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Modeling graded response congruency effects in task switching☆

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ABSTRACT

Compound cue retrieval is a computational model of a mediated route for response selection in task-switching situations. In previous studies, the model has been shown to account for response congruency effects when switching between two tasks, where response congruency reflects the degree of match between relevant and irrelevant task responses associated with a target stimulus. In the present study, the author derived a model prediction of graded response congruency effects in situations involving three tasks. The predicted pattern was observed for both response time and error rate in an experiment in which numerical categorization tasks were performed on single-digit targets. Implications for understanding response congruency effects and for developing models of task-switching performance are discussed.

1. Introduction

Task switching is a domain that is ripe for the development and testing of computational models of cognition. As indicated by two recent reviews of the task-switching literature (Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010), there is a large body of empirical findings that has yet to be explained in a comprehensive and integrated manner. The best prospect for an integrated explanation is a computational model that instantiates the cognitive mechanisms involved in task-switching performance. Recognizing this point, many researchers have proposed different models of task switching over the past several years (e.g., Altmann & Gray, 2008; Brown, Reynolds, & Braver, 2007; Gilbert & Shallice, 2002; Schneider & Logan, 2005; Sohn & Anderson, 2001). Unfortunately, many of these endeavors have been one-off efforts, with the models not investigated beyond the original articles in which they were proposed. Consequently, there has been little in the way of cumulative model development in task switching compared with other domains (e.g., Anderson, 2007; Logan, 2004; Perry, Ziegler, & Zorzi, 2007; Shiffrin, 2003).

An exception is the model of compound cue retrieval proposed by Schneider and Logan (2005), which accounts for how responses are selected in task-switching situations. In the original article, the model was used to explain cue–target congruency effects, which reflect the match or mismatch between a categorically biased cue and a target stimulus when performing semantic categorization tasks. In subsequent articles, compound cue retrieval was used to explain priming and response congruency effects (Schneider & Logan, 2009), target functions (Logan & Schneider, 2010), and stimulus-order effects (Schneider & Logan, 2014). The purpose of the present study was to build on this line of work by deriving and testing a prediction about response congruency effects that the model makes when it is applied to a task-switching situation involving three tasks.

1.1. Response congruency effects

A typical task-switching experiment involves two categorization tasks that share a set of responses. For example, one task might involve categorizing single-digit targets as odd or even, and the other task might involve categorizing targets as smaller or larger than 5, with the relevant task indicated by a cue (e.g., *odd–even* or *small–large*). When task categories are mapped to the same manual response keys (e.g., odd and small mapped to a left key; even and large mapped to a right key), targets differ in their response congruency. Congruent targets are those for which the relevant and irrelevant task responses are the same (e.g., *3* is odd and small, requiring a left keypress response for both tasks). Incongruent targets are those for which the relevant and irrelevant task responses are different (e.g., *7* is odd and large, requiring a left keypress response for the odd–even task but a right keypress response for the small–large task).

A reliable finding in task-switching studies is a response congruency effect: response time (RT) is longer and error rate is higher for

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incongruent targets than for congruent targets (e.g., Brown et al., 2007; Kiesel, Wendt, & Peters, 2007; Meiran & Kessler, 2008; Monsell, Sumner, & Waters, 2003; Schneider, in press; Schneider & Logan, 2009, 2014; Sudevan & Taylor, 1987). Response congruency effects are hypothesized to reflect either a mediated or a nonmediated route for response selection, or both (Kiesel et al., 2007; Meiran & Kessler, 2008; Schneider, in press; Schneider & Logan, 2009, 2014; Yamaguchi & Proctor, 2011).

The mediated route involves categorizing the target with respect to both tasks, then selecting a response based on the instructed category–response mappings and the relevant task cue. The route is considered to be mediated because the pathway from target to response involves an intermediate category representation (e.g., *3* → odd → left key). For a congruent target (e.g., *3*), response selection is facilitated because both target categorizations (*3* is odd and small) are mapped to the same response (e.g., odd and small → left key). For an incongruent target (e.g., *7*), response selection is impaired because the target categorizations (*7* is odd and large) are mapped to different responses (e.g., odd → left key; large → right key), making it necessary to use the task cue to determine the appropriate categorization and response. It is in this way that the mediated route explains response congruency effects.

The nonmediated route involves bypassing categorization and using the target to directly retrieve an associated response from long-term memory based on target–response instances accumulated from past experience (Logan, 1988). The route is considered to be nonmediated because the pathway from target to response does not involve an intermediate category representation (e.g., *3* → left key). For a congruent target (e.g., *3*), response selection is facilitated because the target has been associated with the same response for each task in the past (e.g., *3* → left key for both the odd–even and small–large tasks). For an incongruent target (e.g., *7*), response selection is impaired because the target has been associated with different responses for each task in the past (e.g., *7* → left key for the odd–even task; *7* → right key for the small–large task), making it necessary to use the task cue to determine the appropriate response. It is in this way that the nonmediated route explains response congruency effects.

There is experimental evidence that both the mediated and nonmediated routes can contribute to response congruency effects in task-switching performance. The strongest evidence in favor of the mediated route is the finding of response congruency effects with nonrepeated targets, for which the nonmediated route is nonfunctional because there are no target–response instances to retrieve from long-term memory, thereby making categorization via the mediated route the sole mechanism available for response selection (Schneider, in press). Related evidence for the mediated route includes findings of response congruency effects with unpracticed target–response mappings (Liefooghe, Wenke, & De Houwer, 2012) and with irrelevant distractors that are never presented as targets (Reisenauer & Dreisbach, 2013). The strongest evidence in favor of the nonmediated route is the finding of inverted response congruency effects when category–response mappings are reversed, which implies response selection by using targets to directly retrieve responses from memory via the nonmediated route (Waszak, Pfister, & Kiesel, 2013; Wendt & Kiesel, 2008). Even though both routes can play roles in response selection, the mediated route is of particular interest in the present study because it is instantiated in the model of compound cue retrieval.

1.2. Compound cue retrieval

The core idea behind compound cue retrieval is that the task cue and target are categorized and used together to select a response from long-term memory. The target is categorized with respect to all tasks while the cue indicates the most relevant categorization. The combined category evidence from the cue and the target is used to drive a response-selection process based on the instructed category–response mappings. In its present form, the model does not learn or use any direct associations between targets and responses.[1] Consequently, response selection is based on categorization without access to target–response associations, which means that the model instantiates a form of the mediated route rather than the nonmediated route. The model and its equations are described in greater detail elsewhere (Schneider & Logan, 2005, 2009), so I will provide a condensed explanation of its functioning here.

The process starts with encoding of the cue and the target presented on a trial, resulting in semantic representations that provide evidence for task-relevant categories (Arrington, Logan, & Schneider, 2007; Schneider & Logan, 2010) as opposed to direct evidence for specific responses. Evidence is represented by η values and the evidence for each category is the product of the evidence from the cue and the target:

$$\eta_{\text{category}} = \eta_{\text{cue}} \times \eta_{\text{target}} \tag{1}$$

When a cue or a target is associated with a category, it provides associated evidence (η_a). When a cue or a target is not associated with a category, it provides unassociated evidence (η_u). It is assumed that evidence from associated stimuli is stronger than evidence from unassociated stimuli ($\eta_a > \eta_u$). For example, consider the odd–even and small–large tasks described earlier, and assume a trial on which the cue is *odd–even* and the target is *3*. The cue would provide associated evidence for the odd and even categories ($\eta_{\text{cue}} = \eta_a$) and unassociated evidence for the small and large categories ($\eta_{\text{cue}} = \eta_u$). The target would provide associated evidence for the odd and small categories ($\eta_{\text{target}} = \eta_a$) and unassociated evidence for the even and large categories ($\eta_{\text{target}} = \eta_u$). According to Eq. 1, the product of cue and target evidence would be largest for the odd category ($\eta_{\text{odd}} = \eta_a \times \eta_a$) and smallest for the large category ($\eta_{\text{large}} = \eta_u \times \eta_u$).

The probability of retrieving a given category from long-term memory is the ratio of its evidence over the sum of the evidence for all categories:

$$p_{\text{category}} = \eta_{\text{category}} \Big/ \sum \eta_{\text{category}} \tag{2}$$

When multiple categories are mapped to each response key, the probability of retrieving a given response is the sum of the category probabilities mapped to it:

$$p_{\text{response}} = \sum p_{\text{category}}, \text{ for category} \in \text{response} \tag{3}$$

The response probabilities represent the rates at which evidence accumulates for the responses during a random-walk decision process (Nosofsky & Palmeri, 1997). The random walk accumulates evidence at discrete time steps until the difference in evidence between responses reaches a criterion *C*, at which point the response with more evidence has been selected. The mean time per step and the mean number of steps for the random walk to finish are given by the following equations adapted from Nosofsky and Palmeri (1997) by Schneider and Logan (2005):

$$t_{\text{step}} = 1 \Big/ \sum \eta_{\text{category}} \tag{4}$$

and

$$n_{\text{step}} = \frac{1}{p_{\text{correct}} - p_{\text{error}}} [(\theta_1)(2C) - (\theta_2)(C)], \tag{5}$$

[1] A common misconception about the model is that the cue and the target form a compound stimulus that is associated directly with a response. In reality, cue and target representations remain separated in the model (e.g., see Schneider & Logan, 2005, p. 349), with the "compound" in "compound cue retrieval" referring to the fact that response selection involves a multiplicative (rather than additive) combination of category evidence from the cue and the target.