1** as indicated by the blue dotted diagonal lines in above diagram.

"Template/ Fixed Efficiency Ideal Observer"



Subject knows the test pattern and attempts to match a different template for each test pattern. If the observer's efficiency in using the optimal template is constant across all test pattern, the **pooling exponent is n=2** (Pythagorean summation) as indicated by the red dashed line in above diagram.

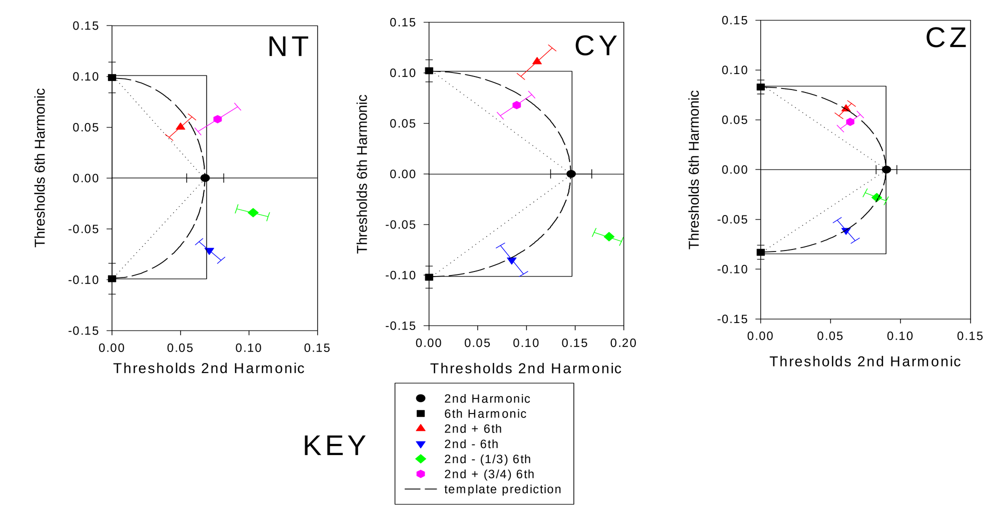
"Multiple Channel"



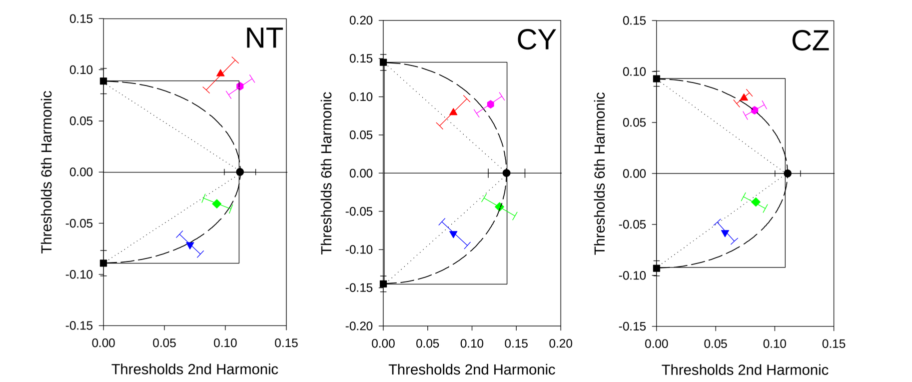
Subject has frequency tuned templates that do not span the 2nd and 6th harmonics. A model with probability summation gives a **pooling exponent of around 4-6**. A model without summation (an inability to attend to both components) corresponds to n=∞ as indicated by the green rectangular solid lines in above diagram.

RESULTS

Long duration

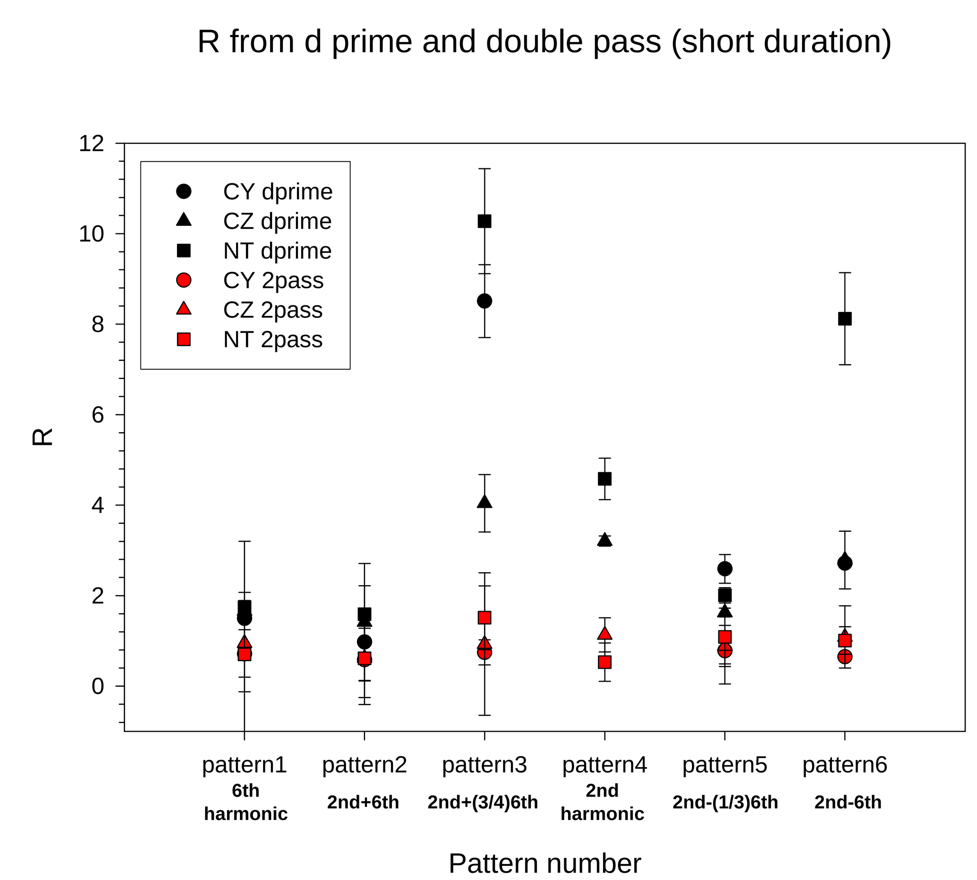


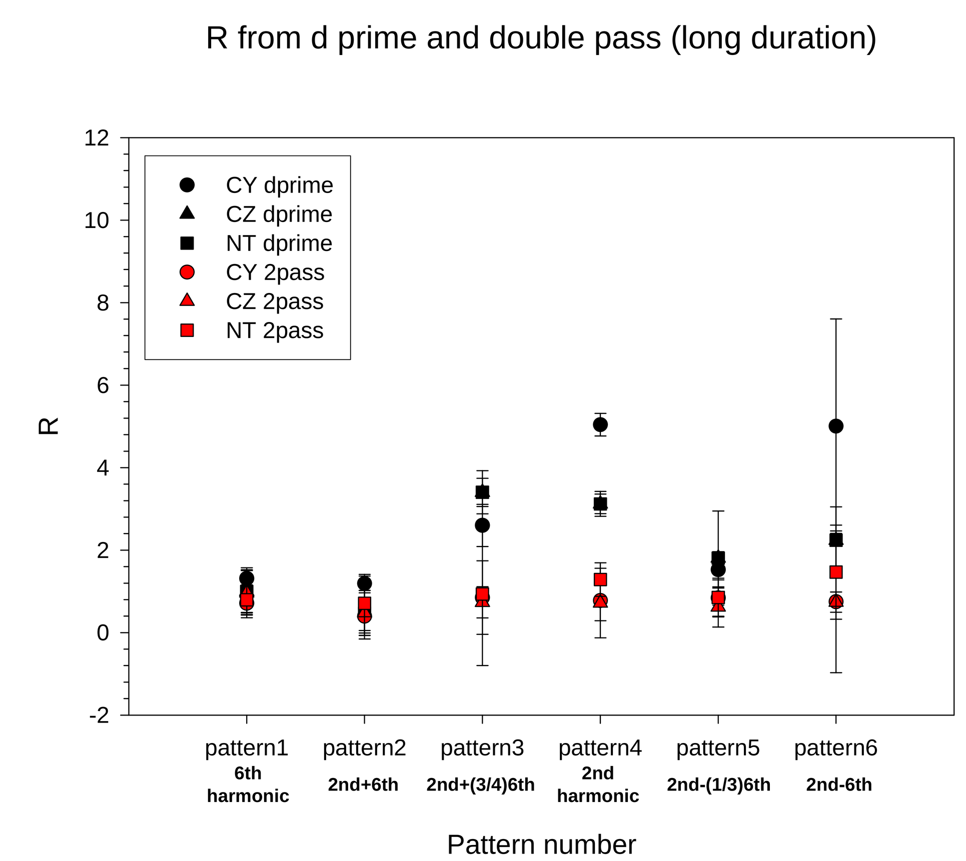
Short duration



(iii) Double Pass Results

NOTE: **error bars** represent the within subject standard error of the mean of the data.





Calculations of R from the d' are consistently higher than R from the double pass covariances by a factor of 2-6. This difference could be explained by subject's using stimulus energy rather than a matched template. This would account for a consistent response for the double pass method while allowing for degraded d' levels.

Overall, the R from double pass were consistent across all patterns. The values were less than 1, which implies a stronger contribution from systematic noise than random noise.

DISCUSSION

(i) The classification images revealed that the subjects were able to create reasonably correct templates particularly for the simpler harmonic patterns, but that there was a great deal of spread to neighboring harmonics and strong but inefficient suppression in the fourth harmonic for the "peaks add" summation conditions.

(ii) We found that some templates can be formed efficiently, improving results beyond that of the multiple channel prediction by Graham & Nachmias. This provides evidence for a template observer in suprathreshold detection tasks. However, the fact that this was not found in all cases suggests that observers had difficulty creating an efficient classification template for some of the compound stimuli.

There were several occasions where the subjects showed summation with pooling exponents of n=2 or lower. This is very different from the zero noise Graham & Nachmias result of n>4. There were other occasions where the data was similar to the Graham & Nachmias finding of no summation. We believe that there are certain templates that are difficult to form. These difficult templates are slightly different for the four observers.

(iii) The striking disagreement between the two method of calculating R, the systematic/random noise ratio was surprising. It indicates that some subjects were using variable templates, but they were consistent in their choice of template. Use of an energy summation method or a multiple channel model would be consistent with this hypothesis.

REFERENCES

Graham, N. & Nachmias, J. (1971) Detection of Grating Patterns Containing Two Spatial Frequencies: A Comparison of Single- Channel and Multiple-Channels Models. *Vision Research,* v.11, pp.251-259.

Levi, D.M, Klein, S.A., & Carney, T. (2000) Unmasking the Mechanisms for Vernier Acuity: Evidence for a Template Model for Vernier Acuity. *Vision Research*, v.40, pp.951-972.