First Plus Third Harmonic Summation in Noise

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INTRODUCTION

Graham & Nachmias (Vision Res.1971) found minimal subthreshold summation of 1st plus 3rd harmonic sinewave gratings, strongly supporting a multiple channel model against an ideal observer template model or a single channel model. However, there is mounting evidence that in the suprathreshold regime the template model does a better job. Levi, et al. (Vision Res. 2000) found that a template model explained observer's behavior on spatial frequency tuning functions better than a standard multi-scale filter model.

We performed the Graham & Nachmias experiment in the presence of noise to discriminate between three summation models for suprathreshold stimuli.

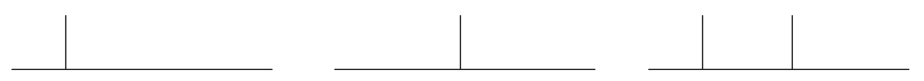
THEORY

A wide variety of models can be summarized by the Minkowski summation relationship:

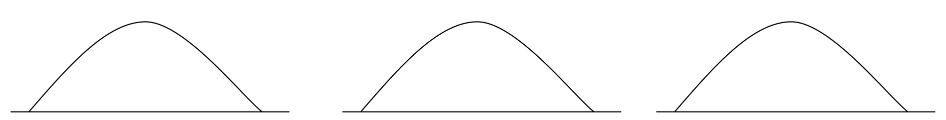
$$(c_1/Th_1)^n + (c_3/Th_3)^n = 1$$

where n is the pooling exponent, c_1 & c_3 are the contrasts and Th_1 & Th_3 are the thresholds of the 1 and 3 c/deg components. For this experiment we considered three possible models.

SAMPLE STIMLULI

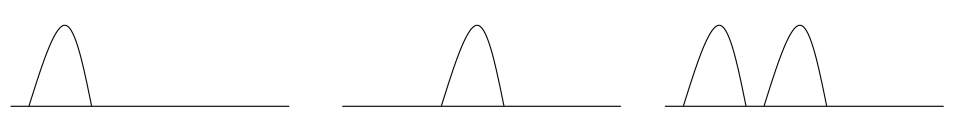


"Single Channel/ Linear Summation"



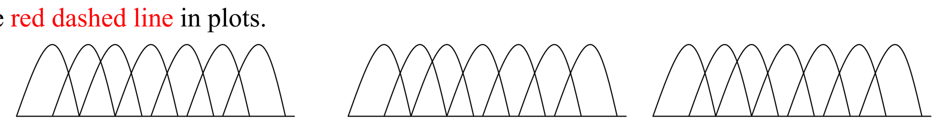
Subject uses one channel (an unvarying template) to respond to all stimuli, regardless of target. This model predicts linear summation with a **pooling exponent of n=1** as indicated by the blue dotted diagonal lines in RESULTS.

"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 plots.

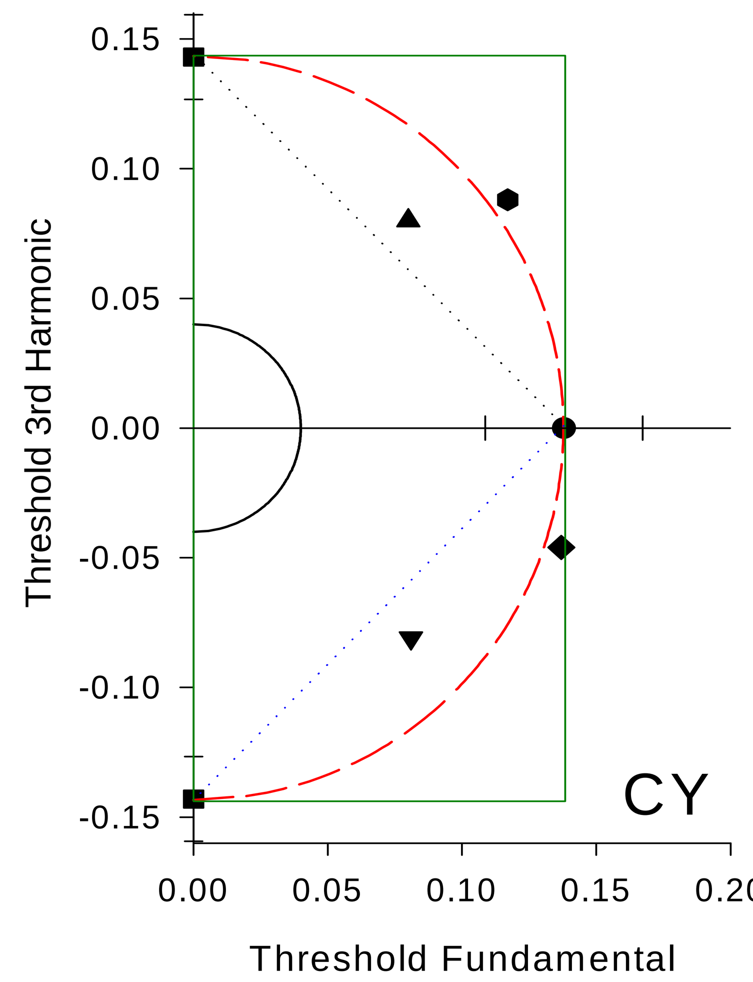
"Multiple Channel"

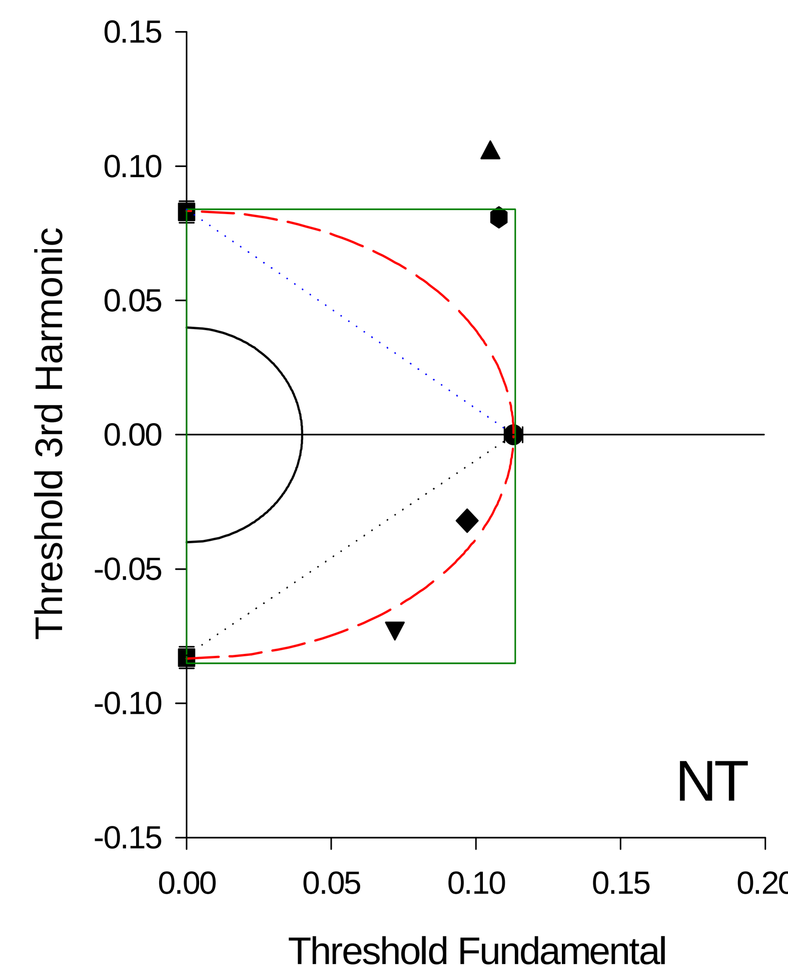


Subject has frequency tuned templates that do not span the 1st and 3rd harmonics. A model with probability summation gives a **pooling exponent of around 4-6**. A model without summation (an inability to attend to both components) corresponds to n=∞ as indicated by the green rectangular solid lines in plots.

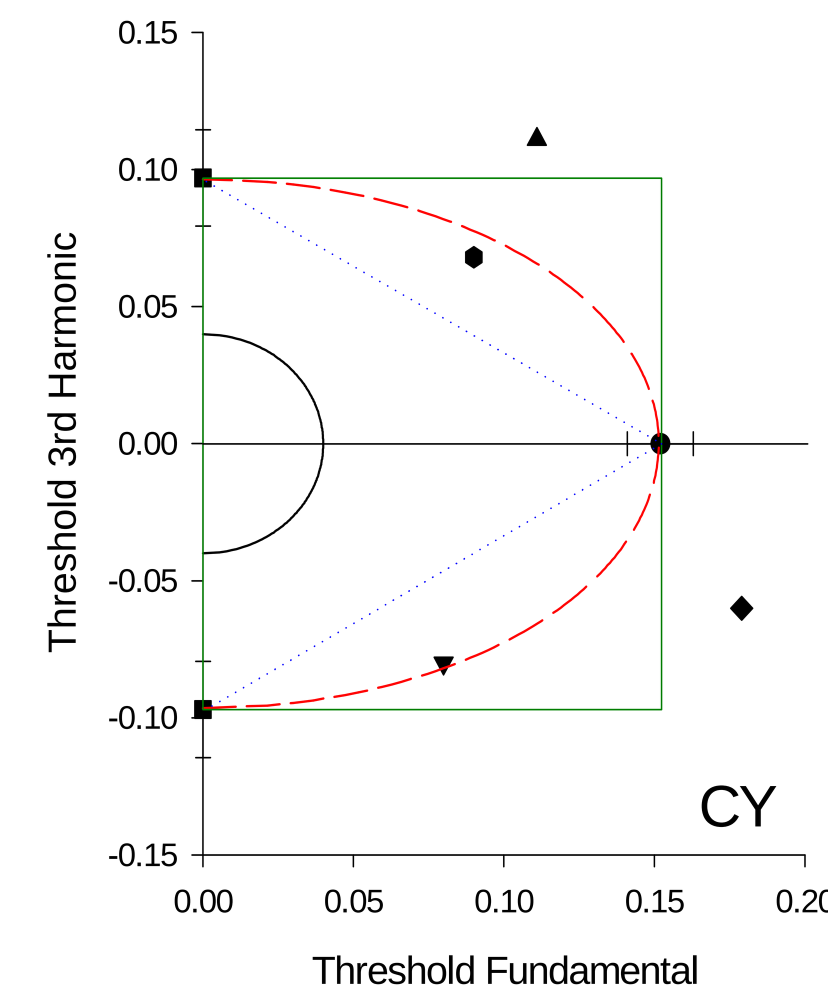
RESULTS

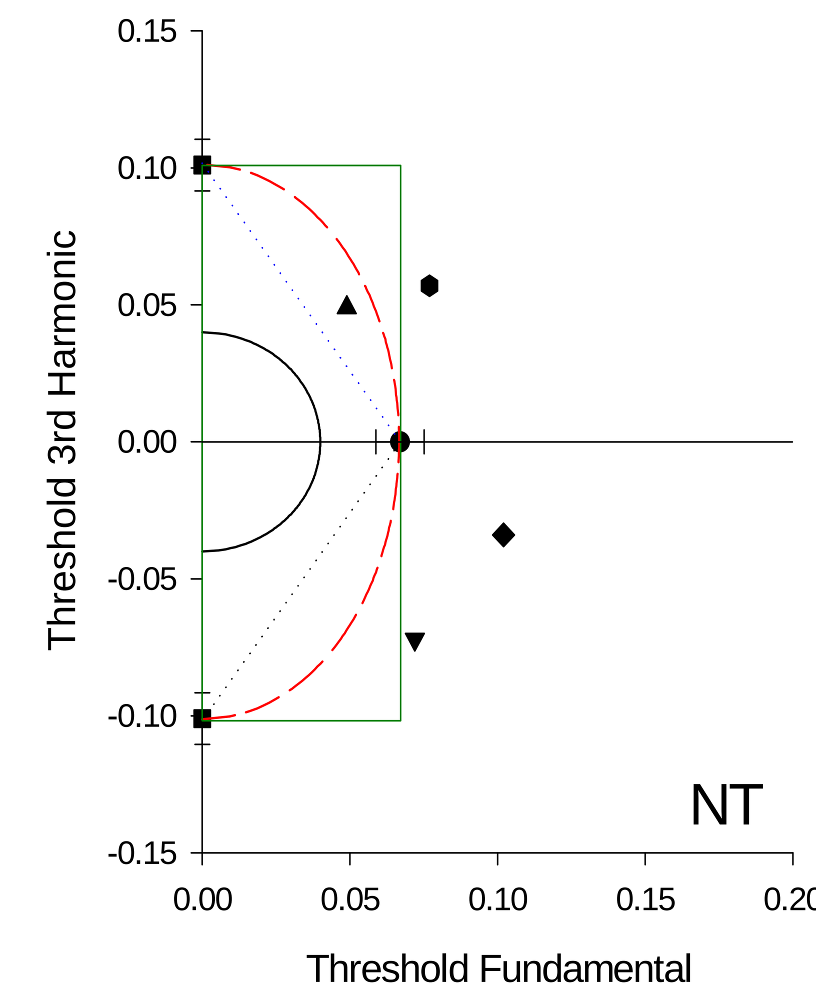
SHORT DURATION





LONG DURATION





KEY

- ● Fundamental
- ■ 3rd Harmonic
- ▲ 1st + 3rd
- ▼ 1st - 3rd
- ◆ 1st - (1/3) 3rd
- ⬢ 1st + (3/4) 3rd
- — ideal observer with efficiency = 1

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

Subject (CY) showed evidence of **strong summation**, with data falling either near the predicted template curve or near the linear summation lines. The main difference between the data of CY and NT is that CY's threshold for the 3rd harmonic is degraded. He may need more practice in developing a template for the 6 cycle 3rd harmonic stimulus.

Subject (NT) showed no summation for the peaks-add condition (1st + 3rd and 1st + (3/4) 3rd patterns) but did show good template summation in the peaks-subtract condition (1st - 3rd and 1st - (1/3) 3rd patterns). NT was apparently able **to form reasonable templates for the peaks-subtract condition but performed like a multiple channel observer in the peaks-add condition**.

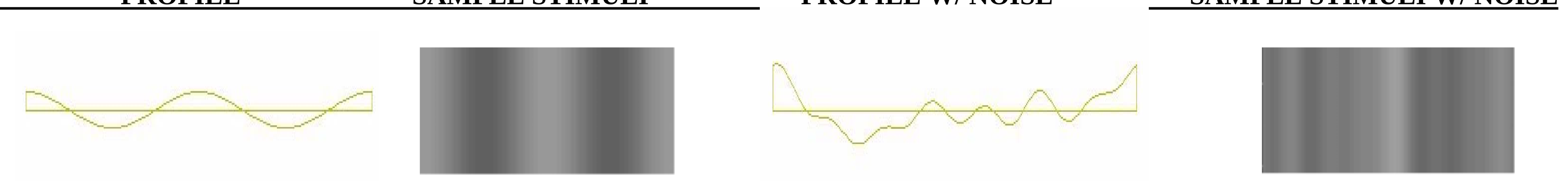
Subject (CY) showed much less evidence of summation, with data falling either near the predicted template curve or near the multiple channel predicted rectangle. The longer duration allowed CY to improve the 3rd harmonic threshold. CY **performed like a noisy template or a multiple channels model would predict**.

Subject (NT) showed improved thresholds for the 1st, 1st + 3rd, and 1st + 3/4 3rd, but not for the other stimuli. This led to performance that looked **like what a noisy template or a multiple channels model would predict**.

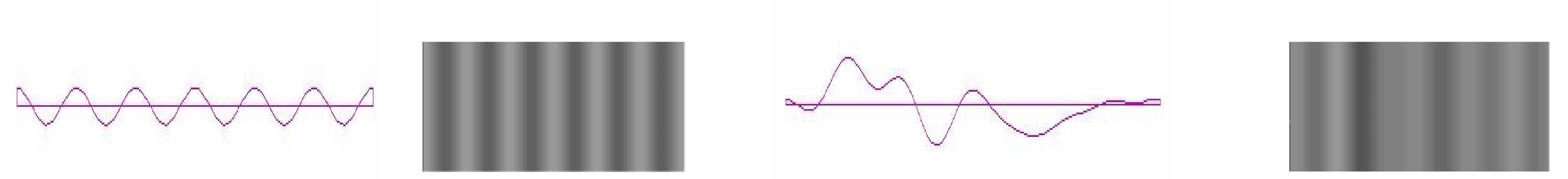
STIMULI

HARMONICS | PROFILE | SAMPLE STIMULI | PROFILE W/ NOISE | SAMPLE STIMULI W/ NOISE

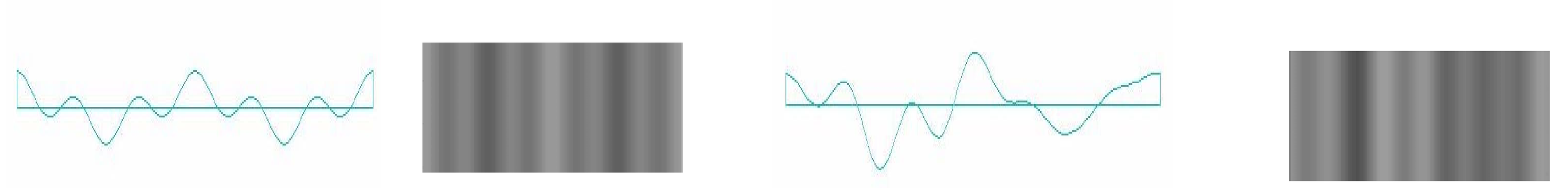
FUNDAMENTAL



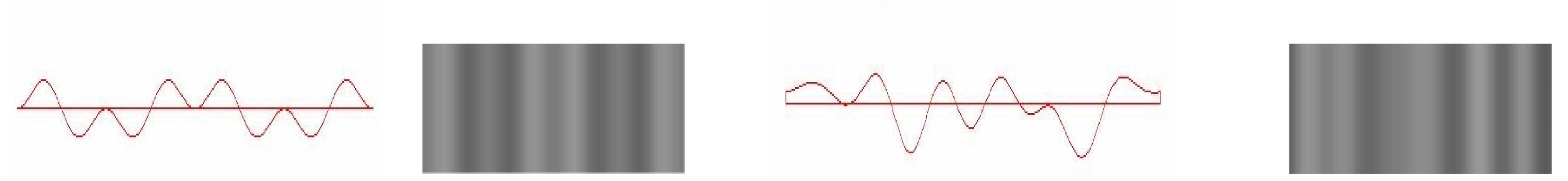
3rd HARMONIC



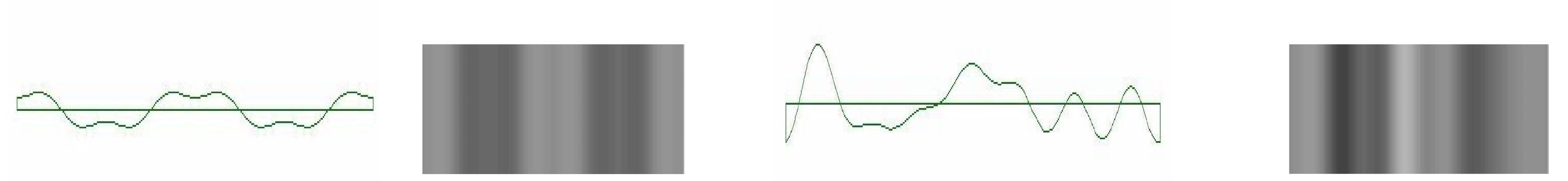
1st + 3rd



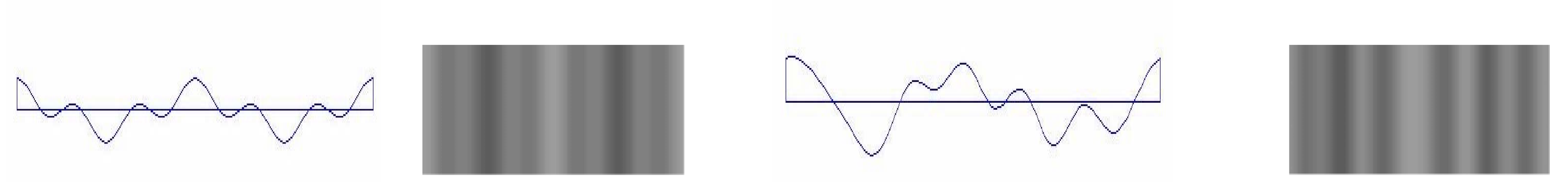
1st - 3rd



1st - (1/3) 3rd



1st + (3/4) 3rd



METHODS

The noise was the sum of seven spatial frequencies from 0.5 to 3.5 c/deg in 0.5 c/deg steps. The contrast of each noise harmonic had a 4% Gaussian standard deviation in both sine and cosine phases. Six cosine phase test patterns were used: 1st (or fundamental), 3rd , 1st + 3rd, 1st -3rd, 1st – (1/3) 3rd and 1st + (3/4) 3rd . Short (0.75 sec) and long (2.0 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.

We used the method of constant stimuli with 4 test contrast levels (0, 1, 2 and 3 times a base contrast) and 4 responses. For example the last test pattern was c*(cos(2πx) + .75 cos(3*2πx)). We used two subjects, both experienced in psychophysical experiments. One subject (CY) was deliberately 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 150 trials per run and 2-4 runs were performed by each subject.

CONCLUSION

CY commented that he did not have a good idea what to look for and mentioned that several of the patterns were particularly "difficult". NT felt that several of the patterns were more difficult to detect than others. For some of the patterns, CY said that his judgments were often made on the basis of contrast alone. This would lead to the linear summation or single channel prediction that he showed some evidence for in the short duration trials.

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 different for the two observers.

In future experiments we will include conditions in which observers are able to refresh their memory of the appearance of the zero noise template while in the middle of a run. Preliminary data from more subjects hints that certain templates are definitely more difficult to form than others, but again are not necessarily the same templates are difficult for each subject.

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.