A mixture model demonstrates use of distinct strategies in a global motion direction task

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Abstract

Mixture models are well known in cognitive psychology, less so in vision. Are there cases where the data allow clear testing as to whether different strategies are employed in a task? Most psychophysical measurements manipulate a single staircase variable to map out a monotonic increasing function, but if performance is limited by different mechanisms over the range of the variable, classical fitting could be inappropriate. We present a data set and analyses that confirm the presence of two visual strategies addressing the same task, with the choice of strategies depending on the staircase variable. In a net-motion discrimination task, stimuli were random-dot kinematograms with a fixed percent coherence, and the contrast ratio between signal and noise dots was the staircase variable. When signal and noise dots have similar contrast, the most effective strategy is to average all local motion vectors across the display. However, low contrast ratios enable a selective-tracking strategy in which attending to the dim signal dots makes them easier to detect, which creates a positive feedback loop driving the signal dot contrast further down until a second threshold is reached.

The model and fitting results

Suppose the global-averaging strategy and the selective-tracking strategy have separate thresholds, each corresponding to a single-regime psychometric function modeled by a Gaussian cumulative distribution function. We use $P_{\mathrm{g}}(\mu_{\mathrm{g}}, \sigma_{\mathrm{g}})$ and $P_{\mathrm{s}}(\mu_{\mathrm{s}}, \sigma_{\mathrm{s}})$ to denote the psychometric functions for global-averaging and selective-tracking strategies respectively. In a given trial, the probability P of getting a correct answer with a choice between the two strategies is given by:

$$P = p_{\mathrm{g}} \cdot P_{\mathrm{g}}(\mu_{\mathrm{g}}, \sigma_{\mathrm{g}}) + (1 - p_{\mathrm{g}}) \cdot P_{\mathrm{s}}(\mu_{\mathrm{s}}, \sigma_{\mathrm{s}}), \tag{1}$$

where p_{g} denotes the probability of choosing the global-averaging strategy. Then we model p_{g} as a function of the staircase variable $x \in$ (-3, 3), which is the log signal-to-noise contrast ratio within the physical range of stimuli. Here p_{g} is itself a logistic that describes the probability ratio of choosing one strategy over the other from 0 to 1 with parameters (β_0, β_1):

$$\log(\frac{p_{\mathrm{g}}}{1 - p_{\mathrm{g}}}) = \beta_0 + \beta_1 \cdot x \ \Rightarrow \ p_{\mathrm{g}} \ = \frac{1}{1 + e^{-(\beta_0 + \beta_1 \cdot x)}}. \tag{2}$$

We maximize log-likelihood of the data to estimate the six parameters (μ_{g}, σ_{g}, μ_{s}, σ_{s}, β_0, and β_1) for each subject at each of three percent coherence levels. Figure 1 illustrates how this model successfully describes our data. For these subjects, there was little use of the selective-tracking strategy when coherence was 8%; but at 16% and 24% coherence, the threshold contrast ratio was lower (as expected) and subjects were able to employ the selective-tracking strategy.

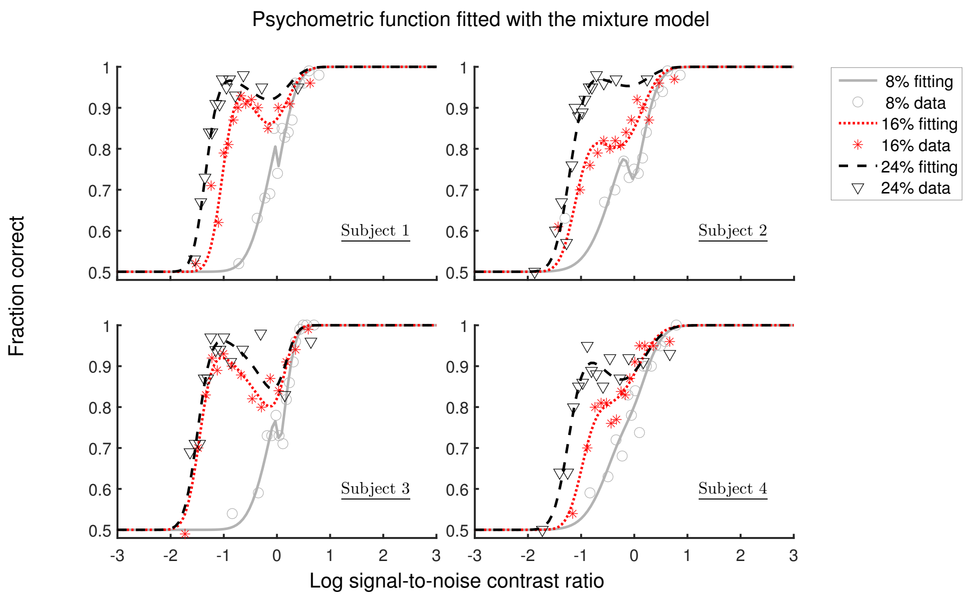

Figure 1: Psychometric functions fitted with the mixture model of global-averaging and selective-tracking strategies. Each panel shows fitting results of one subject at 3 coherence levels.