ELECTROPHYSIOLOGICAL CORRELATES OF THE EFFECTS OF PERCEPTUAL LEARNING ON SIGNAL AND NOISE IN THE HUMAN VISUAL SYSTEM

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1. Background.

Performance in visual tasks often improves with practice[1]. Changes in contrast sensitivity with training could be due to an increase in internal signal strength, an decrease in internal noise or both. So far, linking the effects of perceptual learning to these factors has only been investigated in behavioral paradigms[2,3]. In this study, we investigated the effects of perceptual learning on behavioral and electrophysiological contrast thresholds and tried to relate these changes to the relative contributions of signal and internal noise.

The simplest version of current black-box models of a human information processing in signal detection and discrimination tasks assumes that contrast-invariant internal noise (N_i) is added to the external stimulus, and that the observer performs a noisy contrast-invariant calculation on the resulting quantity[4]. A decision is then made based on the results of the calculation (Figure 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) (see Figure 1.2). Changes in N_i and the efficiency of the calculation (k) will have distinctively different effects on performance across different levels of external noise (Figure 1.2).

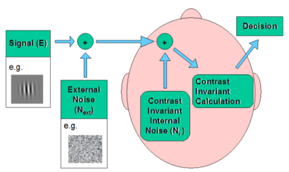

FIGURE 1.1

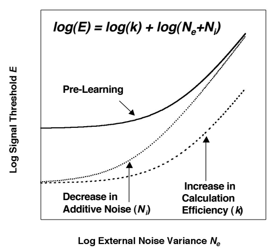

FIGURE 1.2

2. Methods.

In the behavioral task observers had to determine the orientation of a foveally presented counter-phase flickering Gabor pattern (1 c/deg; reversal rate of 18.6 Hz) oriented either left or right of vertical by 4 degrees. The Gabor was embedded in one of five different levels of dynamic external white Gaussian contrast noise. The contrast of the Gabor was varied across trials according to a staircase procedure to obtain 71% correct discrimination thresholds. Observers participated in four 800-trial training sessions.

Steady-state visual evoked potentials (SSVEP's) were recorded from electrode site O_z for each observer both before and after they participated in the behavioral task. During the recording, subjects performed the same orientation discrimination task, with the exception that the signal swept from low to high contrast before the observer made his or her response.

Contrast thresholds at each noise level were derived as a function of VEP response at the temporal signal flicker frequency using a sweep VEP technique[5,6].

Linear functions were fit to both the behavioral and electrophysiological thresholds for each noise level. The slope parameter (k) was used as an index of calculation efficiency and the x-intercept (N_i) was taken as an estimate the magnitude of contrast-invariant internal noise.

3. Behavior.

Figure 3.1 shows behavioral thresholds as a function of external noise contrast for each individual subject as well as the average across subjects. These data show that thresholds increased linearly with external noise (plotted here in log-log coordinates) and that thresholds decreased over the course of the four training sessions.

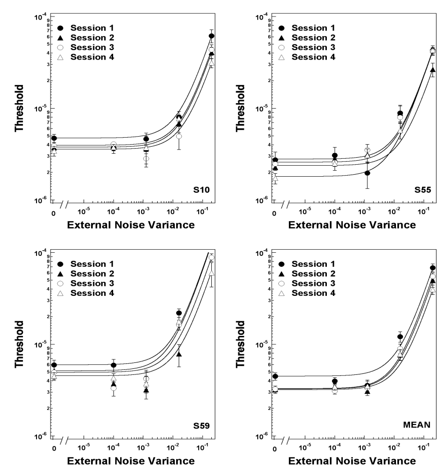

FIGURE 3.1

Figure 3.2 shows the corresponding parameter estimates derived from the data in Figure 3.1. These data show that training predominantly served to increase calculation efficiency (as indexed by a reduction in the slope k), although there was also a small *increase* in N_i in the last training session (see conclusions).

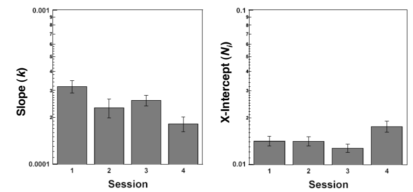

FIGURE 3.2

4. Electrophysiology.

Figures 4.1 and 4.2 show time–frequency spectrograms for a representative subject before (left panel) and after (right panel) training for the lowest (Figure 4.1) and the highest (Figure 4.2) noise conditions. Event-related Spectral Perturbations (ERSP, upper panels in each Figure) and Inter-Trial Coherence (ITC, lower panels in each Figure) are shown throughout the time course of the trials (~10s). Zero ERSP indicates no difference between baseline power and signal power at a particular point in time. Non-significant differences from baseline are colored in green ($p < 0.05$).

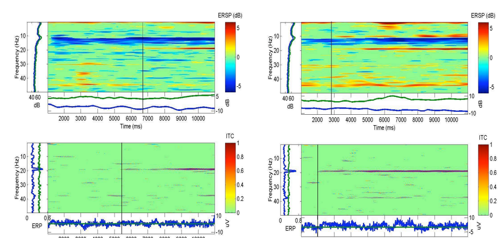

FIGURE 4.1

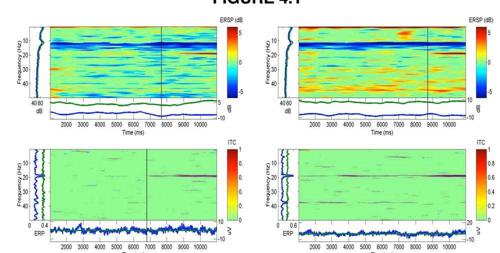

FIGURE 4.2

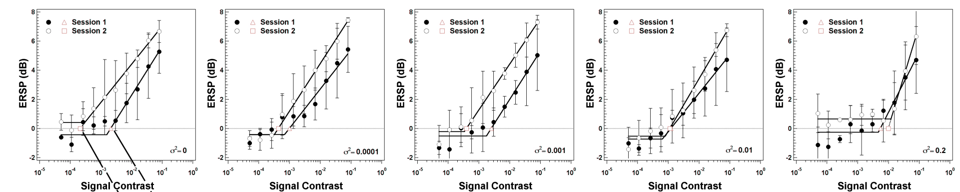

FIGURE 4.3

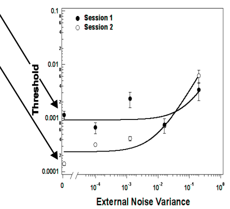

FIGURE 4.4

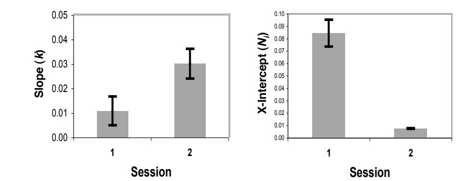

FIGURE 4.5

Figures 4.1 and 4.2 show that significant increases of ERSP and ITC occurred at an earlier points in time (i.e., at lower contrast levels) after training, and that this effect was larger for the lowest than the highest noise condition. Figure 4.3 shows grand average (N = 3) ERSP values as a function of contrast in each external noise condition. The solid lines are the best-fitting (least-squares) bi-linear fits to the data. Contrast thresholds were derived by extrapolating each function to 0 ERSP before (Δ) and after (□) training.

Figure 4.4 shows the resulting electrophysiologically-derived thresholds as a function of external noise contrast before (open symbols) and after (closed symbols) training. The solid lines show the least-squares linear fits to the data. Figure 4.5 shows the corresponding k and N_i parameter estimates for each session. These data show that, unlike the behavioral data, practice reduced electrophysiological contrast thresholds only at the lowest noise conditions, resulting in a large decrease in N_i (and a small *increase* in k).

5. Conclusions.

- At the level of behavior, practice in a Gabor orientation task was predominantly associated with an increase in calculation efficiency.
- At the level of electrophysiology, practice in the same task was predominantly associated with a reduction in additive internal noise.
- One factor that may have contributed to the apparent contradiction between the behavioral and electrophysiological results is that the ERSP was most likely related to the *detectability* of the signals, whereas behavioral thresholds were determined by the *discriminability* between the signals.

6. References.

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