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Conflict tasks and the diffusion framework: Insight in model constraints based on psychological laws

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ABSTRACT

Formal models of decision-making have traditionally focused on simple, two-choice perceptual decisions. To date, one of the most influential account of this process is Ratcliff's drift diffusion model (DDM). However, the extension of the model to more complex decisions is not straightforward. In particular, conflicting situations, such as the Eriksen, Stroop, or Simon tasks, require control mechanisms that shield the cognitive system against distracting information. We adopted a novel strategy to constrain response time (RT) models by concurrently investigating two well-known empirical laws in conflict tasks, both at experimental and modeling levels. The two laws, predicted by the DDM, describe the relationship between mean RT and (i) target intensity (Piéron's law), (ii) standard deviation of RT (Wagenmakers–Brown's law). Pioneering work has shown that Piéron's law holds in the Stroop task, and has highlighted an additive relationship between target intensity and compatibility. We found similar results in both Eriksen and Simon tasks. Compatibility also violated Wagenmakers–Brown's law in a very similar and particular fashion in the two tasks, suggesting a common model framework. To investigate the nature of this commonality, predictions of two recent extensions of the DDM that incorporate selective attention mechanisms were simulated and compared to the experimental results. Both models predict Piéron's law and the violation of Wagenmakers–Brown's law by compatibility. Fits of the models to the RT distributions and accuracy data

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allowed us to further reveal their relative strengths and deficiencies. Combining experimental and computational results, this study sets the groundwork for a unified model of decision-making in conflicting environments.

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1. Introduction

Over the past 40 years, the fundamental process of making decisions on the basis of sensory information, known as perceptual decision-making, has grown up to an extensive field of research. The interest has increased in part due to the introduction of the sequential sampling framework (for reviews, see Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006; Ratcliff & Smith, 2004). To make a decision, it is assumed that the brain accumulates samples of sensory evidence until an absorbing choice boundary is reached. The inherent noise in both the physical stimulus and the neural signal makes the process stochastic, potentially leading to an incorrect choice. The rate of approach to a boundary is called *drift rate*, and depends on the quality of the extracted sensory evidence. The boundary is hypothesized to be under subjective control, and can be modulated depending on timing demands. A higher boundary criterion will require greater evidence accumulation, leading to slower and more accurate decisions. The interaction between drift rate and choice criteria has an obvious property: it provides an integrated account of both response time (RT) and accuracy in choice laboratory experiments.

The drift diffusion model (DDM) developed by Ratcliff and coworkers (Ratcliff, 1978; Ratcliff & Rouder, 1998) belongs to this theoretical frame. The model was originally developed to explain simple two-choice decisions in terms of psychologically plausible processing mechanisms, and has proven to account for a large range of paradigms (for a review, see Ratcliff & McKoon, 2008). However, its extension to more complex decisions is not straightforward and is currently the object of an intense field of research in both experimental psychology (e.g., Hübner, Steinhauser, & Lehle, 2010; Leite & Ratcliff, 2010; Smith & Ratcliff, 2009; Stafford, Ingram, & Gurney, 2011; White, Brown, & Ratcliff, 2011; White, Ratcliff, & Starns, 2011) and neuroscience (e.g., Churchland, Kiani, & Shadlen, 2008; Resulaj, Kiani, Wolpert, & Shadlen, 2009). The present study aims to evaluate whether the DDM can be extended to conflicting situations, and contributes to this emerging field.

1.1. The drift diffusion model: basic architecture and mathematical properties

As other sequential sampling models, the DDM posits that RT is the sum of two components, a non-decision time and a decision-related time. The decision process takes the form of an accumulation of evidence delimited by two boundaries representing alternative choices. The starting point of the diffusion depends on prior expectations, and can be located everywhere on the axis joining the two alternatives, being closer to the more expected alternative. In each moment, the incremental evidence is the difference between sensory inputs supporting choice 1 versus 2. This difference is a random variable which follows a Gaussian distribution, with mean μ (drift rate) and variance σ^2 (diffusion coefficient). The combination of sensory evidence into a single variable and its linear stochastic accumulation over time present an interesting property. If the diffusion is discretized, then the process becomes a random walk and is formally equivalent to the sequential probability ratio test (SPRT; Wald, 1947). SPRT is optimal in the sense that it minimizes expected decision time for any given accuracy level, and maximizes accuracy for a given decision time (Wald & Wolfowitz, 1948). Bogacz et al. (2006) have argued that optimality may be a hallmark of human *cognitive control*, the ability to adapt information processing from moment to moment depending on current goals. According to this view, the DDM may provide a privileged framework to study such control processes, and offers an interesting departure point to approach decision-making in conflicting situations.