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Breaking the rules in perceptual information integration

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ABSTRACT

We develop a broad theoretical framework for modelling difficult perceptual information integration tasks under different decision rules. The framework allows us to compare coactive architectures, which combine information before it enters the decision process, with parallel architectures, where logical rules combine independent decisions made about each perceptual source. For both architectures we test the novel hypothesis that participants break the decision rules on some trials, making a response based on only one stimulus even though task instructions require them to consider both. Our models take account of not only the decisions made but also the distribution of the time that it takes to make them, providing an account of speed-accuracy tradeoffs and response biases occurring when one response is required more often than another. We also test a second novel hypothesis, that the nature of the decision rule changes the evidence on which choices are based. We apply the models to data from a perceptual integration task with near threshold stimuli under two different decision rules. The coactive architecture was clearly rejected in favor of logical-rules. The logical-rule models were shown to provide an accurate account of all aspects of the data, but only when they allow for response bias and the possibility for subjects to break those rules. We discuss how our framework can be applied more broadly, and its relationship to Townsend and Nozawa's (1995) Systems-Factorial Technology.

1. Introduction

Human choices often depend on combining noisy signals from multiple sources. When approaching an intersection on a dark and rainy night, for example, a driver must determine whether traffic lights are red or green and whether pedestrians are crossing. If the light is red, or if pedestrians are crossing, braking is required, following an "OR" decision rule for the presence of either one signal *or* the other. Once stopped, and before continuing a trip, the driver must confirm that the light is green and that no pedestrians are in their path, following an "AND" decision rule requiring both one signal *and* the other. The OR rule allows processing to be terminated after only one signal is detected, whereas the AND rule requires processing both signals, leading Townsend (1974) to describe them as stopping rules requiring, respectively, first-terminating and exhaustive processing of stimuli. Stopping rules have been studied in many areas of human cognition, from categorization (Fific, Little, & Nosofsky, 2010), to consumer choices (Fific & Buckmann, 2013), and memory- and visual-search tasks (Fific, Townsend, & Eidels, 2008; Sternberg, 1966).

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Early investigations of stopping rules manipulated the number of items in either memory or a visual display and focused on the slope of the response time (RT) function as the number of items increases (Sternberg, 1966, 1969; see Algom, Eidels, Hawkins, Jefferson, and Townsend (2015), for a review). However, later work by Townsend and colleagues (e.g., Townsend & Ashby, 1983; Townsend & Colonius, 1997) showed that this approach was flawed, because different rules could predict the same pattern of slopes. Subsequently, Townsend and Nozawa (1995) showed that AND and OR stopping rules do make unique predictions in a design – often called the "double-factorial paradigm" – that manipulates the relative salience of two or more signals.

It has often been found using the double-factorial paradigm that human observers do appear to apply the stopping rule appropriate to the task at hand (e.g., Eidels, Townsend, & Algom, 2010b; Fific, Nosofsky, & Townsend, 2008; Fific et al., 2008; Fific et al., 2010; Little, Nosofsky, & Denton, 2011; Moneer, Wang, & Little, 2016). However, double-factorial designs are not always easy to implement, and Townsend and Nozawa's (1995) analysis does not take account of the effects of mixtures of stopping rules (i.e., applying different rules on different trials). Cousineau and Shiffrin (2004) found evidence for such inconsistent rule application in a difficult visual-search task. On a proportion of trials it appeared that only one of the two items in a display was processed fully, with participants guessing about the other item.

The use of an inappropriate stopping rule can have detrimental effects on behavioural performance. For example, exhaustively processing under an OR requirement requires more effort and slows response with no benefit to accuracy. However, inappropriate stopping may also have benefits. For example, failing to process exhaustively under an AND requirement, and either ignoring the remaining items, or making guesses about them as in Cousineau and Shiffrin's (2004) study, makes responding faster and easier, although it will also cause errors. Depending on the value a participant places on speed over accuracy—perhaps as a function of trying to complete an experiment with minimal effort, or in order to have time to attempt more decisions in a fixed time period—rule breaking may be an attractive and even optimal strategy (Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006).

In the present paper we focus on a perceptual information integration task. Such tasks are of interest because humans are often in a position where they need to integrate information within a sensory modality (Bushmakin & James, 2014; Eidels, Donkin, Brown, & Heathcote, 2010a) as well as across modalities (Alais & Burr, 2004; McGurk & MacDonald, 1976; Stevenson et al., 2014a). Moreover, the irregularities in perceptual integration have been linked to certain disorders like autism and schizophrenia (Stevenson et al., 2014b; Williams, Light, Braff, & Ramachandran, 2010).

Despite both empirical evidence for rule breaking in other tasks, and in at least some cases there being a rational basis for participants to purse a rule-breaking strategy, previous analyses of information integration have not, to our knowledge, considered whether decision makers might sometimes not abide by the rules that experimenters use to score the accuracy of their performance. The present paper develops a framework that takes into account the possibility of rule breaking for tasks requiring both AND and OR rules, and the possibility that a participant can use a mixture of rule-following and rule-breaking strategies. We apply models derived from this framework to the performance of each participant separately to account for the possibility that there will be individual differences in the factors that cause rule breaking, such as the value placed on effort or the speed vs. accuracy.

The nature of the two stopping rules we investigate makes it important to take account of tradeoffs between the speed and accuracy of different responses. These OR and AND designs have built-in biases towards one response or another. Consider the driver OR example presented above; attempting to drive through the intersection, the driver needs to stop if she detects a pedestrian approaching, a red light, or both. In contrast there is only one case in which she can go: if there is a green light and no pedestrians. These contingencies are known to create biases in responding (e.g., Mordkoff & Yantis, 1991). All other things being equal, it is likely that a bias towards responding "YES" will develop under OR instructions and a bias to respond "NO" under AND instructions, because a YES response is required more often in the former case and a NO response more often in the latter case. Attempts to remove those biases by unbalanced presentation of stimuli (e.g., more no-target trials in AND task or more double-target trials in an OR task) create other contingencies and hence other potential biases. In light of this, our experiments used balanced stimulus presentation, and we take account of the potential biases in our models.

In summary, two questions remain unanswered: (1) how well do people abide by AND and OR decision rules, and the related questions of how they manage the associated trade-off between speed and accuracy; and (2) how they select an appropriate level of response bias under each rule. To address these questions, we also investigated two other fundamental questions about the effect of decision rules on the inputs to, and architecture of, the decision process.

First, do response-rule instructions affect only the decision process itself, or do they affect the inputs to the decision process, that is, the evidence on which decisions are based? In particular, is the evidence accumulation rate for each signal the same across decision rules? This question is novel, perhaps because most past analyses have not tried to simultaneously account for responding under two different decision rules by the same participants, as we do here. In contrast, the second question has been the subject of intense scrutiny: is evidence combined before it enters a single decision process (sometimes called a coactive architecture; e.g., Little, Nosofsky, Donkin, & Denton, 2013; Miller, 1978, 1982), or are separate decisions made about each signal and later combined by logical rules (e.g., Eidels et al., 2010a).

To address all of these questions, we develop a unified theoretical framework that expands on Brown and Heathcote's (2008) Linear Ballistic Accumulator (LBA) model of choice RT and on its extension to a logical-rule model of the OR task developed by Eidels, Donkin et al. (2010) and Eidels, Townsend et al. (2010). We generalized Eidels et al.'s model of the OR task to the AND task, and, for both AND and OR models, we also allowed for the possibility that participants sometimes