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A new framework for modeling decisions about changing information: The Piecewise Linear Ballistic Accumulator model

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ABSTRACT

In the real world, decision making processes must be able to integrate non-stationary information that changes systematically while the decision is in progress. Although theories of decision making have traditionally been applied to paradigms with stationary information, non-stationary stimuli are now of increasing theoretical interest. We use a random-dot motion paradigm along with cognitive modeling to investigate how the decision process is updated when a stimulus changes. Participants viewed a cloud of moving dots, where the motion switched directions midway through some trials, and were asked to determine the direction of motion. Behavioral results revealed a strong delay effect: after presentation of the initial motion direction there is a substantial time delay before the changed motion information is integrated into the decision process. To further investigate the underlying changes in the decision process, we developed a Piecewise Linear Ballistic Accumulator model (PLBA). The PLBA is efficient to simulate, enabling it to be fit to participant choice and response-time distribution data in a hierarchal modeling framework using a non-parametric approximate Bayesian algorithm. Consistent with behavioral results, PLBA fits confirmed the presence of a long delay between presentation and integration of new stimulus information, but did not support increased response caution in reaction

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to the change. We also found the decision process was not veridical, as symmetric stimulus change had an asymmetric effect on the rate of evidence accumulation. Thus, the perceptual decision process was slow to react to, and underestimated, new contrary motion information.

1. Introduction

The ability of individuals to update their decision process in the face of dynamically changing information is important in everyday decision-making. For example, consider the simple act of changing lanes on a busy highway. At first, the lane looks clear, but then a car swoops in from the other side. In order to avoid a collision, you must be able to analyze the new information and change your course of action. Although common and clearly of practical importance, such "non-stationary" decisions, where contrary pieces of information are sequentially experienced, are challenging to investigate, both empirically and theoretically.

In this paper we investigate the effect of switching perceptual evidence from favouring one choice to another during the course of the deliberation process, with the aim of developing a tractable and flexible framework to model such situation. Initial conventional analyses revealed a surprising sluggishness or delay in the way the decision process reacts to the changed perceptual (motion) information. We then developed a cognitive model to explain how evidence for each choice is accumulated in order to gain detailed insights into the causes of this delay. The model allows us to compare several explanations of the observed delay. One possibility is that, in reaction to the conflict caused by the change, participants delay their response by requiring a higher standard of evidence. Alternatively there may be a delay before the new information changes the input to the decision process. We also examined whether the input to the decision process is veridical, that is, whether it represents the true magnitude of the change. Before reporting these findings in detail we first provide a brief background on evidence accumulation models and decisions based on non-stationary or conflicting inputs.

1.1. Evidence accumulation and non-stationary decision processes

Although Ratcliff (1980) discussed the importance of changing information over three decades ago, most quantitative models of decision making have focused on "stationary" decisions, where a choice is made on the basis of fixed, unchanging information, or on information that changes randomly around a fixed central tendency (Ratcliff, 1978; Busemeyer & Townsend, 1993; Shadlen & Newsome, 1996; Gold & Shadlen, 2001; Smith & Ratcliff, 2004). Much of this work has supported the idea that decisions are based on evidence for different alternatives that is accumulated over time. A decision is made as soon as a threshold amount of accumulated evidence in favor of one of the choices is obtained. The use of stationary stimuli, and the assumption that they cause a constant rate of evidence accumulation, has made it possible to derive relatively easily computed model predictions for choices as well as the full distribution of response time (RT) for each choice. This setup has enabled models such as the drift–diffusion model (DDM) – Ratcliff's elaboration (Ratcliff, 1978; Ratcliff & McKoon, 2008) of the simple diffusion model (Edwards, 1965) – and the Linear Ballistic Accumulator (LBA) model (Brown & Heathcote, 2008) – a simplification of the Leaky Competitive Accumulator (Usher & McClelland, 2001) and Ballistic Accumulator (Brown & Heathcote, 2005a) models – to be tested against detailed patterns of behavior across a wide range of paradigms with stationary stimuli. Accounting for such detailed findings, including the exact shape of RT distributions and the relative speed of correct and incorrect responses, has become a benchmark for models that claim to provide a general account of choice RT.