Multiple Methods of Modeling and Detecting Perceptual and Cognitive Configurality

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Introduction

A central question in perceptual and cognitive psychology is the nature of the processes that combine the multiple sources of environmental information in order to support the subjective, unitary percepts of objects. Characterization of these processes, at a general level, has been a goal of perceptual and cognitive sciences for more than a century. One of the more promising extant approaches is known as general recognition theory (GRT; Ashby & Townsend, 1986). GRT provides formal, mathematically-specified definitions of the ways in which perceptual dimensions (e.g., the various elements of a face) can interact during perception and identification, and generalizes the signal-detection-based distinction between perceptual and decisional effects to multidimensional stimuli.

Mean-Shift Integrality

One situation in which information about the internal perceptual and decision spaces may be difficult to obtain is when a mean-shift occurs in a set of stimuli (see, e.g., Maddox & Ashby, 1992). This particular situation is one in which a change in level of one dimension of a multidimensional stimulus results in a shift of the internal representation such that all relative distances are preserved (Figure 1). Here the equal-likelihood contours for bivariate distributions 2 and 4 have been shifted upwards yet their relationship is identical to that for distributions 1 and 3. Here, the distance (or marginal d') between distributions 2 and 4 is the same as that between distributions 1 and 3, and for both pairs, the decision bound lies in the same relative location. In such a situation, the decision bound can shift in a piecewise (left panel) or continuous (right panel) manner. A continuous decision bound gives rise to correlations in observable responses to the two dimensions: as the evidence pertinent to dimension x increases (for example responses to y increasingly fall below the decision bound (see Figure 1).

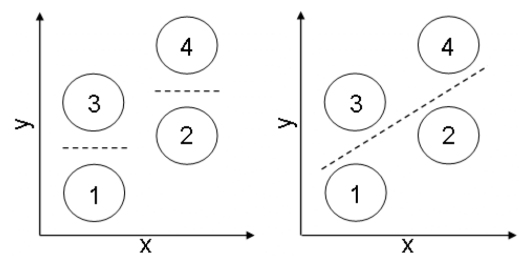

Figure 1: Illustration of mean-shift integrality. Left panel: Piecewise decision bound. Right panel: Continuous decision bound.

Mean-shift could arise if changing the level of one dimension produces a complete shift in the information for the other dimension, as has been hypothesized to be the case in a number of classic phenomena in face perception (e.g., the Thatcher illusion). This possibility has been acknowledged to be problematic for standard methods of estimating the nature of the perceptual space from standard behavioral data (Ashby & Townsend, 1986; Thomas, 2001). In addition, the ability to identify the presence of a mean shift takes on substantive importance in experimental contexts that rely on the diagonal distances within the perceptual evidence space (e.g., the difference between the two diagonal distances as an index of holistic processing. In such situations, it is easily possible to arrive at erroneous conclusions regarding either these diagonal distances or the more-standard marginal distances, absent critical additional converging evidence for the nature of the perceptual space (as provided in, e.g., Kadlec & Hicks, 1998; Wenger & Ingvalson, 2003).

Multiple Measures

The present project was intended as a first step in assessing the extent to which it is possible to reduce inferential errors in the context of mean-shift integrality by augmenting standard methods with statistical methods that to date have not been applied to this problem. The standard approach is based on a set of marginal measures of sensitivity and bias, drawn from classic signal detection theory (Ashby & Townsend, 1986; Kadlec & Townsend, 1992), and these approaches are shown to have elevated Type II error rates in identifying the conditions for mean-shift integrality.

The first of the novel methods is an approach developed by DeCarlo (2003) in which probit models are used to determine signal detection measures in multidimensional stimulus space. For each distribution, in each dimension, a probit model is implemented: $y^* = \beta x + \mu$, where y^* is the dependent variable (response) and x is the explanatory variable (correct response). Such models can be used to determine *d'* (from β), *c* (the threshold for the outcome, y^*) and bivariate correlations (revealed in the residuals, μ).

The second novel method is drawn from methods of categorical data analysis, specifically estimates of polychoric and tetrachoric correlations based on response frequencies. In particular, we assume that the entire response space is sampled from a bivariate normal distribution with a single response threshold on each of the two dimensions. Given a 2x2 response contingency table, we estimate both the tetrachoric correlation and response thresholds with maximum likelihood estimation (Olsson, 1979). A mean-shift will give rise to correlation between response frequencies because the change in decision bound causes systematic variation, particularly in response frequencies from diagonally opposite distributions. These correlations will result in a non-zero tetrachoric correlation within the bivariate distribution of the response space.

Approach and Outcomes

We evaluated these methods using simulated data sets, representing the absence and presence (in varying magnitude) of mean shifts. Using the sets of measures, alone and in all possible combinations, we estimated the relative frequency of inferential errors. The standard approach, as expected, produced regular inferential (Type II) errors in the presence of mean-shift integrality. However, when augmented with the new methods, the rate of such errors was substantially decreased.

Like the traditional approach, the probit model provides relative information about marginal *d'*s and *c*s. The outputs from each approach are largely in agreement, barring a conservative bias for bivariate correlations in the traditional method and a liberal bias for differences in *d'*s in the probit models. Because both methods provide relative estimates they cannot be used to detect mean-shift integrality directly. However, unlike the traditional approach, the probit model method includes the estimation of residuals, which allows a direct test for bivariate correlations within the underlying perceptual distributions. When a mean-shift in distributions is accompanied by a continuous shift in the decision bound, the probit models identify bivariate correlations of the same sign and similar magnitude across all distributions. They also identify any shift in decision bound relative to the distributions. Such evidence of mean-shift indicates a need for a direct test using the polychoric correlation method.

Tetrachoric correlations applied to data sampled from mean-shift distributions accompanied by a continuous decision bound shift revealed significant non-zero correlations in the response space when the mean-shift is of medium to large magnitude. These estimates are sensitive to the magnitude of the mean shift, and inferential errors based on correlation alone increase as mean-shift magnitude decreases.

Neither the probit nor the polychoric correlation approaches can identify a piecewise shift in the decision bound, because relative locations are maintained, such that response frequencies remain unaffected and do not exhibit correlations. The results suggest that, although mean-shift integrality can pose a serious inferential challenge, a multi-measure approach can reduce the potential for inferential errors. As such, the approach is consistent in spirit with the original (Ashby & Townsend, 1986) multi-measure approach to estimating GRT models.

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