DECAY OF VISUAL MEMORY IS DUE TO DECREASED SIGNAL, NOT INCREASED NOISE

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1. Background.

Memory for visual patterns can decay over both long and short periods of time[1,2]. Changes in sensitivity as memory decays could be due to a decrease in internal signal strength, an increase in internal noise or both. Black-box models have been used to discriminate between the effects of these two factors in many tasks[3,4].

The simplest version of these models assumes that contrast-invariant internal noise (N_i) is added to the external stimulus, and that the observer performs a contrast-invariant calculation on the resulting quantity. A decision is then made based on the results of the calculation (FIG. 1.1). The observer's threshold (E) will be some proportion k of the sum of N_i and an externally added noise (N_e). Changes in contrast-invariant internal noise (N_i) and the efficiency of the calculation (k) will have distinctively different effects on performance across different levels of external noise (FIG. 1.2).

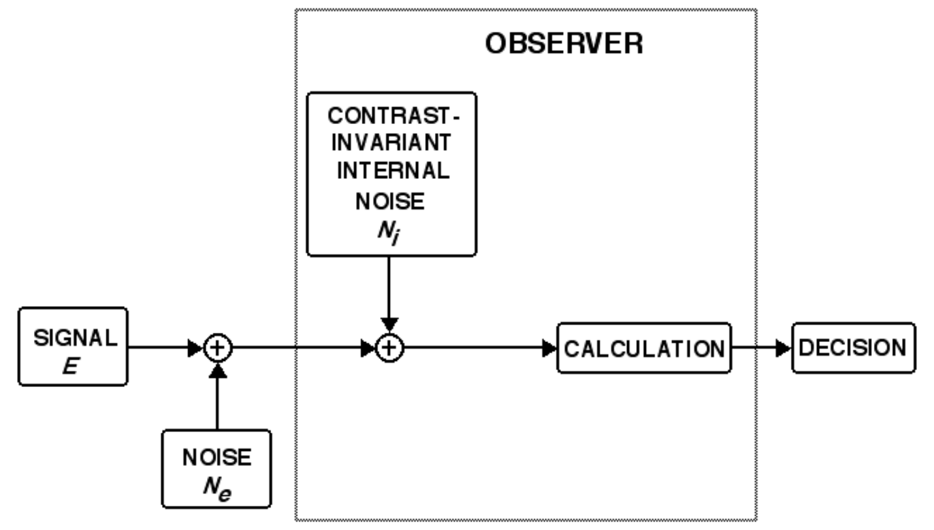

FIGURE 1.1

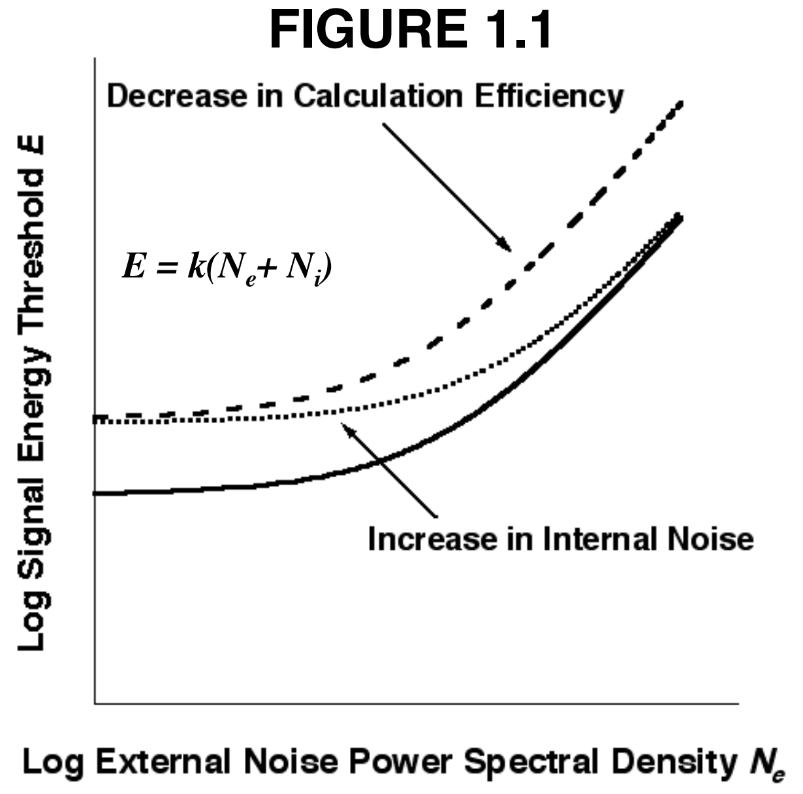

FIGURE 1.2

2. Methods.

Observers performed a two-interval same/different discrimination task with randomly generated pairs of textures (2-4 c/image band-pass filtered Gaussian noise fields) embedded in Gaussian white noise. Each interval was 500 ms, and the delay between intervals was either 100, 500 or 2000 ms. The same delay was used throughout a session (FIG. 2.1). Texture contrast was manipulated across trials to obtain 71% correct discrimination thresholds (FIG. 2.2).

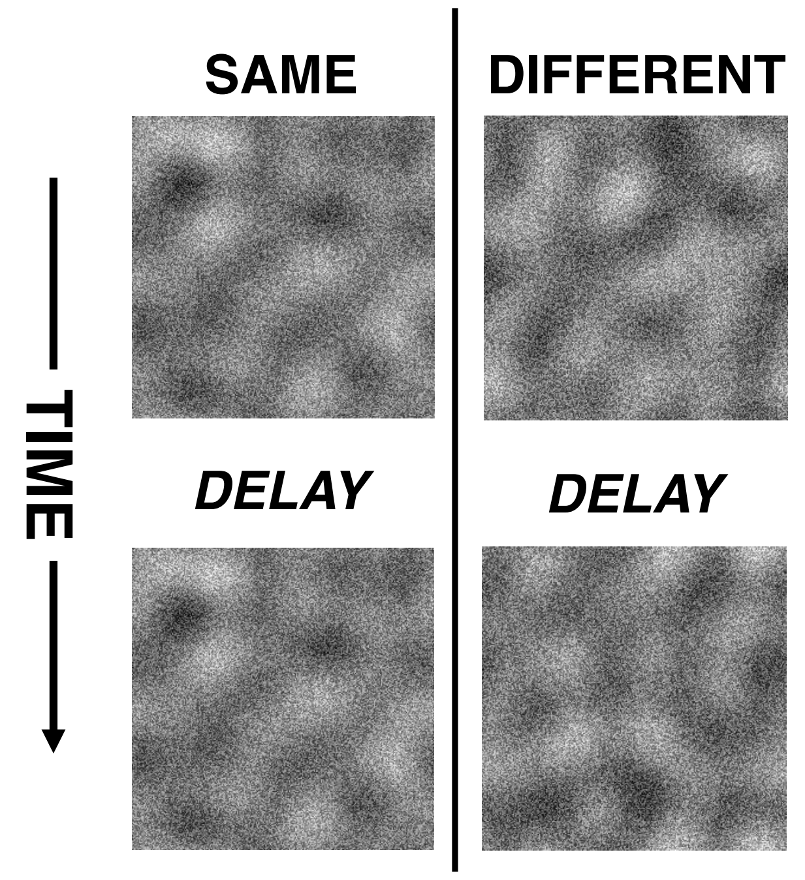

FIGURE 2.1

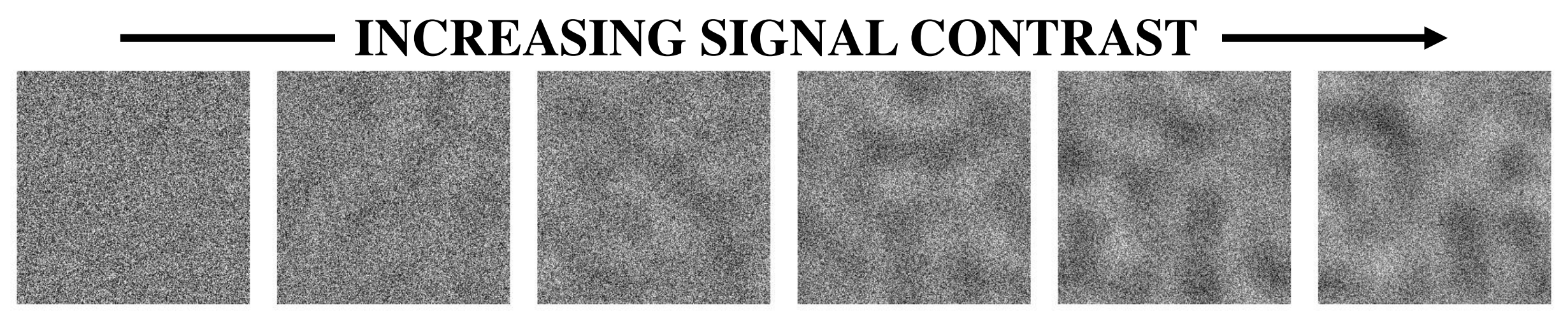

FIGURE 2.2

3. Experiment 1: Calculation Efficiency and Contrast-Invariant Internal Noise.

At each time delay, discrimination thresholds were measured for 5 observers across 5 levels of external noise. Linear functions were fit to each observer's thresholds as a function of the level of external noise. The slope parameter (k) was used to compute calculation efficiency and the x-intercept (N_i) to estimate the magnitude of contrast-invariant internal noise. The slope parameter for an optimal observer (k_{ideal}) was estimated by Monte Carlo simulations, and calculation efficiency was defined as k_{ideal}/k_{human}. Figure 3.1 plots thresholds and linear fits for two observers at each time delay. Figure 3.2 plots the corresponding calculation efficiency and internal noise estimates for all 5 observers.

These data show that calculation efficiency declined with increasing time delay, and that the majority of the effect occurred after 500ms. However, contrast-invariant internal noise remained relatively fixed with increasing time delay (although there was a small increase in noise for observers JMI and JSW).

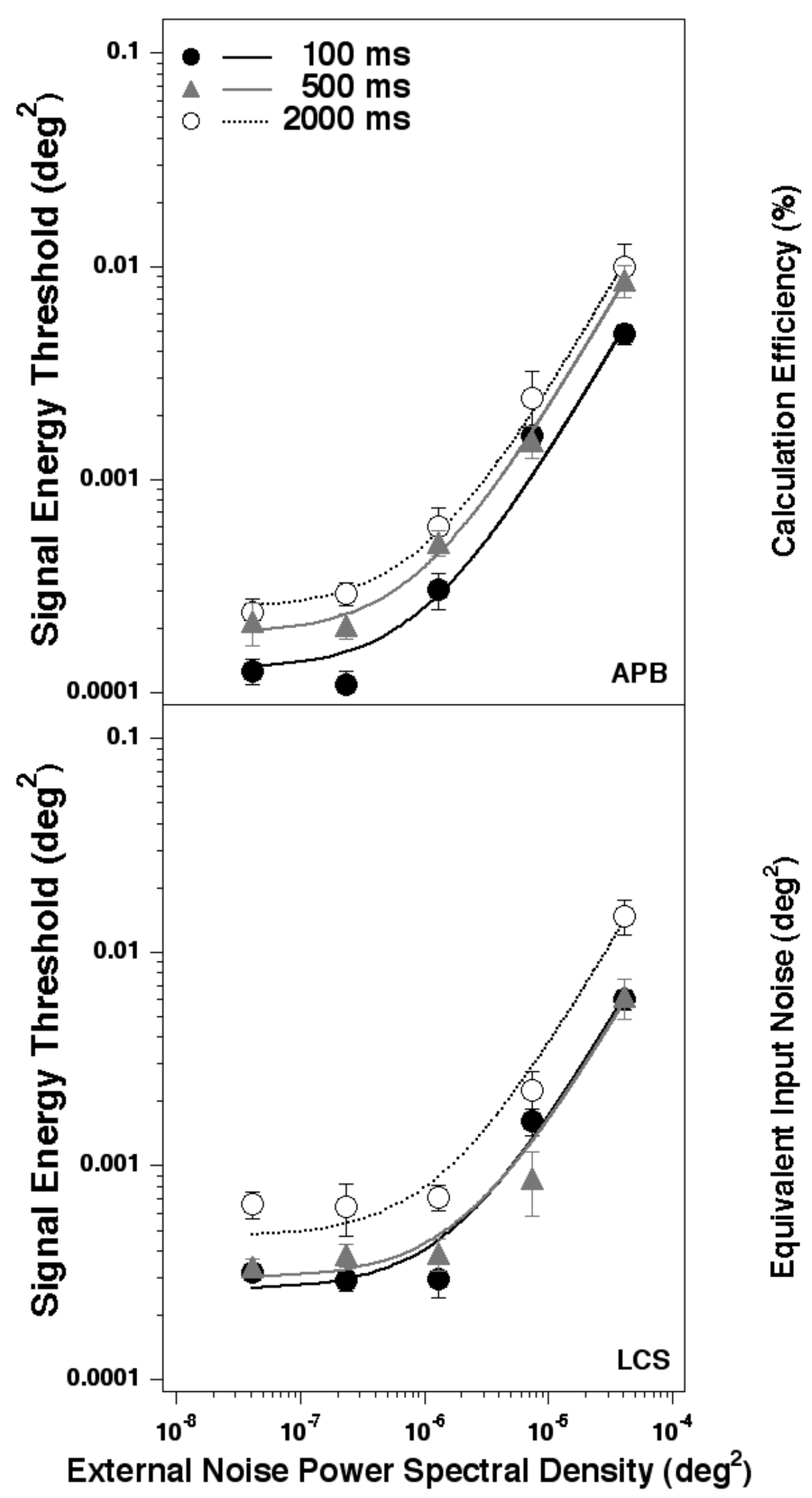

FIGURE 3.1

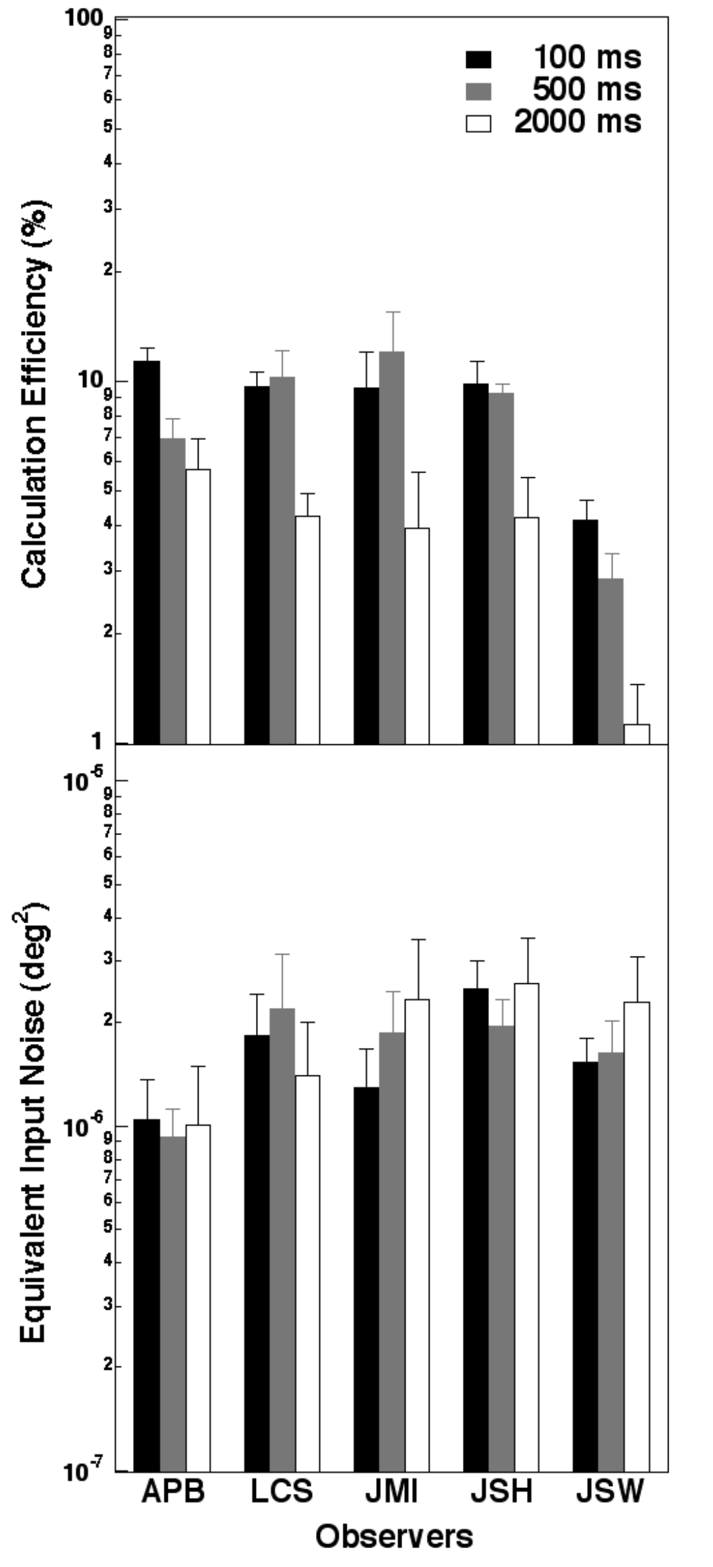

FIGURE 3.2

4. Experiment 2: Contrast-Dependent Internal Noise.

There is both psychophysical[5,6] and physiological[7] evidence for a second kind of internal noise that grows with the level of external noise. It can be shown[5,6] that a change in proportional contrast-dependent internal noise will have the same effect across thresholds as a change in calculation efficiency. An independent estimate of contrast-dependent internal noise can be obtained by double-pass response consistency in high external noise[5,6]. The same 5 observers performed the discrimination task in high external noise only, and made two identical passes through the same stimulus set in each session. Figure 4.1 plots percent correct performance as a function of percent agreement of responses between the two passes for two observers. In these plots, an increase in contrast-dependent noise would shift the data leftward. Figure 4.2 plots the corresponding efficiency and internal/external noise ratio estimates for all 5 observers.

These data show that contrast-dependent internal noise did not increase with the passage of time, and imply the results of Experiment 1 were due to non-stochastic changes in the efficiency of internal calculations.

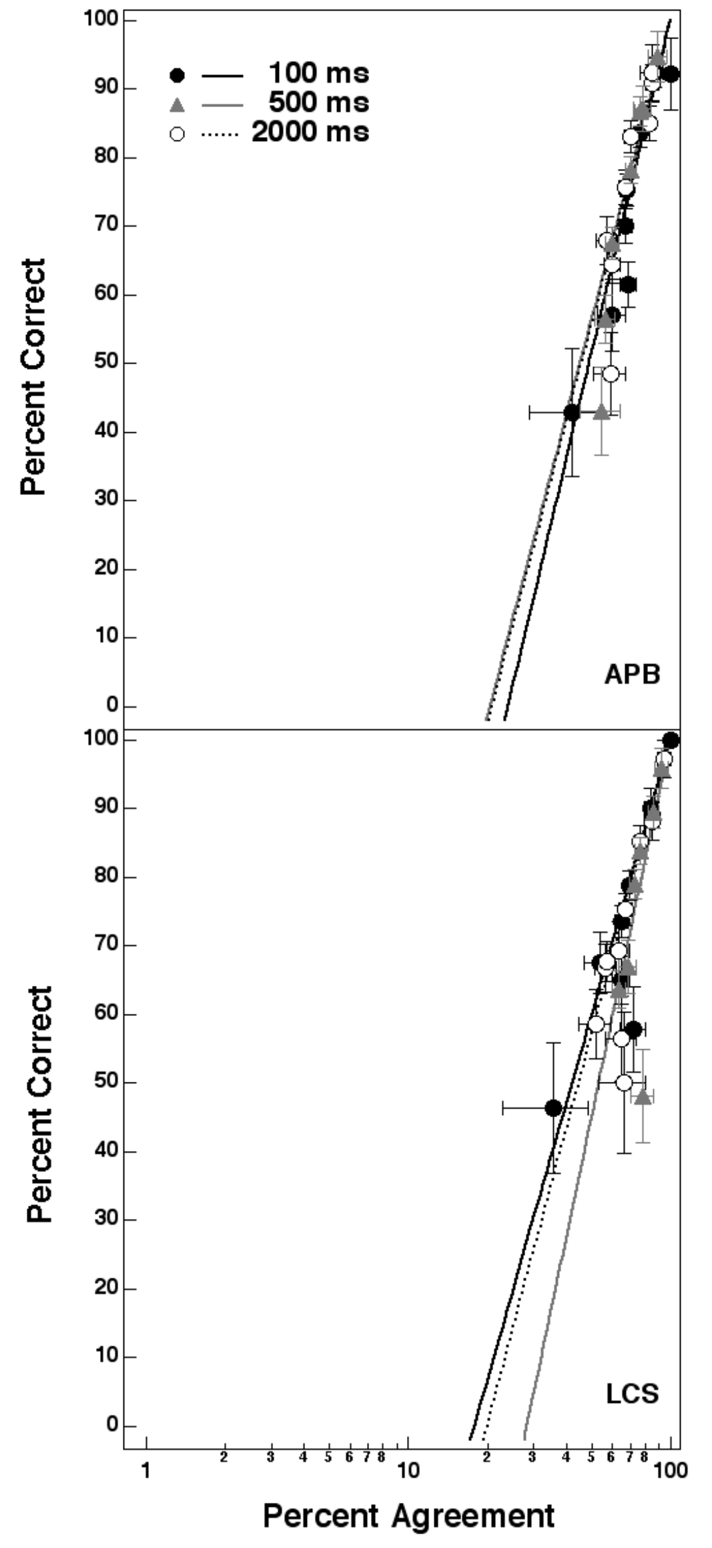

FIGURE 4.1

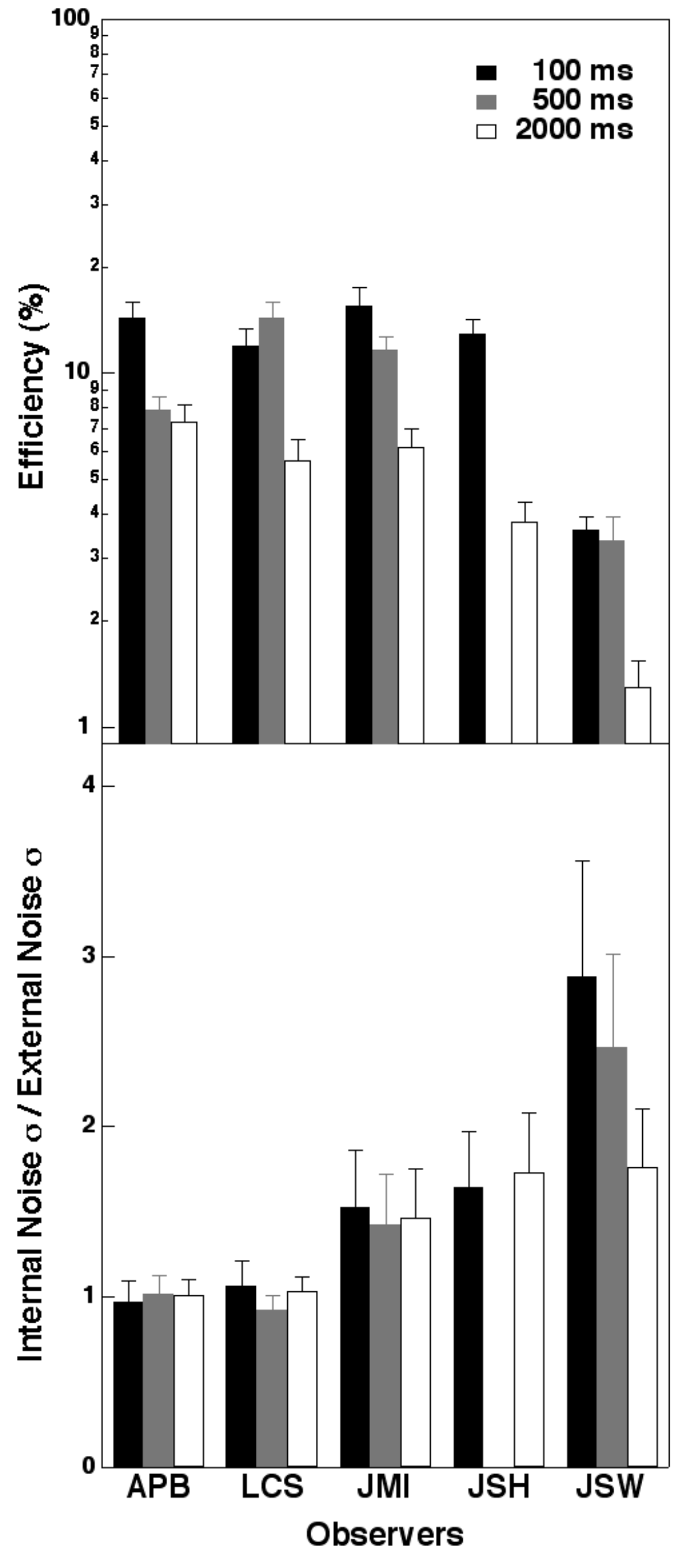

FIGURE 4.2

5. Experiment 3: Internal Filter.

One way to conceptualize an observer's calculation is in terms of an internal filter. In our task, only the frequencies where the signal is present (2-4 c/image) carry any information, making the ideal filter restricted to this region. A departure from the ideal filter shape would reduce calculation efficiency. We estimated the characteristics of observers' internal filters by computing the correlation between the noise added to the signals and observers' responses across trials[8,9]. This analysis reveals the parts of the stimulus where noise influenced observers' responses. Although the spatial profile of the textures changed on every trial in our task, the bandwidth of the textures in the frequency domain remained fixed. Thus, the analysis was performed on the Fourier spectra of the noise. The data from the 100 and 2000 ms conditions from Experiment 2 as well as data from two new observers were used to determine which spatial frequencies observers used as memory decayed. Figure 5.1 plots the correlation between observer's 'different' responses and the power of the external noise at each spatial frequency (collapsed across orientation) in the first interval, second interval, and the difference between the second and first intervals. These data reveal that observers tended to rely upon frequencies higher than the signal pass-band at the longer time delay, suggesting that at least part of the reduction in calculation efficiency with memory decay in this task is due to a shifting of the internal filter to include uninformative higher frequencies outside of the signal band.

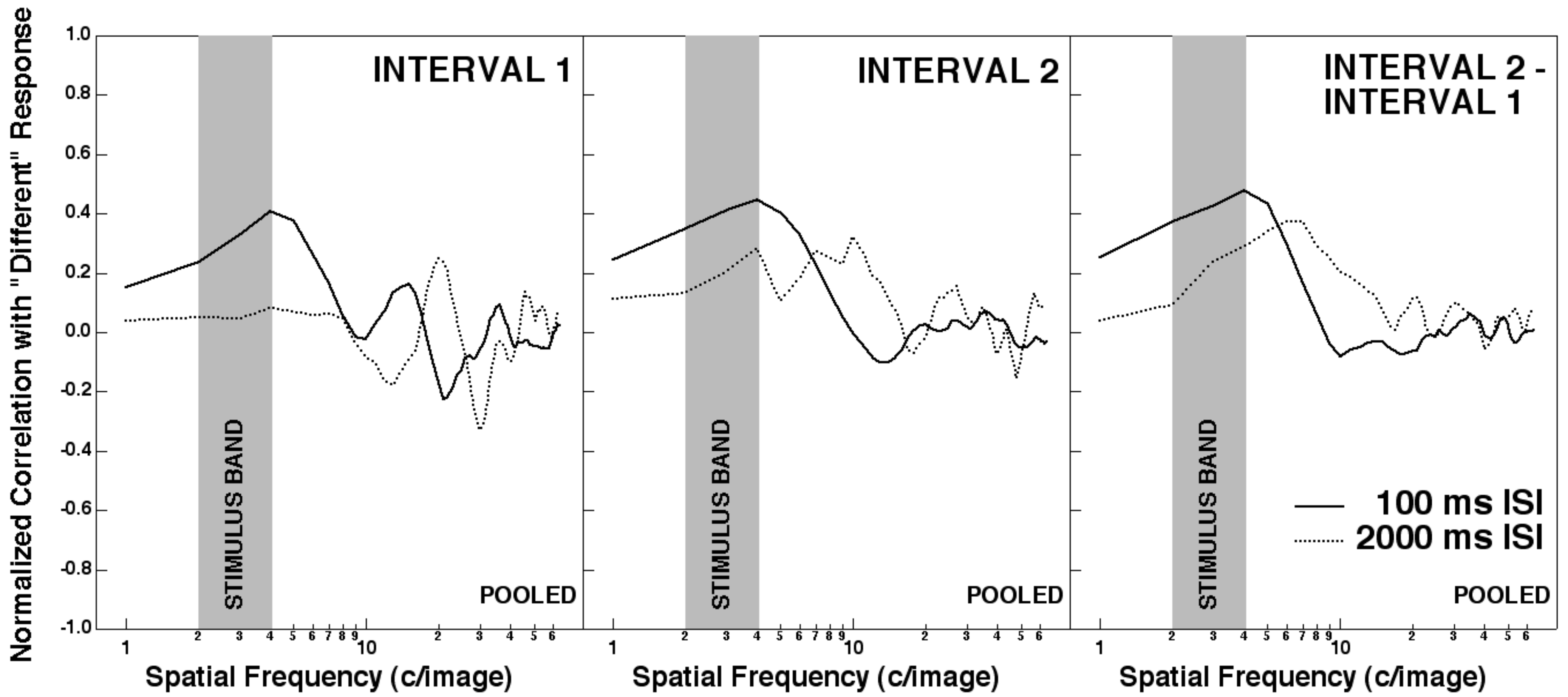

FIGURE 5.1

6. Conclusions.

- Increasing the delay between stimulus intervals from 100 to 2000 ms reduced calculation efficiency by about a factor of two but had little or no effect upon both contrast-invariant and contrast-dependent internal noise.
- . The reduction in calculation efficiency may be due in part to observer's tendency to use uninformative frequencies outside of the stimulus pass-band at longer time delays.
- Future work will explore i) why observers adopt this sub-optimal strategy as memory decays; and ii) whether this effect generalizes to other visual memory tasks.

7. References & Acknowledgments.

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