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Abstract

Conflict adaptation is an important phenomenon that reflects the dynamic processes of cognitive control. However, it remains unclear whether differences in conflict level can elicit conflict adaptation. This study employed a variant of the letter Flanker task, manipulating conflict level by altering target-distractor congruency to investigate how changes in conflict level influence cognitive control adjustments. The results revealed that participants' reaction times increased with higher conflict levels; furthermore, the congruency of previous trials affected the interference effect in current trials, with typical conflict adaptation observed between no-conflict and low-conflict, no-conflict and high-conflict, and low-conflict and high-conflict conditions. These findings indicate that, beyond the mere presence or absence of conflict, changes in conflict level can also elicit conflict adaptation, supporting the notion that greater conflict drives stronger cognitive control, and that the function of conflict-induced cognitive control may be implemented through attentional focusing. This finding provides direct evidence supporting the attentional regulation mechanism of conflict monitoring theory and holds significant implications for advancing research on conflict adaptation.

Full Text

Changes in Conflict Level Trigger Conflict Adaptation

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Abstract

Conflict adaptation is an important phenomenon in cognitive control research that reflects the dynamic adjustment of control processes. However, it remains unclear whether differences in conflict level can trigger conflict adaptation. The present study employed a modified letter Flanker task, manipulating conflict level by varying target-distractor congruency to investigate how changes in conflict level influence cognitive control adjustments. Results showed that participants' reaction times increased with higher conflict levels. Moreover, the congruency of previous trials affected the interference effect in current trials, with typical conflict adaptation observed between no-conflict and low-conflict, no-conflict and high-conflict, and low-conflict and high-conflict conditions.

These findings demonstrate that, beyond the mere presence or absence of conflict, changes in conflict level can also trigger conflict adaptation, supporting the notion that greater conflict drives stronger cognitive control. Furthermore, the function of conflict-induced cognitive control may be implemented through attentional focusing. This discovery provides direct support for the attentional modulation mechanism of conflict monitoring theory and has important implications for advancing research on conflict adaptation.

Keywords: cognitive control; conflict level; conflict adaptation; attention focus
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Introduction

Cognitive control is fundamental to goal-directed behavior. In laboratory settings, conflict tasks are commonly used to investigate cognitive control. For instance, in the color-word Stroop task (Stroop, 1935), participants must identify the ink color of a word (the task-relevant dimension) while ignoring the word' s meaning (the task-irrelevant dimension). Reaction times are consistently slower in incongruent conditions than in congruent conditions, and the difference between them is termed the interference effect. The magnitude of this interference effect reflects both the signal strength of task-irrelevant dimensions relative to task-relevant dimensions and the level of cognitive control applied (Braem et al., 2019). Previous research has found that the interference effect following incongruent trials is often smaller than that following congruent trials, a phenomenon known as conflict adaptation or the congruency sequence effect (Gratton et al., 1992; Liu et al., 2012).

Two dominant theories currently explain conflict adaptation. Conflict monitoring theory posits that conflict adaptation is regulated by top-down cognitive control. When a previous trial is incongruent, it triggers an adjustment mechanism that increases the level of cognitive control, whereas congruent trials do not produce such adjustment. Consequently, the interference effect is smaller after incongruent trials than after congruent trials, manifesting as "adaptation" to conflict. Conflict adaptation is thus interpreted as resulting from individuals' monitoring of conflict in previous trials, leading to better control of conflict in current trials (Botvinick et al., 2001; Botvinick et al., 1999). Neuroimaging evidence indicates that conflict adaptation involves an evaluation process supported by the anterior cingulate cortex (ACC) and a control process supported by the dorsolateral prefrontal cortex (dlPFC) (Botvinick, 2007; Botvinick et al., 2004). In contrast, the adaptation-by-binding theory suggests that conflict adaptation may result from the interaction between online learning and arousal. Unlike conflict monitoring theory, this perspective proposes that the locus coeruleus (LC) mediates between conflict monitoring and conflict resolution. The LC releases norepinephrine throughout the brain, which affects active representations of task-relevant information in online learning, leading to better adaptation (Verguts & Notebaert, 2008; 2009).

In recent years, scholars have proposed new theoretical explanations for conflict adaptation. The distractor head start hypothesis suggests that, after controlling for feature repetitions and episodic learning, conflict adaptation is more likely to be triggered when distractors appear before the target, emphasizing that temporal differences in response activation play an important role in driving cognitive control adjustments (Weissman et al., 2015; Weissman et al., 2014). Additionally, Egner (2014) integrated "association" (bottom-up) and "control" (top-down) perspectives on explaining congruency sequence effects and proposed a multi-level learning theory, which posits that learning at different levels works synergistically to achieve goals. Specifically, learning connects external stimuli with appropriate internal states. Based on cognitive and neural evidence, Chiu and Egner (2019) further proposed context-control learning, where external cues trigger appropriate top-down control settings in a bottom-up manner. Moreover, Dignath et al. (2019) integrated control and episodic retrieval theories, suggesting that abstract control settings can be stored together with stimuli, responses, and contexts in event files. These theories, based on different experimental paradigms and designs, reveal the nature of conflict adaptation from various angles and may be complementary.

An important question in conflict adaptation research concerns how conflict properties interact with adaptation. Some studies have found that previous stimulus conflict can lead to conflict adaptation (Notebaert & Verguts, 2006; Verbruggen et al., 2006). Liu et al. (2012) used 2-1 mapping Flanker and Stroop tasks with six color stimuli, strictly controlling for feature integration and balancing responses and stimuli. They found that both previous-trial stimulus conflict and response conflict could trigger conflict adaptation, but only current-trial response conflict reflected conflict adaptation. Brain imaging studies have also shown that different regions of the ACC and dlPFC may be responsible for processing stimulus conflict and response conflict in Stroop tasks (Kim et al., 2010; Kim et al., 2011). It can thus be argued that conflict monitoring can identify conflict types and trigger corresponding cognitive control adjustments.

However, previous studies have only included different conflict types in previous trials, so their results can only speak to the influence of previous conflict type on conflict adaptation. In reality, differences in conflict level also exist within the same conflict type. Can the conflict monitoring system detect differences in conflict level across previous trials and subsequently trigger conflict adaptation? This is an important question that has not been adequately investigated. Due to limited relevant empirical research, theories such as conflict monitoring and adaptation-by-binding have not explicitly addressed the relationship between conflict intensity and cognitive control adjustment. The present study seeks to investigate this issue to deepen our understanding of the mechanisms underlying conflict adaptation.

Previous studies have typically manipulated conflict level by altering the activation strength of competing responses. Danielmeier et al. (2009) manipulated conflict level by varying the distance between flankers and target arrows (near vs. far). Other studies have used Flanker tasks to manipulate stimulus onset asynchrony (SOA) between targets and distractors to change conflict intensity. Presenting distractors before target stimuli strengthens flanker-based response activation, resulting in larger interference effects than when targets and distractors appear simultaneously (Eriksen & Schultz, 1979; Flowers, 1980; Weissman et al., 2014). Wendt et al. (2014) used a priming-probe Flanker task to manipulate flanker-target SOA to vary conflict level, with prime-trial SOAs of 0 ms and -150 ms and probe-trial SOA of 0 ms. They found that interference effects in current trials decreased when previous trials had high conflict (SOA of -150 ms), but no conflict adaptation effect was observed when previous trials had low conflict (SOA of 0 ms), supporting the idea that visual attention adjustment depends on conflict intensity. The conflict adaptation effect after high-conflict trials was associated with increased prestimulus pupil diameter, reflecting enhanced cognitive effort after high-conflict trials. Since pupil diameter changes are often used as an index of LC activity modulated by conflict or arousal (Rajkowski et al., 1993), this study largely supports the adaptation-by-binding theory. Additionally, Foster et al. (2011) used an adapted two-letter Flanker task to parametrically manipulate target-distractor congruency, creating four conflict levels: congruent (e.g., SSSSSSS), low incongruency (e.g., HSSSSSH), medium incongruency (e.g., HHSSSHH), and high incongruency (e.g., HHHSHHH). Results showed that reaction times and error rates increased with conflict level, and the interference effect between congruent and incongruent trials (including low, medium, and high incongruency) was smaller after high-incongruency trials than after low- and medium-incongruency trials, indicating that changes in conflict level can trigger conflict adaptation. However, this study had limitations: first, the two-letter stimulus set could not exclude feature repetitions, so Foster et al.' s (2011) conflict adaptation effects might have resulted from both feature integration and conflict monitoring, failing to demonstrate that conflict plays a key role in adaptive control. Second, the proportions of trial types differed substantially, with only two trial types (congruent vs. incongruent) in current trials. The ratio of congruent to incongruent trials can influence interference effects and thus affect conflict adaptation (Mayr & Awh, 2009). The 7:3 ratio of congruent to incongruent trials exaggerated conflict-induced interference effects and resulted in insufficient numbers of low, medium, and high incongruency trials in current trials for detailed analysis.

To address these issues, the present study used a four-letter Flanker task that completely avoids feature repetitions, thereby excluding bottom-up feature binding effects. Congruent and incongruent trials were equally probable, with incongruent trials further divided into low-conflict and high-conflict conditions, each accounting for 25% of total trials. This design ensures overall environmental stability while facilitating investigation of the dynamic process of conflict adaptation.

The present study used an adapted letter Flanker task to systematically manipulate conflict level and explore the triggers of conflict adaptation, thereby testing the relationship between conflict intensity and cognitive control adjustment. We hypothesized that the conflict intensity of previous trials would affect the cognitive control level in current trials, with greater conflict driving stronger cognitive control adjustment. If conflict adaptation exists between no-conflict and low-conflict and between no-conflict and high-conflict, but not between low-conflict and high-conflict, this would suggest that only the presence or absence of conflict triggers conflict adaptation and that greater conflict cannot elicit stronger cognitive control adjustment. However, if conflict adaptation exists among all three conditions—no-conflict and low-conflict, no-conflict and high-conflict, and low-conflict and high-conflict—this would indicate that changes in conflict level, beyond mere conflict presence, can trigger conflict adaptation, thereby validating that greater conflict drives stronger cognitive control adjustment.

Method

Participants

Thirty-one university students aged 18-23 years (16 males) voluntarily participated in the experiment, with a mean age of 19.74 years (SD = 1.32). All participants were right-handed, had normal or corrected-to-normal vision, no color blindness or weakness, and no history of mental illness. Participants received compensation based on their task performance. Prior to the experiment, sample size was estimated using G*Power 3.1 software, with an effect size of 0.25 (medium), power of 0.95, and alpha level of 0.05, yielding a required sample size of 22.

Apparatus

The experiment was programmed using E-Prime 2.0.10.92 software and run on a computer that presented stimuli and recorded responses. The monitor resolution was 1280$×$768 with a refresh rate of 60 Hz. Participants viewed the screen from a distance of 70 cm.

Task and Procedure

The experiment adapted the letter Flanker task from Forster et al. (2011). Stimuli consisted of four types of white uppercase letters (F, H, N, and P) presented in 28-point Arial font. Five horizontally arranged uppercase letters appeared at the center of a black screen. The stimulus dimensions were 5.3 cm × 1.3 cm (visual angle: 4.33° × 1.06°). The central letter served as the target stimulus, while the flanking letters were distractors. The congruency between flankers and the central target was manipulated to create three conditions: 100% congruent for no-conflict trials (e.g., NNNNN), 50% congruent for low-conflict trials (e.g., HNNNH), and 0% congruent for high-conflict trials (e.g., HHNHH). This parametric manipulation of target-distractor congruency separated incongruent conditions into low- and high-conflict levels.

The experimental procedure is illustrated in [Figure 1: see original paper]. Each trial began with a 500 ms white fixation point at the center of the screen, followed by stimulus presentation. Participants were instructed to ignore the flanking letters and respond only to the central letter using a button press. They placed their left middle and index fingers on keys "1" and "2" and their right index and middle fingers on keys "9" and "0" . The central letters "F, H, N, P" corresponded to keys "1, 2, 9, 0" , respectively. The stimulus disappeared after a response within 1500 ms or after the time limit elapsed. A feedback screen appeared for 800 ms: a blank screen for correct responses, "Incorrect" for errors, and "No response detected" for slow responses. A 500 ms fixation point followed before the next trial began.

The experiment employed a 3 (previous trial congruency: no-conflict, low-conflict, high-conflict) × 3 (current trial congruency: no-conflict, low-conflict, high-conflict) within-subjects design. The formal experiment comprised six blocks presented in random order. Each block contained 97 trials (with the first trial excluded from analysis), including 48 congruent and 48 incongruent trials. Incongruent trials were equally divided into 24 low-conflict and 24 high-conflict trials, with balanced stimulus-response mapping. The entire experiment included 582 trials. Within each block, there were 24 no-conflict followed by no-conflict trials, 12 trials each for no-conflict followed by low-conflict, no-conflict followed by high-conflict, low-conflict followed by no-conflict, and high-conflict followed by no-conflict trials, and 6 trials each for low-conflict followed by low-conflict, low-conflict followed by high-conflict, high-conflict followed by low-conflict, and high-conflict followed by high-conflict trials. Trials were pseudo-randomly arranged to avoid distractor-distractor, distractor-target, target-distractor, and target-target repetitions across consecutive trials, thereby eliminating feature integration effects. Since no-conflict trials accounted for 50% of all trials while low-conflict and high-conflict trials each accounted for 25%, each distractor type paired more frequently with no-conflict targets than with low- or high-conflict targets, potentially introducing episodic learning confounds. However, within low- and high-conflict trials, all stimulus types occurred with equal frequency, eliminating episodic learning effects. A practice block preceded the formal experiment, consisting of 48 randomly arranged trials (24 no-conflict, 12 low-conflict, and 12 high-conflict) with the same response rules. Participants needed to achieve at least 85% accuracy to proceed to the formal experiment.

Data Analysis

The first trial of each block (1.03%), error trials and post-error trials (6.71%), and trials with reaction times exceeding $±3*standarddeviationsfromtheconditionmean*(1.13^{2}$ reported as the effect size measure and 90% confidence intervals provided.

Results

Interference Effects

One-way repeated measures ANOVA on mean reaction times and error rates across congruency conditions (no-conflict, low-conflict, high-conflict) revealed significant differences in reaction times, $F(2, 60) = 106.51$, $p < 0.001$, $\text{p}^2 = 0.78$, 90% CI [0.69, 0.83], reflecting a significant interference effect of trial congruency. Post-hoc comparisons showed that reaction times in the no-conflict condition (708.63 ± 66.23 ms) were significantly shorter than in low-conflict and high-conflict conditions (both ps < 0.001), and reaction times in the low-conflict condition (751.18 ± 69.24 ms) were significantly shorter than in the high-conflict condition (767.83 ± 70.20 ms) ($p < 0.001$), demonstrating the pattern RT_{no}-conflict < RT_{low}-conflict < RT_{high}-conflict. For error rates, differences across congruency conditions were marginally significant, $F(2, 60) = 2.90$, $p = 0.063$, $\text{p}^2 = 0.09$, 90% CI [0.00, 0.20]. Post-hoc comparisons revealed a marginally significant difference between no-conflict (3.11 ± 2.59%) and low-conflict (3.92 ± 2.91%) error rates ($p = 0.069$), while no significant differences were found between no-conflict or low-conflict and high-conflict (3.72 ± 3.03%) error rates.

Conflict Adaptation Effects

A 3 (previous trial congruency: no-conflict, low-conflict, high-conflict) × 3 (current trial congruency: no-conflict, low-conflict, high-conflict) repeated measures ANOVA on mean reaction times and error rates (see [Figure 2: see original paper]C, 2D) was conducted, with descriptive statistics presented in .

Statistical results for the reaction time analysis are shown in . The main effect of previous trial congruency was significant, $F(2, 60) = 13.32$, $p < 0.001$, $\text{p}^2 = 0.31$, 90% CI [0.14, 0.43]. Multiple comparisons revealed that reaction times following low-conflict trials were significantly shorter than those following no-conflict and high-conflict trials (both ps = 0.001), with no significant difference between no-conflict and high-conflict trials ($p = 1.00$). The main effect of current trial congruency was also significant, $F(2, 60) = 103.82$, $p < 0.001$, $\text{p}^2 = 0.78$, 90% CI [0.68, 0.82], with reaction times in no-conflict trials significantly shorter than in low- and high-conflict trials (both ps < 0.001), and low-conflict reaction times significantly shorter than high-conflict ($p < 0.001$). Crucially, the interaction between previous and current trial congruency was significant, $F(4, 120) = 13.06$, $p < 0.001$, $\text{p}^2 = 0.30$, 90% CI [0.17, 0.38], indicating that previous trial congruency influenced interference effects in current trials.

A 3 (previous trial congruency: no-conflict, low-conflict, high-conflict) × 2 (current trial congruency: no-conflict, low-conflict) repeated measures ANOVA revealed significant main effects of previous trial congruency, $F(2, 60) = 21.38$, $p < 0.001$, p^2 = 0.42, 90% CI [0.24, 0.53], and current trial congruency, $F(1, 30) = 94.42$, $p < 0.001$, p^2 = 0.76, 90% CI [0.61, 0.83], as well as a significant interaction, $F(2, 60) = 19.70$, $p < 0.001$, p^2 = 0.40, 90% CI [0.22, 0.51]. To identify the source of this interaction, interference effects (RT_{low}-conflict - RT_{no}-conflict) were analyzed with previous trial congruency as a repeated factor. Multiple comparisons showed that interference effects after low-conflict and high-conflict trials were significantly smaller than after no-conflict trials (both ps < 0.001), with no significant difference between low-conflict and high-conflict trials ($p = 0.208$). Further analysis revealed significant main effects and interactions for previous trial congruency (no-conflict, low-conflict) × current trial congruency (no-conflict, low-conflict), $F(1, 30) = 35.43$, $p < 0.001$, p^2 = 0.54, 90% CI [0.32, 0.67], showing classic conflict adaptation: interference effects were significantly smaller after low-conflict trials (15.68 ms) than after no-conflict trials (61.70 ms). Similarly, previous trial congruency (no-conflict, high-conflict) × current trial congruency (no-conflict, low-conflict) showed significant main effects ($p = 0.011$, $p < 0.001$) and interaction, $F(1, 30) = 22.86$, $p < 0.001$, p^2 = 0.43, 90% CI [0.20, 0.58], demonstrating classic conflict adaptation: interference effects were significantly smaller after high-conflict trials (31.00 ms) than after no-conflict trials (61.70 ms). The interaction between previous trial congruency (low-conflict, high-conflict) and current trial congruency (no-conflict, low-conflict) was marginally significant, $F(1, 30) = 3.55$, $p = 0.069$, p^2 = 0.11, 90% CI [0.00, 0.28], with interference effects marginally smaller after high-conflict trials (31.00 ms) than after low-conflict trials (15.67 ms).

A 3 (previous trial congruency: no-conflict, low-conflict, high-conflict) × 2 (current trial congruency: no-conflict, high-conflict) repeated measures ANOVA showed no significant main effect of previous trial congruency, $F(2, 60) = 1.17$, $p = 0.318$, p^2 = 0.04, but a significant main effect of current trial congruency, $F(1, 30) = 166.23$, $p < 0.001$, p^2 = 0.85, 90% CI [0.74, 0.89], and a significant interaction, $F(2, 60) = 10.43$, $p < 0.001$, p^2 = 0.26, 90% CI [0.10, 0.38]. Analyzing interference effects (RT_{high}-conflict - RT_{no}-conflict) with previous trial congruency as a factor revealed that interference effects after high-conflict trials were significantly smaller than after no-conflict and low-conflict trials ($p < 0.001$, $p = 0.011$), with no difference between no-conflict and low-conflict trials ($p = 0.862$). Further analysis showed a significant interaction between previous trial congruency (no-conflict, high-conflict) and current trial congruency (no-conflict, high-conflict), $F(1, 30) = 25.08$, $p < 0.001$, p^2 = 0.46, 90% CI [0.22, 0.60], demonstrating classic conflict adaptation: interference effects were significantly smaller after high-conflict trials (34.28 ms) than after no-conflict trials (70.84 ms). The interaction between previous trial congruency (low-conflict, high-conflict) and current trial congruency (no-conflict, high-conflict) was also significant, $F(1, 30) = 9.90$, $p = 0.004$, p^2 = 0.25, 90% CI [0.05, 0.43], showing classic conflict adaptation: interference effects were significantly smaller after high-conflict trials (34.28 ms) than after low-conflict trials (61.14 ms).

A 3 (previous trial congruency: no-conflict, low-conflict, high-conflict) × 2 (current trial congruency: low-conflict, high-conflict) repeated measures ANOVA revealed significant main effects of previous trial congruency, $F(2, 60) = 13.88$, $p < 0.001$, $p^2 = 0.32$, 90% CI [0.15, 0.44], and current trial congruency, $F(1, 30) = 27.70$, $p < 0.001$, $p^2 = 0.48$, 90% CI [0.25, 0.62], and a significant interaction, $F(2, 60) = 11.06$, $p < 0.001$, $p^2 = 0.27$, 90% CI [0.11, 0.39]. Analyzing interference effects (RT_{high}-conflict - RT_{low}-conflict) with previous trial congruency as a factor showed that interference effects after low-conflict trials were significantly larger than after no-conflict and high-conflict trials ($p = 0.005$, $p < 0.001$), with no difference between no-conflict and high-conflict trials ($p = 1.00$). Further analysis revealed significant main effects and interaction for previous trial congruency (no-conflict, low-conflict) × current trial congruency (low-conflict, high-conflict), $F(1, 30) = 11.97$, $p = 0.002$, $p^2 = 0.29$, 90% CI [0.08, 0.46], showing reversed conflict adaptation: interference effects were significantly larger after low-conflict trials (45.47 ms) than after no-conflict trials (9.15 ms). The interaction between previous trial congruency (low-conflict, high-conflict) and current trial congruency (low-conflict, high-conflict) was also significant, $F(1, 30) = 20.22$, $p < 0.001$, $p^2 = 0.40$, 90% CI [0.17, 0.56], demonstrating classic conflict adaptation: interference effects were significantly smaller after high-conflict trials (3.28 ms) than after low-conflict trials (45.47 ms).

For error rates, the main effect of previous trial congruency was not significant, $F(2, 60) < 1$, $p = 0.725$, $p^2 = 0.01$. The main effect of current trial congruency was marginally significant, $F(2, 60) = 2.55$, $p = 0.086$, $p^2 = 0.08$, 90% CI [0.00, 0.18]. The interaction between previous and current trial congruency was also not significant, $F(4, 120) < 1$, $p = 0.963$, $p^2 = 0.01$, indicating that interference effects in current trials were not influenced by previous trial congruency in terms of error rates.

Discussion

The present study investigated the triggers of conflict adaptation by manipulating conflict level in a letter Flanker task. Results showed that participants' reaction times increased with conflict level, demonstrating that our manipulation of conflict level through target-distractor congruency was effective. More importantly, by experimentally eliminating low-level feature integration and feature priming effects, we obtained a pure measure of conflict adaptation. Reaction times showed that previous trial congruency influenced interference effects in current trials, with conflict adaptation observed between no-conflict and low-conflict, no-conflict and high-conflict, and low-conflict and high-conflict conditions.

Extensive research has shown that conflict adaptation is task-specific. Studies integrating Stroop and Flanker (or Simon) tasks have demonstrated that cognitive control adjustments for subsequent performance are only triggered when subsequent trials are Stroop trials rather than Flanker or Simon trials, suggesting that conflict adaptation occurs within the same conflict type (Egner et al., 2007; Funes et al., 2010). Consequently, Egner (2008) proposed that conflict-driven control is domain-specific and may be processed by multiple independent conflict-control loops operating in parallel. Moreover, the nature of conflict (stimulus conflict vs. response conflict) differentially influences conflict adaptation (Liu et al., 2012). These findings provide evidence that conflict monitoring systems convey information about specific conflict types.

However, it remains unclear whether differences in conflict level within the same conflict type can trigger conflict adaptation. The present study addressed this question by manipulating conflict level within a single conflict type. Botvinick (2001) hypothesized that the cognitive system continuously monitors conflict level in the ACC, defining conflict as “energy”in the response layer, where greater co-activation of competing response units indicates higher conflict. This signal is transmitted to the dlPFC, which then adjusts attentional processing of task-relevant and irrelevant dimensions. By varying target-distractor congruency to affect the activation strength of competing responses, we found that reaction times in the high-conflict condition were significantly longer than in low- and no-conflict conditions, with low-conflict reaction times longer than no-conflict times. This confirms that our manipulation of conflict level was effective.

By adapting the letter Flanker task to parametrically manipulate conflict level while controlling for feature integration confounds, we found that previous trial congruency influenced current trial interference effects, with conflict adaptation observed across all pairwise comparisons between no-conflict, low-conflict, and high-conflict conditions. These results support Foster et al. (2011) and demonstrate that changes in conflict level affect cognitive control levels in subsequent trials, inducing adaptive phenomena. The classic conflict adaptation patterns between no-conflict and low-conflict and between no-conflict and high-conflict align with previous qualitative studies of congruent and incongruent conditions (Notebaert, Gevers, et al., 2006; Notebaert & Verguts, 2011; Ullsperger et al., 2005), indicating that conflict presence can trigger adaptation. More importantly, conflict adaptation between low-conflict and high-conflict conditions demonstrates that greater conflict drives stronger cognitive control adjustment, providing direct evidence that conflict monitoring is sensitive to fine-grained changes in conflict magnitude and that changes in conflict level can trigger adaptation. Additionally, using low-conflict as a transitional condition between no-conflict and high-conflict allows for dynamic characterization of the conflict adaptation process and provides insights into how people adapt to complex, changing environments in real life.

Regarding the relationship between conflict intensity and cognitive control level, Takezawa and Miyatani (2005) manipulated spatial distance between target and distractor stimuli (far vs. near) in an arrow Flanker task and found that greater target-distractor proximity produced larger interference effects. Moreover, the influence of previous trial conflict level on task performance depended on current trial congruency: greater previous-trial conflict led to longer reaction times in current congruent trials, indicating that previous conflict magnitude determined the strength of response inhibition in current trials. For current incongruent trials, reaction times were faster and more accurate after incongruent than after congruent trials, demonstrating conflict-driven attentional focusing. However, previous incongruent trial conflict level did not affect current incongruent trial reaction times. These results suggest that conflict monitoring may modulate subsequent performance through selective attention and response preparation control, with these two control forms showing different sensitivities to conflict magnitude. Similarly, our study shows that conflict monitoring is sensitive to changes in conflict level, with previous trial conflict level potentially determining current trial cognitive control level, possibly implemented through attentional focusing.

Some studies have taken opposing views, suggesting that greater conflict does not drive stronger cognitive control adjustment. Rey-Mermet and Meier (2014) examined how conflict level induced by bivalent stimuli (with two task-relevant features) affects the bivalency effect (cognitive control adjustment following bivalent stimulus-induced conflict) using two adapted task-switching experiments. Bivalent stimuli were divided into congruent (same response) and incongruent (different responses) types, with congruent bivalent stimuli containing only task conflict and incongruent bivalent stimuli containing both task and response conflict. Univalent stimuli had no conflict (only one task-relevant feature). Results showed similar bivalency effects after congruent and incongruent bivalent stimuli, suggesting that greater conflict does not drive greater cognitive control adjustment and that cognitive control adjustment under bivalency effects is only sensitive to conflict occurrence, not magnitude. In contrast, Grundy and Shedden (2014) found that incongruent bivalent stimuli produced larger bivalency effects than congruent bivalent stimuli, concluding that greater conflict produces larger bivalency effects. However, these studies manipulated conflict level without maintaining the same conflict nature, and their conclusions remain controversial, requiring further investigation. At the neural level, Kerns et al. (2004) and Kerns (2006) used fMRI with color-word Stroop and Simon tasks to test conflict monitoring theory, finding that ACC activity related to previous trials could predict enhanced PFC activity and behavioral adaptation in subsequent trials, indicating that previous conflict intensity influences subsequent cognitive control engagement. Furthermore, Foster et al.' s (2011) ERP research showed that the N2 component is sensitive to conflict degree and its induced control adjustments, results further validated by Clayson and Larson (2011). Combined with previous research, our results support the conclusion that greater conflict drives stronger cognitive control.

Our findings support the notion that greater conflict drives stronger cognitive control adjustment, but how does conflict intensity affect cognitive control level, and how is this control function implemented to resolve conflict? To address these questions, we must consider task characteristics. In the letter Flanker task, the central target is spatially separated from the flanking distractors, suggesting that participants may adopt a spatial attention strategy to better resolve conflict. The zoom-lens model proposes that attentional focus size can be controlled through precues, with processing resources distributed relatively uniformly within the attentional focus. Moreover, attentional focus size is inversely related to processing efficiency: as the attentional region increases, resource density decreases (Eriksen & James, 1986). Additionally, Botvinick et al. (2001) simulated sequential adjustments in the Eriksen Flanker task (Gratton et al., 1992) and developed a conflict monitoring-control feedback model. The conflict monitoring system transforms conflict signals in the response layer into control signals transmitted to the spatial attention layer. Based on conflict monitoring output, attention layer inputs are adjusted across trials to implement control functions: high conflict leads to more concentrated input to central attention units, while low conflict results in more uniform attention input distribution. Assuming the total control signal input to the attention layer remains constant, attention input distribution varies between unfocused [1 1 1] and tightly focused [0 3 0] configurations (Botvinick et al., 2001; p640, Figure 7 [Figure 7: see original paper]).

From this, we infer that conflict monitoring assesses conflict magnitude (e.g., degree of co-activation of multiple responses), and changes in conflict level modulate attention allocation weights to task-relevant and irrelevant dimensions, leading to gradual changes in selective processing. In other words, conflict-induced cognitive control functions may be implemented through attentional focusing. By manipulating target-distractor congruency to vary conflict level, our study further explores the attentional modulation mechanism of cognitive control. We hypothesize that as previous trial conflict increases, enhanced cognitive control in current trials may lead to narrowed attentional scope, with attention gradually focusing on task-relevant information following no-conflict, low-conflict, and high-conflict trials. Therefore, our conflict adaptation findings can be explained by conflict monitoring theory combined with attentional focusing. For conflict adaptation between no-conflict and low-conflict and between no-conflict and high-conflict, increased cognitive control after high-conflict trials may focus attention on task-relevant information (the central letter), reducing flanker interference. Smaller control adjustments triggered after low-conflict trials may focus attention on the three central identical letters (with distractors near the target facilitating processing), reducing interference from outermost distractors. No such adjustment occurs after no-conflict trials, with attentional resources distributed uniformly, resulting in larger interference effects after no-conflict trials than after low- or high-conflict trials. Interestingly, conflict adaptation between low-conflict and high-conflict showed that smaller adjustments triggered after low-conflict trials resulted in relatively lower cognitive control levels and attentional scope possibly narrowed to the three central letters, facilitating processing of current low-conflict trials but hindering conflict resolution in current high-conflict trials, leading to larger interference effects. In contrast, substantial cognitive control enhancement after high-conflict trials may focus more attentional resources on the central letter, facilitating processing of current high-conflict trials while eliminating the facilitative effect of identical letters flanking the target in current low-conflict trials, ultimately producing smaller interference effects after high-conflict than after low-conflict trials. The adaptation-by-binding theory suggests that conflict increases arousal levels, which enhances Hebbian learning. If this mechanism operates through attentional focusing, it could also explain our results, though future research should combine neurophysiological measures for verification.

Additionally, we observed a reversed conflict adaptation phenomenon. The Flanker effect between high-conflict and low-conflict conditions showed reversed adaptation when comparing no-conflict and low-conflict conditions, primarily because reaction times for low-conflict trials following low-conflict trials were significantly reduced compared to those following no-conflict trials. According to conflict monitoring theory and attentional focusing, when the previous trial is no-conflict, cognitive control levels are low and attentional scope is broad (covering all five letters), resulting in longer reaction times for both current low-conflict and high-conflict trials. When the previous trial is low-conflict, cognitive control increases accordingly and attentional scope narrows further (possibly focusing on the three central letters), with distractors near the target facilitating responses, leading to significantly reduced reaction times for current low-conflict trials. Processing of current high-conflict trials is constrained by both cognitive control level and attentional strategy, producing a reversed conflict adaptation pattern. Moreover, the interaction between previous trial congruency (low-conflict, high-conflict) and current trial congruency (no-conflict, low-conflict) showed a significant trend. This trend primarily reflected that, compared to previous low-conflict trials, the increase in reaction times for low-conflict trials following high-conflict trials was greater than that for no-conflict trials, showing a reversed conflict adaptation trend. This may be related to the unusually fast reaction times in low-conflict-low-conflict trials, where enhanced cognitive control after low-conflict trials may focus attention on the three central letters, and distractors adjacent to the target in low-conflict trials provide strong facilitative effects. The slowing of reaction times in high-conflict-low-conflict trials may occur because the facilitative effect of identical letters flanking the target disappears in current low-conflict trials, causing response delays. Thus, the reversed interaction trend between previous trial congruency (low-conflict, high-conflict) and current trial congruency (no-conflict, low-conflict) may be influenced by the overall complex task environment and spatial attention strategies. Notably, reversed conflict adaptation occurred in conditions where previous and current trial types were not identical, distinguishing it from classic conflict adaptation phenomena. Therefore, reversed conflict adaptation represents an interactive effect of previous and current trial congruency, possibly related to overall task environment and spatial attention strategies, and similarly supports the notion that greater conflict drives stronger cognitive control adjustment.

In summary, our findings demonstrate that changes in conflict level, beyond the mere presence or absence of conflict, can trigger conflict adaptation. Based on previous research, we infer that conflict monitoring can identify not only conflict type but also conflict magnitude, thereby implementing flexible, dynamic cognitive control adjustments. These findings provide direct support for the attentional modulation mechanism of conflict monitoring theory. However, conflict monitoring theory posits that congruent and incongruent stimuli activate competing response selection channels for task-relevant and irrelevant dimensions, generating varying degrees of conflict even when final responses are identical (Egner et al., 2005). This perspective is conceptually problematic, as congruent stimuli are generally considered to involve no conflict (Algom & Chajut, 2019). Therefore, existing theoretical models need to clarify and refine the theoretical concept and operational definition of "conflict" to facilitate quantitative research on conflict adaptation. Furthermore, our investigation of how changes in conflict level affect cognitive control adjustments provides a new perspective on adaptive control and conflict adaptation phenomena. Future research should more comprehensively characterize the emergence and influencing factors of conflict adaptation to provide multi-faceted evidence for the mechanisms underlying adaptive behavior.

Our study has several limitations. First, the results cannot exclude the role of expectancy. The repetition expectancy theory suggests that participants typically expect consecutive trials to be of the same type, broadening attentional scope (parallel strategy) after congruent trials and narrowing it (focusing strategy) after incongruent trials, leading to conflict adaptation patterns in reaction times (Gratton et al., 1992). Since our experimental design necessarily included consecutive no-conflict, low-conflict, or high-conflict trials, our results cannot rule out explanations based on repetition expectancy theory. Second, some findings are difficult to interpret, such as the lack of significant differences in interference effects between no-conflict and high-conflict conditions following no-conflict and low-conflict trials, and between low-conflict and high-conflict conditions following no-conflict and high-conflict trials. These occurred when previous and current trial congruency did not correspond, possibly due to the complex task environment. Finally, as a behavioral study, we could not directly test hypotheses regarding neural arousal level changes in the adaptation-by-binding theory or examine newer theories such as the distractor head start hypothesis and context-control learning. Future research should combine neurophysiological measures or use different experimental paradigms to manipulate conflict level for further investigation. Notably, our attentional focusing theory represents an extension based on conflict monitoring theory and the zoom-lens model, which could be further validated through eye-tracking experiments or by altering low-conflict conditions (e.g., HNNNH → NHNHN).

In conclusion, using an adapted letter Flanker task, the present study investigated how changes in conflict level affect cognitive control adjustments. The results demonstrated that previous trial congruency influenced interference effects in current trials, with conflict adaptation observed between no-conflict and low-conflict, no-conflict and high-conflict, and low-conflict and high-conflict conditions. Therefore, we conclude that changes in conflict level, beyond the mere presence or absence of conflict, can trigger conflict adaptation, indicating that greater conflict drives stronger cognitive control adjustment, and that conflict-induced cognitive control functions may be implemented through attentional focusing.

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Note: Figure translations are in progress. See original paper for figures.