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Contingency learning is reduced for high conflict stimuli

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ABSTRACT

Recent theories have proposed that contingency learning occurs independent of control processes. These parallel processing accounts propose that behavioral effects originally thought to be products of control processes are in fact products solely of contingency learning. This view runs contrary to conflict-mediated Hebbian-learning models that posit control and contingency learning are parts of an interactive system. In this study we replicate the contingency learning effect and modify it to further test the veracity of the parallel processing accounts in comparison to conflict-mediated Hebbian-learning models. This is accomplished by manipulating conflict to test for an interaction, or lack thereof, between conflict and contingency learning. The results are consistent with conflict-mediated Hebbian-learning in that the addition of conflict reduces the magnitude of the contingency learning effect.

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1. Introduction

Stroop (1935) was the first to show that it is difficult to report the ink color of a color word (i.e. identifying the color blue for the word RED written in blue ink). The ubiquitous finding is that incongruent stimuli (i.e. RED written in blue ink; RED_{BLUE}) are responded to slower than congruent stimuli (i.e. RED_{RED}), the so-called Stroop effect. Current accounts of the Stroop effect suggest that it occurs because the strength of association between the word and its response is stronger than the strength of association between the color and its response (i.e., Cohen, Dunbar, & McClelland, 1990; MacLeod & Dunbar, 1988). More recent additions to this idea stipulate the amount of response conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004) or likelihood of committing an error (Brown & Braver, 2005) cause micro-adjustments in the amount of top-down control on a trial-by-trial basis (see MacDonald, Cohen, Stenger, & Carter, 2000). This conflict-monitoring hypothesis maintains that conflict is detected by the anterior-cingulate cortex (ACC), which functions as a performance monitor, and then recruits executive functions in the dorsolateral prefrontal cortex (DLPFC) in order to mediate the conflict. Behavioral indices such as the sequential-congruency effect (Gratton, Coles, & Donchin, 1992) and error-related slowing (Rabbitt, 1966) are widely thought to reflect the operation of this ACC-DLPFC system.

Although this interpretation is widely accepted, it is not without its critics (e.g., Grinband et al., 2011; Schmidt, 2013). Much of this criticism stems from the philosophical position that cognitive control, the mental processes which help coordinate and adapt behavior to meet situational demands like those found in the Stroop task, must be volitional. For example, Schmidt and de Houwer (2011) showed that low-level stimulus information – feature repetitions and the frequency with which the color and the word dimensions co-occur (i.e., contingency) – can entirely explain the sequential congruency effect under some conditions (but see Blais, Stefanidi, & Brewer, 2014). They therefore argued that the sequential congruency effect can not be a product of cognitive control.

In an attempt to reconcile these ideas, Egner (2014) argues that lower level processes such as feature integration, and higher level processes such as response selection, are components along a continuous hierarchy of cognitive control. More concrete levels include processes involved in associating physical stimulus features with specific motor responses, as well as those involved in specifying how perceptual identification of the stimulus and stimulus-response (S-R) learning occurs. More abstract levels include processes that are relatively generalizable, such as those involved in goal maintenance, performance monitoring, and binding contextual cues to internal processing states or strategies. These concrete and abstract features are encoded and bound together into a dynamic event file in memory (Hommel, 1998). The occurrence of any one of these features triggers the retrieval of this event file, reducing the reliance on the slower more effortful top-down processes (see also Logan, 1988). This framework offers an appealing resolution to the fact that sequential congruency effects (Gratton et al., 1992) can arise from both lower-level S-R learning (Mayr, Awh, & Laurey, 2003) and higher-level conflict adaptation (Ullsperger, Bylsma, & Botvinick, 2005). The framework proposed by Egner (2014) highlights that the several factors that modulate conflict in the Stroop task include lower level components such as feature contingencies or stimulus-response associations (Bugg, 2014; Melara & Algom, 2003), and higher level strategic components (Logan, Zbrodoff, & Williamson, 1984).

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This framework is embodied in the widely accepted conflict-monitoring idea (Botvinick et al., 2001, 2004), especially the most recent iterations in which conflict-modulated Hebbian-learning operates at the level of each item (e.g., the words blue and yellow) rather than uniformly across all items within the experiment (i.e., Blais, Robidoux, Risko, & Besner, 2007; Blais & Verguts, 2012; Verguts & Notebaert, 2008) providing a comprehensive account of several effects by utilizing both top-down and bottom-up mechanisms.

Proportion congruency effects such as item-specific proportion congruency (ISPC) effect are often used to measure the top-down and bottom-up components of cognitive control. The ISPC effect refers to the fact that the Stroop effect can be modulated on an item-by-item basis such that within a single block of trials, individual stimuli that are mostly congruent show a larger Stroop effect than those that are mostly incongruent (Bugg, Jacoby, & Chanani, 2011; Bugg, Jacoby, & Toth, 2008; Jacoby, Lindsay, & Hessels, 2003; Jacoby, McElree, & Trainham, 1999). Bugg (2015) describes conditions under which the ISPC is mostly driven by top-down attentional settings reactively retrieved by item-specific control processes, in comparison to when it is driven by the bottom-up associative processes of contingency learning – conditions which map nicely onto the framework described by Egner (2014). Further support for an interaction between low-level and high-level processes is also demonstrated in Hutcheon and Spieler (2014) who show that the consistency, or lack thereof, of the association between stimulus features and conflict impacts whether conflict adaptation effects generalize across words in ISPC manipulations. It is interesting to point out that when contingency information is salient, even a neutral word (e.g., MOVE, TABLE) can show an ISPC-like pattern (Schmidt & Besner, 2008; Schmidt, Crump, Cheesman, & Besner, 2007). Because of this, Schmidt and colleagues argue that item-specific learning and sequential congruency effects are entirely bottom-up – there is no conflict to signal top-down mechanism. As an alternative to the conflict-monitoring idea, Schmidt (2013) proposed the parallel episodic processing model (PEP) which demonstrates that at least some control processes can be explained solely by implicit contingency learning, a low-level variation of stimulus-response (S-R) learning that relies on episodic memory.

The purpose of the current manuscript is to examine the extent to which contingency learning and conflict monitoring are related. The conflict-mediated Hebbian-learning hypothesis (i.e., Blais & Verguts, 2012; Blais et al., 2007; Verguts & Notebaert, 2008) makes the explicit claim that the control system is a conflict-reinforced learning system. That is, the ACC detects conflict and uses this to reinforce control on an item-by-item basis. Because the conflict-modulated Hebbian-learning model posits that contingency and conflict affect the same mechanism – the readjustment of attention on an item-by-item basis – it predicts that contingency and conflict will interact. In contrast, the PEP model (Schmidt, 2013) accounts for the control effects by appealing to memory storage and retrieval processes for the episodic memories of trials. Response conflict (i.e., congruency) occurs in this model at the response layer, but it does not feedback to any attentional system. This leads to the clear prediction that contingency and congruency should not interact, but instead produce additive effects.

To be clear, there are two major differences between the conflict-modulated Hebbian-learning (i.e., Blais & Verguts, 2012; Blais et al., 2007; Verguts & Notebaert, 2008) and the PEP model (Schmidt, 2013). First, the mechanism of learning is conceptually different. The former learns via strengthening of connection weights and the latter through episodic instances. For the purposes of this paper, this difference is not important for the performance of the models. The second difference is consequential. The conflict monitoring model states that the response conflict between the word and the color moderates how strongly associated a word and color become. When conflict is high, the association between the color and word is decreased because attention to the color is very high, effectively limiting how well the word is processed, thus predicting an interaction between the conflict and proportion contingency (Fig. 1a). Conversely, in Schmidt's (2013) PEP model, conflict is inconsequential to S-R learning, thus predicting only a main effect proportion contingency (Fig. 1b). To adjudicate between these competing models, we replicate and extend Schmidt et al. (2007) by adding a condition in which all stimulus words are incongruent.

2. Methods

2.1. Participants

For 0.80 power to detect an effect as small as 30 ms, we needed N > 120, 30 participants per cell. Therefore, a total of 146 English-speaking undergraduate students were recruited from Arizona State University's Introduction to Psychology research participation pool in exchange for course credit in accordance with the Institutional Review Board. The study required approximately one hour to complete.

2.2. Procedure

Subjects were randomly assigned to one of the four cells in the Proportion Contingent (50% vs. 75%) by Word Type (Conflict vs. Neutral) design. Subjects performed a Stroop task using the words BLUE, GREEN, ORANGE, RED, YELLOW in the conflict condition and replicating Schmidt et al. (2007) using MOVE, GRIP, SENT, FALL, BEAD in the neutral condition. The colors used in both conditions were blue, green, orange, red, and yellow. In the 50% condition, each word was presented in a certain color 50% of the time (60 trials per block) for the high contingency trials, and 16.67% of the time in three other colors (20 trials per block) for the low contingency trials. In the 75% condition, each word was presented in a certain color 75% of the time (90 trials per block) for the high contingency trials, and 8.33% of the time in three other color (10 trials per block) for the low contingency trials. It is important to note that in the conflict condition, this resulted in no word being presented in its corresponding color (i.e. $BLUE_{BLUE}$). The actual trial counts per cell are shown in Table 1.

Participants sat at a comfortable distance from the screen and keyboard within a small study cubicle in a room that allowed us to run as many as eight people at a time. Presentation of stimuli for the experiment was controlled by E-Prime 2.0 software (Psychology Software Tools, 2002). Each color was randomly mapped to the C, V, B, N and M keys then remained fixed for the duration of the experiment. The stimulus remained onscreen until the subject responded. A fixed inter-trial-interval (ITI) of 600 ms separated trials. The program was designed to repeat all incorrect and slow (RT > 3000 ms) trials at the end of a block until participants responded correctly or fast enough.[1] There were 8 blocks of trials presented, the first two blocks were practice blocks and were not analyzed. During this practice phase each of the response labels were presented on the screen in order corresponding to the response keys and feedback was provided in the form of a + or − symbol. This served as the fixation marker for the next trial. For the final six experimental blocks the response labels were removed from the screen and there was no feedback; a * was used as the fixation marker. Participants were still required to repeat any trial that was incorrect or responded to too slowly.[2]

3. Results

We excluded 26 participants from analysis for high errors, 18 of these responded to the word rather than the font color in the conflict

[1] After running the first 52 participants, it was found that 18 of the 26 people in the Conflict condition were responding to the word instead of responding to the color of the text. These 18 participants were excluded from analysis and an adjustment was made to the program.

[2] 5.40% of trials were repeated. This changed the proportion contingent manipulations, on average, by 0.48% in the 50% contingent condition, and 0.64% in the 75% contingent condition. A re-analysis of the data without the repeated trials included did not change the significance of the original analysis.

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