



Modeling 2-alternative forced-choice tasks: Accounting for both magnitude and difference effects

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ABSTRACT

We present a model-based analysis of two-alternative forced-choice tasks in which two stimuli are presented side by side and subjects must make a comparative judgment (e.g., which stimulus is brighter). Stimuli can vary on two dimensions, the difference in strength of the two stimuli and the magnitude of each stimulus. Differences between the two stimuli produce typical RT and accuracy effects (i.e., subjects respond more quickly and more accurately when there is a larger difference between the two). However, the overall magnitude of the pair of stimuli also affects RT and accuracy. In the more common two-choice task, a single stimulus is presented and the stimulus varies on only one dimension. In this two-stimulus task, if the standard diffusion decision model is fit to the data with only drift rate (evidence accumulation rate) differing among conditions, the model cannot fit the data. However, if either of one of two variability parameters is allowed to change with stimulus magnitude, the model can fit the data. This results in two models that are extremely constrained with about one tenth of the number of parameters than there are data points while at the same time the models account for accuracy and correct and error RT distributions. While both of these versions of the diffusion model can account for the observed data, the model that allows across-trial variability in drift to vary might be preferred for theoretical reasons. The diffusion model fits are compared to the leaky competing accumulator model which did not perform as well.

1. Introduction

The majority of the decision-making literature has focused on tasks involving categorization of a single stimulus into one of two response options. As such, most of the modeling work in this domain has focused on this type of task and the behavioral findings associated with it. In this article we examine performance in five perceptual 2-alternative forced-choice (2AFC) tasks in which two stimuli are presented and the task is to make a comparative judgment (e.g., which of the two patches contains more white pixels). In these 2AFC tasks, the representation of evidence used to make a decision can differ on two dimensions, namely the difference between the stimuli and the magnitudes of the two stimuli. This added degree of freedom in the manipulation of stimulus values can result in behavioral effects that are not observed in tasks with only a single stimulus (Teodorescu & Usher, 2013). We briefly describe the differences between 2AFC tasks and standard tasks (with more detail in Section 7) and demonstrate that two variations of a standard diffusion model (Ratcliff, 1978; Ratcliff & McKoon, 2008) can account for these differences. Modeling results are compared with the only other model previously shown to be theoretically sensitive to both dimensions of the 2AFC task – The Leaky Competing Accumulator (LCA, Teodorescu, Moran, & Usher, 2016; Usher & McClelland, 2001).

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When subjects are shown a single stimulus and asked to decide which of two categories it belongs to (e.g., is this a word or not, does this patch of pixels contain more black or more white pixels), evidence for the stimulus belonging to one of the categories is necessarily evidence against it belonging to the alternative category. In contrast, in the 2AFC task, when two stimuli are presented and the task is to decide which is more extreme on some scale, then strong evidence in favor of one stimulus is not necessarily evidence against the other stimulus (because the other stimulus could be strong or weak). Thus in 2AFC tasks there can be effects of both stimulus differences (the relative strength difference between the two presented stimuli) and overall stimulus magnitude (the total strength of the two items).

When there is a greater difference between the two stimuli (on the decision-relevant dimension) then subjects tend to respond more quickly and more accurately. This effect has been observed in a variety of domains (perceptual decision-making: Polania, Krajbich, Grueschow, & Ruff, 2014; Teodorescu & Usher, 2013; value-based decision-making: Hunt et al., 2012; Polania et al., 2014) and is analogous to difficulty effects observed in standard 2-choice tasks (Ratcliff & McKoon, 2008). However, the overall magnitude of the pair of presented stimuli also affects both RT and accuracy in the 2AFC task. This effect has been observed in a variety of tasks. Hunt et al. (2012) and Polania et al. (2014) found that more desirable pairs of stimuli produced shorter reaction times than less desirable pairs of stimuli in a value-based task. Teodorescu et al. (2016), Hunt et al. (2012), and Polania et al. (2014) found that larger or brighter pairs of stimuli produced shorter reaction times than smaller or darker pairs of stimuli in perceptual tasks, and Bowles and Glanzer (1983) found that pairs of old stimuli produced shorter reaction times than pairs of new stimuli in a memory task. In a numerosity discrimination task, Ratcliff and McKoon (in press) found that for a constant difference in numerosity between two arrays, as overall numerosity increased, accuracy decreased and reaction time decreased. Last, Niwa and Ditterich (2008) and Pirrone, Azab, Hayden, Stafford, and Marshall (2017) found speedups in RT with increasing stimulus magnitude for decisions with zero evidence (i.e. choice between N equal value alternatives).

2. Modeling

The overall magnitude effects provide a set of behavioral results that are not observed in standard 2-choice data that use a single 1D stimulus. As Teodorescu and Usher (2013) have pointed out, since these 1D stimuli are inherently competitive, standard 2-choice tasks are not ideal for distinguishing between models with different forms of competition (e.g., feed-forward input competition, as in some variants of the diffusion model, or response competition, as in LCA). In most sequential-sampling models for 2-choice decisions, information from the stimulus is accumulated noisily until some decision threshold is reached and then a response is made. There are many ways in which models of decision-making can differ (the nature of evidence accumulated, the competition between the two response alternatives, the stopping rule, etc), but the most relevant aspect in terms of fitting the overall magnitude effect in 2AFC data is the nature of evidence being accumulated.

There are several ways that decision models can represent the nature of evidence from the stimulus. In models with a single accumulation process (such as the diffusion model; Ratcliff & McKoon, 2008), evidence on each trial is typically modeled as a single value representing the rate of accumulation for that item. In a standard 2-choice task, this value would represent the item's strength on some dimension relevant to the decision (e.g., memory strength) relative to a neutral criterion value. In a 2AFC task, this value could represent the strength difference between the two presented items (again, on some relevant dimension). However, while difference based evidence representation would, naturally, be able to handle magnitude difference effects, it would be unable to handle overall magnitude effects that maintain a constant magnitude difference. This invariance prediction is a direct consequence of the fact that only the magnitude difference would be available to the decision process. In models with multiple accumulation processes (e.g., LCA, Usher & McClelland, 2001; LBA, Brown & Heathcote, 2008; accumulator models, Vickers, 1970), each accumulator receives input in favor of one of the response alternatives. In a standard 2-choice task, these inputs may be normalized to reflect the uni-dimensional nature of the stimuli (i.e., evidence in favor of one response is evidence against the other response). However, in a 2AFC task this normalization may not be appropriate and evidence in both accumulators might increase with stimulus magnitude.

On the other hand, accumulator models without competition may be able to handle overall magnitude effects, but have difficulty producing magnitude difference effects. For example, Hunt et al. (2012, supplementary information) used simulations of an independent race model to demonstrate that overall magnitude values produced large effects while magnitude differences produced fairly small effects. In contrast, accumulator models with competition can produce both patterns of effects. Teodorescu et al. (2016) demonstrated that competitive two alternative accumulator models could qualitatively handle both the overall magnitude and magnitude difference effects though they differed with how well they fit the data. They found that a version of the diffusion model with an accumulation rate based on the stimulus difference could account for both patterns of effects when the within-trial noise in the accumulation process was dependent on the overall magnitude of the stimuli. They also found that the Leaky Competing Accumulator (LCA) model could account for both patterns of effects because of competition between accumulators from lateral inhibition. Although the input to the accumulators in the LCA model is absolute, the lateral inhibition between the accumulators allows the model to produce difference effects that evolve and grow over time. Since the inhibition is based on the amount of accumulated evidence, towards the beginning of each trial the amount of inhibition is small and the accumulation process is sensitive to magnitude effects, similar to that of an independent race model (see also Niwa & Ditterich, 2008, for a comprehensive discussion). As more evidence is accumulated, however, the amount of inhibition increases such that the accumulation process becomes more similar to that of a diffusion model (see Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006; Heathcote, 1998; Marshall et al., 2009). Teodorescu et al. (2016) examined these effects using a single task and three conditions: (1) a baseline condition; (2) a condition in which the difference between the pair of stimuli was constant and the overall brightness increased compared to baseline; and (3) a condition

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