Exploring the Gratton and Proportion Congruency Effects in a Parity/Magnitude Task-Switching Paradigm: Implications for the Conflict-Driven Control Model

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Abstract

We investigated the Gratton effect and the proportion congruency effect using a parity/magnitude task-switching paradigm. The conflict-driven control model posits that conflict between stimulus dimensions triggers a controller, directing attention to the relevant dimension. Contingency learning account, however, proposes that individuals learn the S-R pairings, which causes them to speed up their reaction times in time. In our study, participants decided the parity or magnitude of a digit. These tasks alternated across trials. Congruency was defined as the match between the stimulus-response rules of the current task with the other task. Therefore, there was no irrelevant dimension, no conflict within the stimulus, or no focus on the relevant dimensions. Conflict-driven control directs the conflict that arises when multiple, competing rules are held in working memory. Importantly, the stimulus-response contingency remains the same across different levels of conflict. We observed both the proportion congruency effect and the Gratton effect in both reaction times and error rates. Our results suggest that the conflict-driven control incorporates conflict between rules, arising from holding conflicting rules in immediate memory. Contingency learning alone cannot fully explain the the proportion congruency effects observed in our task-switching paradigm.

Keywords: task-switch; congruency effect; interference; cognitive control; congruency effect

Introduction

We are constantly encounter stimuli with various properties, and these properties may convey either compatible or conflicting information about how we should respond. In the laboratory, the Stroop task (Stroop, 1935) is commonly used to investigate cognitive control. In this task, conflict arises between the word and color dimensions of the stimulus (MacLeod, 2005). Reaction times are slower, and correct response rates are lower when there is a conflict in comparison to when there is no conflict between the dimensions, which is called the Stroop effect.

The conflict-driven model of cognitive control (Botvinick et al. in 2001; Verguts and Notebaert in 2008) proposes that when a conflict is detected in the information processing system, a control mechanism is triggered to control attention. The control mechanism increases the influence of the relevant information on response selection while simultaneously suppressing influence of the irrelevant information. This adjustment reduces the conflict within the system.

Experimental evidence shows that conflict-driven cognitive control operates at different levels. At the trial level, the congruency of a preceding stimulus influences the control in the current stimulus, a result known as the Gratton effect (GE, Gratton et al., 1992). For example, when the previous stimulus is congruent, the Stroop effect is larger compared to when it is incongruent. At the list-of-trials level, the attention control is modulated by the proportion of congruent trials in a sequence (Logan et al., 1984) a finding termed as the Proportion Congruency Effect (PCE). For example, the Stroop effect is smaller in a list consisting of mostly incongruent trials compared to a list consisting of mostly congruent trials.

Conflict-driven cognitive control has been challenged with memory-based mechanisms. Stimulus-response bindings and stimulus-response contingency learning has been proposed as alternative explanations for the GE and the PCE, respectively (Hommel, 1988; Schmidt, 2013). When we encounter a trial, the stimulus and the response is bound and held in the memory. Responses are slower in the next trial if the same stimulus is paired with a different response (or a different stimulus is paired with the same response). According to the stimulus-response binding account, this memory-driven process, but not attention control, account for the GE. Some evidence suggests a GE independent of bindings, but this effect is small and requires further investigation. Similarly,

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when there is a contingency between stimulus and response in a list of trials, we immediately learn these associations. According to the learning account of the PCE, we learn these contingencies, and the PCE is primarily driven by contingency learning. The PCE effect independent of any contingencies was observed but the effect was smaller compared to the PCE that is contributed by contingency learning. These findings suggest that memory and learning play a crucial role in the GE and PCE, alongside conflict-driven attention-control mechanisms.

In both the GE and the PCE, the source of conflict is the trial itself. Conflict may extend beyond trial, and it may exist between different tasks, as in task switching experiments. In experiments like the parity-magnitude task-switching paradigm, a cue precedes the stimulus, instructing participants to respond based on the cued task. In the parity task, participants decide whether a digit is even or odd and they respond with the left or right arrow. In the magnitude task, they determine if a digit is smaller than 5 or not and respond with the same buttons. Participants alternate between these two tasks, which are defined by different stimulus-response rules.

Two critical findings are observed with task-switching experiments. First, there is a switch cost, where responses are slower when the task changes between trials compared to the task repetitions (Kandalowski et al., 2019). Second, responses are faster when the S-R rules matches across tasks than when they differ. For instance, the digit 2, being both even and smaller than 5, prompts a faster response using the left arrow in the parity judgment. Conversely, digit 3, odd and smaller than 5, requires different responses (right arrow in the parity task and left arrow in the magnitude task), resulting in a slower response in the parity judgment.

In our study, we observed the PCE and the GE with the parity-magnitude task-switching paradigm. The key aspect of our experiment was that the conflict arises from maintaining different stimulus-response (S-R) mappings in working memory, rather than presenting conflicting information within the stimulus itself. Since the conflict wasn't driven by the stimulus itself, we could keep the stimulus-response contingency the same while changing the task context and thus the required response.

Participants used the same response buttons for both magnitude and parity tasks. In the magnitude task, they decided if a digit was smaller or larger than 5. In the parity task, they determined if a digit was even or odd. A congruent stimulus required the same button response in both tasks, while an incongruent stimulus required one button half the time and the other button the other half. We created lists with different Proportions of Congruency (PC) by varying the number of incongruent stimuli.

The conflict-driven control account predicts the congruency effect (the difference in response time between congruent and incongruent trials) should be different across lists. The effect should be largest in the Mostly Congruent (MC) list, smaller in the Equally Congruent (EC) list, and smallest in the Mostly Incongruent (MI) list. In contrast, the contingency learning account predicts no difference in the congruency effect across the lists.

Method

Participants

There were 60 students from TOBB University. The experimental procedure approved by the TOBB University Human Research Committee, and we followed to the ethical standards of the American Psychological Association (APA).

Procedure

The experiment was programmed with MATLAB Psychtoolbox. There were 256 stimuli in a single block. Stimuli were digits 1, 2, 3, 4, 6, 7, 8, 9 presented in red or blue frames. When the stimulus was within the red frame, participants decided whether the number is bigger or smaller than 5 (left arrow for smaller, right arrow for bigger than 5). When the stimulus was within the blue frame, participants decided whether the number is odd or even (left arrow for odd, right arrow for even). The inter-trial-interval was 0.5 s. Congruency is defined with respect to the key pressed for the stimulus. If it is the same key for both of the tasks, the stimulus would be classified as congruent; if not it would be incongruent. There were 256 stimuli in a single block of trials. Mostly congruent condition included 75% congruent trials and 25% incongruent trials, while mostly incongruent condition included 75% incongruent trials.

Each participant completed the entire procedure in less than 30 minutes. Prior to the experiment, participants provided informed consent, and the experimenter briefly explained the rules. There was a practice session consisting of 64 stimuli. If 90% accuracy rate threshold was not reached, participants repeated the practice session until the criterion was reached. Participants repeat the practice maximum of two times. Following the experiment, participants received a debriefing. The assignment of participants to each level of proportional congruency (equally-congruent, mostly congruent, mostly incongruent) was random. The generation of the stimulus list were not done by adding sequences of random stimuli blocks together, but rather creating a list as a single block of randomly ranked digit-task pairings.

Results

Reaction Time

Reaction times were calculated as the duration (in seconds) from the onset of stimulus presentation to the initiation of the response. For each participant, the reaction time for the initial stimulus, reaction times for incorrect responses, and reaction times deviating by more than +/- 3 standard deviations from the participant's mean reaction times were excluded from the analysis. The same threshold was used to filter participants, but no participants are eliminated. Subsequently, the mean correct reaction times were calculated for all participants and conditions. Analyses were conducted with the data of all 60 participants.

RT data was analyzed with 3 (proportion congruency: equally congruent, mostly congruent, mostly incongruent) x 2 (previous stimulus: congruent, incongruent) x 2 current stimulus: congruent, incongruent) x 2 (task repetition, task alternation) mixed factor ANOVA, with list-level proportion congruency as the between subject factor.

The main effect of current stimulus was significant, *F*(1, 57) = 22.09, *p* < .001, η^2p = 0.28. A significant interaction was found between current stimulus and proportion congruency, *F*(2, 57) = 4.10, *p* = .010, η^2p = 0.15, showing the Proportion Congruency Effect in our data (see Figure 1). The main effect of task repetition/alternation was significant, *F*(1, 57) = 156.87, p < .001, η^2p = 0.73. Responses were faster when the task was repeated as compared to when they were alternated, showing the switch cost in our experiment (see Figure 2). There was a significant interaction between task repetition/alternation and proportion congruency, *F*(2, 57) = 7.77, *p* = .001 , η^2p = 0.21. There was a higher switch cost in the mostly congruent list, as compared to the equally congruent list, and to the mostly incongruent list. A significant interaction was observed between previous stimulus and current stimulus, *F*(1, 57) = 14.63, *p* < .001, η^2p = 0.20, showing a Gratton effect in our experiment (Figure 3).

We filter out task repetitions and digit repetitions in the RT data, and conduct a 3 (proportion congruency: equally congruent, mostly congruent, mostly incongruent) x 2 (previous stimulus: congruent, incongruent) x 2 current stimulus: congruent, incongruent) mixed factor ANOVA, with list-level proportion congruency as the between subject factor. The main effect of current stimulus was significant, *F*(1, 57) = 20.12, *p* < .001, η^2p = 0.26. The main effect of proportion congruency was also significant, *F*(2, 57) = 4.92, *p* = .011, η^2p = 0.15. A significant interaction was found between current stimulus and proportion congruency, *F*(2, 57) = 3.77, *p* = .029, η^2p = 0.12, showing the Proportion Congruency Effect.

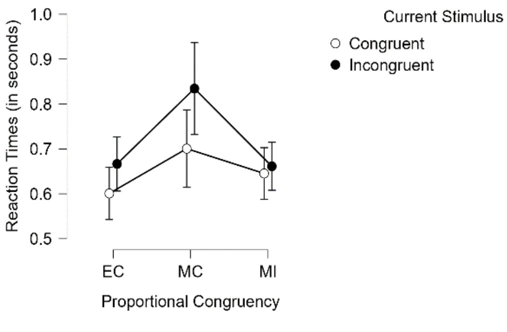

Figure 1: Proportion congruency effect for reaction times (EC: Equally Congruent, MC: Mostly Congruent, MI: Mostly Incongruent).

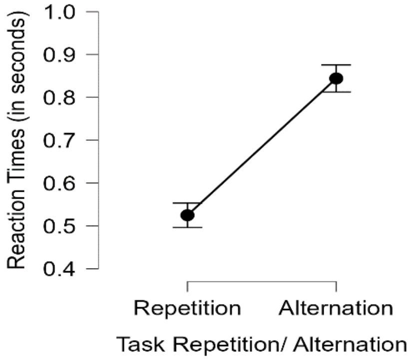

Figure 2. Switch Cost for reaction times.

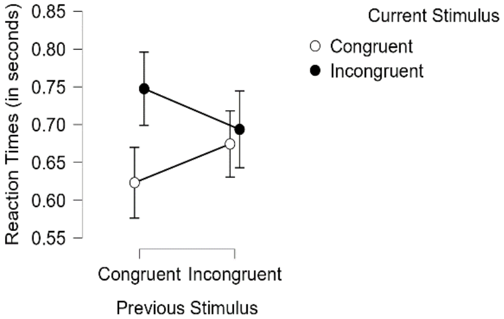

Figure 3. Gratton effect for reaction times.

Error Rates

The main effect of current stimulus was significant, *F*(1, 57) = 33.04, *p* < .001, η^2p = 0.37. The main effect of previous stimulus was significant, F(1, 57) = 4.20, p = .045, η^2p = 0.07. The main effect of task repetition/alternation was significant, *F*(1, 57) = 10.77, p = .002, η^2p = 0.16, showing a switch cost in error rates. A significant interaction was observed between previous stimulus and current stimulus, *F*(1, 57) = 7.49, *p* = 0.008, η^2p = 0.12, showing a Gratton effect in error rates. A significant interaction was observed between previous stimulus and task repetition/alternation, F(1, 57) = 4.16, p = 0.046, η^2p = 0.07. A significant interaction was observed between current stimulus and task repetition/alternation, F(1, 57) = 5.33, p = 0.025, η^2p = 0.09. The switch cost was larger when the current stimulus is incongruent. A significant three-way interaction was observed, between current stimulus, previous stimulus and task repetition/alternation *F*(1, 57) = 9.91, *p* = .003, η^2p = 0.15. The Gratton effect was disappeared when the task alternates.

The error rates were also analyzed with a 3 (proportion congruency: equally congruent, mostly congruent, mostly incongruent) x 2 (previous stimulus: congruent, incongruent) x 2 current stimulus: congruent, incongruent) mixed factor ANOVA, with list-level proportion congruency as the between subject factor, which was used to analyze data after task repetitions and digit repetitions are filtered out the data. The main effect of current stimulus was significant, F(1, 57) = 33.44, p < .001, η^2p = 0.37. The main effect of previous stimulus was significant, F(1, 57) = 5.16, p = .027, η^2p = 0.08.

A significant interaction was found between previous stimulus and current stimulus, $F(1, 57) = 7.74$, $p = .007$, $\eta^2 p = 0.12$, showing the Gratton Congruency Effect in filtered error rate data.

Discussion

The Gratton effect and the proportion congruency effect in our parity/magnitude task-switching experiment suggest that conflict-triggered control operates even in the absence of conflict in the stimulus. In the mostly congruent list, participants responded faster when the stimulus-response mappings of the parity/magnitude tasks were congruent compared to when they were incongruent. However, this reaction time difference was not observed in the mostly incongruent list. Critically, the reaction times for congruent stimuli were similar between the mostly congruent and mostly incongruent lists. This reaction time pattern suggests that participants diminish the cost of the irrelevant stimulus-response mappings. Control system addresses the effects of the incongruent S-R mappings of the other task.

In the neural network implementation of the conflict monitoring model (Botvinick et al., 2001; Verguts and Notebaert, 2008), conflict is defined as the global energy in the response layer (Hopfield, 1982). This global energy is computed by calculating the covariation of activations of alternative responses, weighted with connections. In the parity/magnitude task-switching experiment, there is no irrelevant dimension in the stimulus. Conflict arises from the stimulus-response (S-R) mappings of the alternative task. Consequently, the conflict-monitoring model needs to be extended to accommodate situations where task rules is explicit and predetermined, yet S-R mappings of the other task leaks into the decision-making system.

The PCE is influenced by the process of learning contingencies. However, it's important to note that contingency learning is not sufficient to fully account for the PCEs that we observed in our task-switching paradigm. This highlights the need for further investigation to fully understand the relation between the PCE and contingency learning.

The observed GE in the error rates data, but not in the reaction time data when we filter out the trials that with task repetitions and digit repetitions. Stimulus-response bindings and stimulus-response contingency learning has been proposed as alternative explanations for the GE and the PCE, respectively. Our results show that S-R bindings has important contributions, and conflict-driven control is not the whole story. Conflict driven control at the trial level still operates even when the task is switched.

Our study emphasizes the importance of task-switching paradigms in understanding the relation between conflict-driven attentional control and memory-based mechanisms, such as stimulus-response bindings and contingency learning. By systematically manipulating conflict within task-switching paradigm, we were able to isolate the effects of stimulus-response contingency learning in our study. Future research utilizing task-switching designs will be important to understand how we adapt our responses in dynamic environments.

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