A signal detection model for the analysis of continuous response gradients and an application to confidence rating data

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Many perceptual tasks result in behavioral gradients depicting a continuous response as a function of stimulus value. Examples are gradients of confidence in perceptual decisions or response times. In many cases, researchers are interested in linking the mechanisms underlying continuous behavioral measures and perceptual choices. For example, a common question is to what extent metacognitive confidence judgments depend on the same internal variables as perceptual choices.

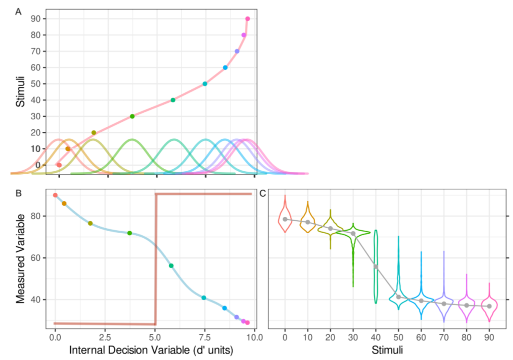

Figure 1

The signal detection model for perceptual choices in a study with multiple stimuli (i.e., a psychometric function) proposes that a transducer function relates stimulus differences to the mean of a sensory evidence variable (Figure 1A). Gaussian internal noise is added to that mean to determine the value of evidence in a given trial (bottom of Figure 1A), and a step function determines what evidence values result in a discrete response (Figure 1B, in red). A behavioral gradient involves a continuously-valued response, so the key change to this model involves replacing the step function by a continuous function, which we assume is monotonic (Figure 1B, in blue). Such a behavioral link function transforms the sensory evidence to a continuous response (Figure 1C).

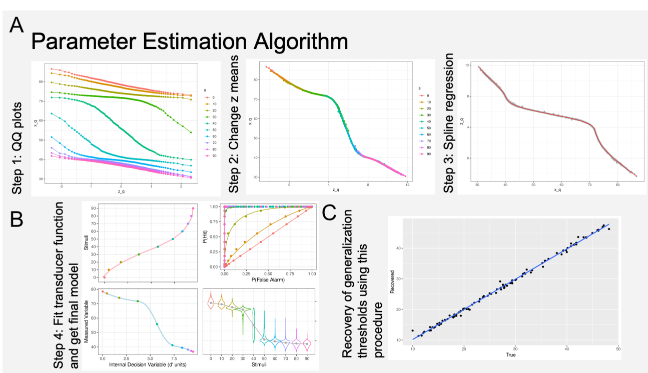

Figure 2

To estimate the parameters of this model, we can start with the continuous data and work our way backwards (Figure 2). First, we obtain quantiles from the distribution of responses to each stimulus, and we plot them against corresponding quantiles of the standard Gaussian distribution (i.e., QQ-plots for each stimulus). Second, we change the means of all Gaussian distributions to optimize the Spearman rank correlation of the x-quantiles and the z-quantiles. Third, we use monotone spline regression to estimate the function depicted in this QQ-plot. Finally, we fit the transducer function to the mean of each distribution. This algorithm does a good job of recovering the model originally used to generate a dataset (compare Figure 1 and Figure 2B).

One of the parameters of the transducer function is a threshold corresponding to $d' = 1$; a single value expressed in the scale of the stimuli, and thus comparable across tasks using the same stimulus dimension. Figure 2C displays the accuracy of the algorithm to recover the threshold from simulated data. The correlation between the true and recovered values of the threshold is 0.9981.

We applied the model to data from a perceptual decision making experiment, in which participants were presented with random dot motion stimuli with four different proportions of coherently moving stimuli, and asked to both choose the direction of motion and rate the confidence on their responses on a continuous 50-point scale. The new model was fitted to the confidence data using the QQ algorithm, and the traditional SDT model of the psychometric curve was fitted to the choice data using traditional methods. Figure 3 shows a comparison of the two obtained transducer functions for a representative participant. Sensitivity in the confidence task rises more slowly with motion coherence than sensitivity in the choice task, with a threshold of 0.058 in the former and 0.031 in the latter.

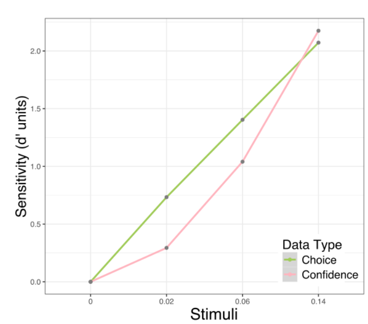

Figure 3

In sum, the proposed model and estimation procedure allow one to accurately answer questions about the mechanisms underlying differences in behavioral gradients. One can directly compare transducer and behavioral link functions across tasks that share the same stimulus space or behavioral response, respectively. An issue with the presented algorithm is that it requires relatively large numbers of trials per stimulus, but adaptive psychophysics can be used to more efficiently estimate model parameters.