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Self-referential information optimizes conflict adaptation

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Abstract

Self-referential information has been shown to optimize behavioral performance in various domains. The present study examined the role of self-referential information as a cue to enhance cognitive control and, more specifically, conflict adaptation. A revised color Stroop task was used with stimuli consisting of possessive pronouns and color words (e.g., "my green"). The results showed that self-referential information reduced conflict adaptation (the congruency sequence effect at trial level in Experiment 1, at block level in Experiment 2, and the list-wide proportion congruency effect at block level in Experiment 3). These findings suggest that self-referential information can act as a cue to optimize conflict adaptation. This study highlights the role of self-referential information in cognitive control adjustments.

Keywords Self-referential information · Conflict adaptation · Stroop task

It has been widely acknowledged that self-referential information can capture attention automatically (Bola et al., 2021; Pfister et al., 2012; Tacikowski & Nowicka, 2010), enhance alertness and attention (Li et al., 2022), and improve individuals' recognition performance about self-referential memory contents compared with memory contents about others (Klein & Kihlstrom, 1986; Symons & Johnson, 1997; Turk et al., 2011; Yin et al., 2019, 2021). Furthermore, self-referential information influences cognitive control through various mechanisms, including attentional regulation (Aben et al., 2019), motivational enhancement (Botvinick & Braver, 2015; Yee et al., 2019), and memory performance (Egner, 2014). It may also integrate with task-relevant cues in cognitive control processes (Dignath et al., 2019) and play a role in action control (Frings et al., 2020).

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Interestingly, a recent research found that self-referential information enhanced cognitive control, which was indexed by the reduced congruency effect (CE) in the Stroop task (Dignath et al., 2022). Dignath et al. (2022) proposed that self-referential information may signal the need for increased cognitive control to protect against interference from irrelevant information. As the control account is mainly based on this single study, one objective of the present study is to test the viability of this account with a new design. More importantly, the modulations of the CE are thought to reflect adjustments in cognitive control, and more specifically 'conflict adaptation' (Braem et al., 2019; Gratton et al., 1992). Dignath et al. (2022) proposed various mechanisms to address the impact of self-referential information on CE, such as stronger need of control, stronger activation of irrelevant information, and potential effects on arousal and emotions. However, it is unclear whether and how self-referential information influences the more specific aspect of conflict adaptation.

The conflict adaptation

Cognitive control allows people to act goal-guided behavior and shields from interference (Miller & Cohen, 2001). The Stroop color-word task (Stroop, 1935) is a typical paradigm for investigating cognitive control, in which participants need to name the color of a word while ignore its meaning. Their reaction time (RT) is usually slower in incongruent

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trials (word meaning different from color) compared with congruent trials (word meaning same as color). The CE is the RT difference between incongruent and congruent trials, reflecting cognitive control. Adaptive control leads to conflict adaptation, as evidenced by two indicators: the congruency sequence effect (CSE) and the list-wide proportion congruency effect (LWPCE). The CSE shows smaller CEs after incongruent than after congruent trials (Duthoo et al., 2014; Egner, 2007). The LWPCE shows smaller CEs in mostly incongruent (MI) blocks than in mostly congruent (MC) blocks (Bugg & Crump, 2012; Gratton et al., 1992; Logan & Zbrodoff, 1979).

Multiple factors may contribute to the generation of conflict adaptation. A conflict monitor detects conflict and signals the need for increased cognitive control, resulting in a smaller CE after incongruent trials (Botvinick et al., 2001). However, contingency learning proposes that conflict adaptation comes from learned stimulus–response associations within specific trial sequences (Schmidt, 2013a, b, 2019). Feature integration theory (Hommel et al., 2004) suggests that conflict adaptation is driven by the integration and binding of stimulus and response features in working memory. In order to accurately examine the role of cognitive control, we controlled for potential confounding factors. Following the recommendations of Braem et al. (2019), by controlling for contingency learning, participants would not form stimulus-response associations based on trial sequences. Additionally, by mitigating the impact of feature integration, the genuine cognitive control mechanisms from the effects of stimulus and response feature interactions in working memory could be disentangled.

The impact of self-referential information on conflict adaptation

To examine the impact of self-referential information on conflict adaptation, we first explored its influence on the CSE. Previous studies have shown that larger conflict (associated with incongruent trials) leads to a larger CSE (Forster et al., 2011; Wendt et al., 2014; Zhang et al., 2021). Conflict monitoring theory posits that increased activation of irrelevant information leads to stronger conflict, thereby resulting in a larger CSE (Botvinick et al., 2001). However, the situation becomes more complex regarding the involvement of self-referential information in this context. Self-referential information serves as a cue to improve cognitive control, affecting both incongruent and congruent trials (Dignath et al., 2022), which may lead to a reduction in CE following both congruent and incongruent trial types. However, the prediction regarding the need of control situation is unclear, two factors should be considered. One is that after experiencing conflict, cognitive control has been enhanced. In this case, self-referential information signals for a need of control, it may not further enhance control compared with the low-control state following congruent trials. The other is that the monitoring of conflict in previous trials may interfere with self-referential information's ability to trigger the need for control, and further reduce control enhancement compared with the low-control state. Therefore, in situations requiring increased control, self-referential information may reduce the CSE.

We also examined the impact of self-referential information on the LWPCE. The conflict monitoring theory suggests that both the LWPCE and CSE share the same control mechanism (Botvinick et al., 2001). Therefore, the prediction for the LWPCE outcome aligns with that for the CSE, i.e., self-referential information reduces the LWPCE. However, an alternative view posits that the CSE and LWPCE involve separate control mechanisms (De Pisapia & Braver, 2006; Dosenbach et al., 2008). The CSE reflects reactive, transient, and phasic adjustments of cognitive control, while the LWPCE reflects proactive, sustained, and tonic adjustments of cognitive control. In this case, self-referential information may have different effects on these two measures. Specifically, when activating irrelevant information, self-referential information may enhance sensitivity to conflict and lead to flexible adjustments in cognitive control strategy for each trial (Braem et al., 2019), potentially resulting in larger LWPCE compared with control conditions. Conversely, if self-referential information acts as a signal for the need of control, akin to its effect on the CSE, it may be more effective in enhancing cognitive control when the control state (MC condition) is low (Carter et al., 2001), leading to a smaller LWPCE.

The present study

The present study aimed to investigate the role of self-referential information as a cue in modulating conflict adaptation (Experiments 1 and 2 for CSE; Experiment 3 for LWPCE). To address the possibility that the priming within a trial might activate the irrelevant information and lead to increased conflict (Dignath et al., 2022; Kałamała et al., 2020), we removed the priming in consecutive trials to eliminate this potential confounding factor. In Experiment 1, we used a modified version of the task, wherein self-referential information was manipulated by presenting the Color-Stroop task with or without the inclusion of self-referential possessive pronouns on a trial-by-trial basis. In Experiment 2, we used a block design in which the presence or absence of self-referential information remained constant within each block. Finally, Experiment 3 aimed to further investigate whether self-referential information had an impact on the LWPCE.

Experiment 1

Method

Participants

A priori power analysis was performed using the G*Power 3.1 (Faul et al., 2007). Our experiment employed a four-factor repeated measures analysis of variance (ANOVA) with a total of 16 measurements. These factors encompassed 2 levels of previous congruency (congruent vs. incongruent), 2 levels of current congruency (congruent vs. incongruent), 2 levels of previous self-referential information (self-reference condition "my" vs. non-self-reference condition "the"), and 2 levels of current self-referential information (self-reference condition "my" vs. non-self-reference condition "the"). We assumed a correlation of 0.5 between the repeated measurements, considering that prior research has typically reported correlations falling within the range of 0.6 to 0.8 (Bakeman, 2005). The main effects of interest in our four-factor ANOVA were self-referential information and congruency, as well as their second-order and third-order interactions with the other factors. We did not consider fourth-order interactions, as they are rarely meaningful in cognitive psychology research. We assumed a non-sphericity correction coefficient of 1. The expected power of the test was set to value of 0.95, and the significance level was p = .05. We selected an effect size of $f = 0.25$ for our power analysis based on Cohen's (1988) guidelines for four-way ANOVA, considering it as a medium effect size. This resulted in an estimate of approximately 15 participants. However, we actively recruited additional participants, resulting in a final total sample size of 30 (28 females and two males, age: $M = 20.47$ years, range: 18–24) participants. The decision to exceed the initial sample size was made to enhance the statistical power of the study and to ensure a robust evaluation of the research hypotheses. All the participants were right-handed and had a normal or corrected-to-normal vision. They all signed written informed consent, and filled in the questionnaire about sex in three Experiments (i.e., a free-response box was given in which they were allowed to respond that their sex was male, female or any other group). In addition, this study was performed in line with the principles of the Declaration of Helsinki, and the Human Ethics Committee of China approved this study.

Stimuli and procedure

The experimental procedure was conducted on a 19-in. monitor (1,280 × 1024 pixels, 60-Hz refresh rate). The E-Prime software 2.0.10.182 used stimulus presentation and data acquisition (Schneider et al., 2012). The modified Color-Stroop task was applied in the experiment. Furthermore, the stimuli consisted of four Chinese color words and the pronouns for blue, red, green, and yellow ("蓝," "黄," "绿," and "黄" in Chinese); the possessive pronoun "我的" (Chinese for "my"), and the definite article "这个" (Chinese for "the"). Moreover, all words were written in the center of the screen using a 35-point Courier New Font.

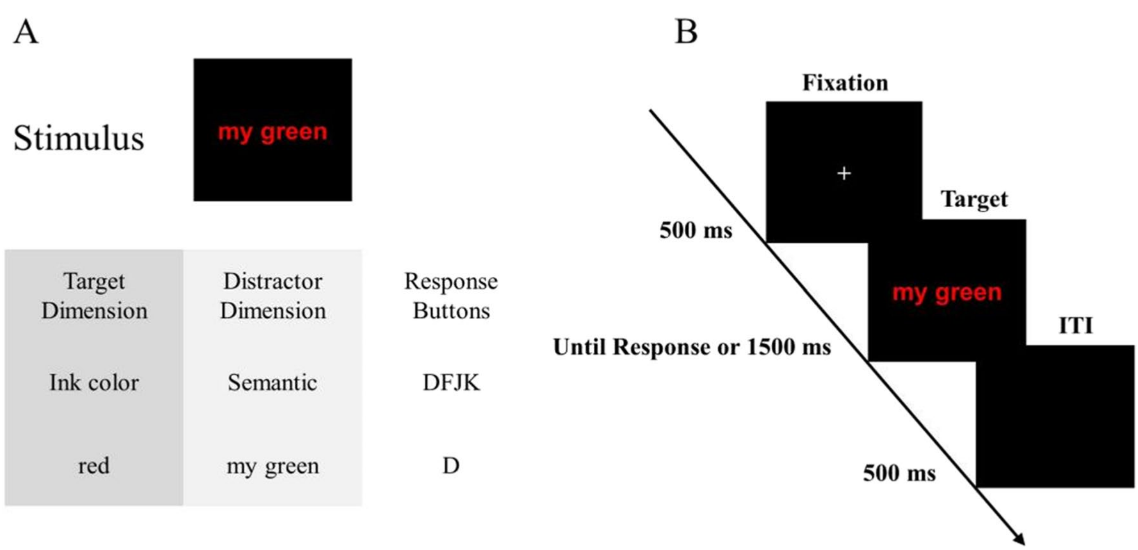

Fig. 1 Stimuli, experimental procedure, and task design. **A** Target and distractor dimensions for each experiment, participants were instructed to press the keys "D", "F", "J", and "K" in response to the corresponding ink color (i.e., red, green, yellow, or blue) while ignoring the semantic. In the shown stimulus, participants had to press "D". **B** The trial sequence of Experiments 1 to 3. Respectively, Experiment 1 was trial-wise; Experiment 2 was block-wise; Experiment 3 was different proportion congruency in block level. (Color figure online)

As shown in Fig. 1B, each trial started with the presentation of a 500-ms fixation cross. Thereafter, the stimuli (i.e., pronoun and color word) were presented for 1,500 ms until a response was received. The following trial started after a response-stimulus interval of 500 ms. The participants were instructed to respond to the ink color of the word as quickly and accurately as possible while ignoring the meaning of the word. Subsequently, they were instructed to press “D” with the left index finger, “F” with the left middle finger, “J” with the right index finger, or “K” with the right middle finger. The ink colors “red,” “green,” “yellow,” and “blue” respectively correspond to the “D,” “F,” “J,” and “K” keys on the keyboard. We manipulated the congruency of stimuli by pairing four words (RED, GREEN, YELLOW, BLUE) and their corresponding colors into two sets (RED-GREEN and YELLOW-BLUE). Each set was presented in either odd or even trials (balanced across blocks), but cross-set combinations (e.g., RED in yellow ink) were not allowed. By restricting the stimuli combinations to within each set, we aimed to ensure that any observed conflict adaptation effects were primarily driven by the congruency of the stimuli within the same set, and not influenced by other non-conflict factors (Braem et al., 2019).

是不是说红-绿只能在一个block里在单数或偶数位置上出现

A 2 (previous congruency: congruent vs. incongruent) × 2 (current congruency: congruent vs. incongruent) × 2 (previous self-referential information: the self-reference condition “my” vs. the non-self-reference condition “the”) × 2 (current self-referential information: the self-reference condition “my” vs. the non-self-reference condition “the”) design was employed in this experiment. First, participants completed one practice block of 32 trials. However, the participants could only begin the formal experiment when the average accuracy rate in the study exceeded 90%. The formal experiment comprised 6 blocks which each consisted of 97 trials. Specifically, the first trial of each block was excluded from further analyses. Furthermore, each block comprised four different trial types (i.e., congruent with self-reference, congruent with non-self-reference, incongruent with self-reference, and incongruent with non-self-reference) which were presented equally 24 times. Finally, the order of the 97 trials was generated pseudorandomly to produce 16 sequences, each comprising six trials.

不理解这里说的什么意思

Data analyses and results

Initially, this study discarded the first trial of each block (0.9%), trials with RTs exceeding 3 standard deviations (*SD*s) that are above or below the mean RT (1.0%), any response error trials (4.9%), and post-error trials (4.4%) from further analyses. To compare the effects of previous self-referential information, current self-referential information, previous congruency, and current congruency on Error Rates and RTs, we conducted a four-factor repeated measures ANOVA. The main effects and interactions between factors were analyzed, and the results are presented below. The interactions were indeed tested in the raw error rates and RTs. However, in the subsequent decomposition, we converted the error rate and RT data into magnitudes to facilitate the interpretation and visualization of the interaction effects. This conversion was solely for the purpose of presenting the results in a more accessible format. Bayesian ANOVAs were also performed, using default priors within R. Bayes Factors (BFs) provide an estimate of the strength of evidence for the data under the null and alternative hypotheses. For ANOVA, BF_{incl} are used to measure the strength of evidence for the inclusion of each factor and interaction in the model, including BF_{01} to assess evidence for the null hypothesis. For *t* tests, BF_{10} are reported, indicating evidence for the presence of an effect, with BF_{01} assessing evidence for the absence of an effect. BF < 1 indicates support for the null hypothesis, while BF > 1 supports the alternative hypothesis. We adopt the commonly used classification scheme, where BF 1–3 equates to anecdotal evidence, BF 3–10 as moderate evidence, BF 10–100 as strong evidence, and BF > 100 as very strong evidence (Lee & Wagenmakers, 2014; van Doorn et al., 2021).

Error rates A four-factor repeated-measures ANOVA showed that a significant main effect of current congruency, $F(1, 29) = 12.03$, $p = .002$, $\eta_p^2 = 0.29$, $BF > 100$. The error rates were higher in the incongruent condition (6.0%) than in the congruent condition (3.9%). The main effect of the previous currency was also significant, $F(1, 29) = 22.35$, $p < .001$, $\eta_p^2 = 0.44$, $BF = 2.40$. The previous congruent trials (5.4%) were higher error rate than the previous incongruent trials (4.5%). The main effect of the previous self-referential information was not significant, $F(1, 29) = 4.00$, $p = .055$, $\eta_p^2 = 0.12$, $BF = 0.50$ ($BF_{01} = 2.00$). The main effect of the current self-referential information was not significant, $F(1, 29) < 1$, $BF = 0.08$.

The interaction between the previous congruency and the current congruency was not significant, $F(1, 29) = 3.78$, $p = .062$, $\eta_p^2 = 0.11$, $BF = 0.98$ ($BF_{01} = 1.02$). The interaction between the previous congruency and the previous self-referential information was not significant, $F(1, 29) = 4.17$, $p = .050$, $\eta_p^2 = 0.13$, $BF = 0.63$ ($BF_{01} = 1.59$). The interaction between the current congruency and the previous self-referential information was not significant, $F(1, 29) = 3.04$, $p = .092$, $\eta_p^2 = 0.09$, $BF = 0.40$ ($BF_{01} = 2.50$). The interaction between the previous congruency and the current self-referential information was not significant, $F(1, 29) < 1$, $BF = 0.16$. The interaction between the current congruency and the current self-referential information was not significant, $F(1, 29) = 1.77$, $p = .062$, $\eta_p^2 = 0.19$, $BF = 0.19$ ($BF_{01} = 5.26$). The interaction between the previous self-referential information and the current self-referential information was significant, $F(1, 29) = 8.49$, $p = .007$, $\eta_p^2 = 0.23$, $BF =$ 6.92. This showed that the previous self-reference and current self-reference trials (4.1%) were lower error rate than the previous self-reference and current non-self-reference trials (5.1%). The previous non-self-reference and current non-self-reference trials (4.7%) were lower error rate than the previous non-self-reference and current self-reference trials (5.8%). All other interactions were not significant.

The ANOVA also revealed significant interactions between three factors on the Error rates. The interaction between the previous congruency, the current congruency, and previous self-referential information was not significant, $F(1, 29) < 1$, $BF = 0.21$ ($BF_{01} = 4.76$). The interaction between the previous congruency, the current congruency, and current self-referential information was not significant, $F(1, 29) = 1.75$, $p = 0.196$, $\eta_p^2 = 0.06$, $BF = 0.35$ (BF_{01} $= 2.86$). The interaction between the previous congruency, the previous self-referential information, and current self-referential information was not significant, $F(1, 29) < 1$, BF $= 0.21$ ($BF_{01} = 4.76$). The interaction between the current congruency, the previous self-referential information, and current self-referential information was not significant, $F(1, 29) < 1$, $BF = 0.17$ ($BF_{01} = 1.88$).

The four-factor repeated-measures ANOVA on the Error rates did not reveal a significant interaction, $F(1, 29) < 1$, $BF = 0.32$ ($BF_{01} = 3.13$).

RTs A four-factor repeated measures ANOVA on the RT data was performed to compare the effects of the previous self-referential information, the current self-referential information, the previous congruency, and the current congruency. We found that the main effect of the previous currency was significant, $F(1, 29) = 12.25$, $p = .002$, $\eta_p^2 = 0.30$, BF $= 4.33$. The previous congruent trials ($M = 697.81$ ms) were responded to slower than the previous incongruent trials (M $= 686.97$ ms). The main effect of the current currency was also significant, $F(1, 29) = 61.24$, $p < .001$, $\eta_p^2 = 0.68$, BF $= 9.47$. The current congruent trials ($M = 672.60$ ms) were responded to faster than the current incongruent trials ($M =$ 712.18 ms). The main effect of the previous self-referential information was not significant, $F(1, 29) = 1.48$, $p = .233$, $\eta_p^2 = 0.05$, $BF = 0.18$ ($BF_{01} = 5.56$). The main effect of the current self-referential information was also not significant, $F(1, 29) < 1$, $BF = 0.12$ ($BF_{01} = 8.33$).

The ANOVA also revealed significant interactions between two factors on RT data. The interaction between the previous congruency and the current congruency was significant, $F(1, 29) = 74.79$, $p < .001$, $\eta_p^2 = 0.72$, $BF >$ 100, indicating the presence of the typical CSE (33.77 ms). The interaction between the previous congruency and the previous self-referential information was significant, $F(1, 29) = 26.30$, $p < .001$, $\eta_p^2 = 0.48$, $BF = 16.56$. The interaction between the current congruency and the previous self-referential information was significant, $F(1, 29) = 24.14$, $p < .001$, $\eta_p^2 = 0.45$, $BF = 54.49$. The CE was reduced by the self-reference condition (25.88 ms) in contrast to the non-self-reference condition (53.5 ms). The interaction between the previous congruency and the current self-referential information was not significant, $F(1, 29) <$ 1, $BF = 0.15$ ($BF_{01} = 6.67$). The interaction between the current congruency and the current self-referential information was not significant, $F(1, 29) < 1$, $BF = 0.16$ ($BF_{01} =$ 6.25). The interaction between the previous self-referential information and the current self-referential information was significant, $F(1, 29) = 37.04$, $p < .001$, $\eta_p^2 = 0.56$, $BF >$ 100. This showed that the previous self-reference and current self-reference trials ($M = 677.23$ ms) were responded to faster than the previous self-reference and current non-self-reference trials ($M = 703.25$ ms). The previous non-self-reference and current non-self-reference trials ($M = 678.94$ ms) were responded to faster than the previous non-self-reference and current self-reference trials ($M = 710.15$ ms).

The ANOVA also revealed significant interactions between three factors on RT data. The interaction between the previous congruency, the current congruency, and previous self-referential information was significant, $F(1, 29)$ $= 5.75$, $p = 0.023$, $\eta_p^2 = 0.17$, $BF = 3.55$. As illustrated in Fig. 2 and Table 1, the CSE was reduced for the self-reference condition (14.82 ms), $F(1, 29) = 3.38$, $p = .076$, $\eta_p^2 = 0.10$, compared with the non-self-reference condition (52.24 ms), $F(1, 29) = 34.32$, $p < .001$, $\eta_p^2 = 0.54$. The interaction between the previous congruency, the current congruency, and current self-referential information was not significant, $F(1, 29) = 1.41$, $p = .245$, $\eta_p^2 = 0.05$, $BF =$ 0.43 ($BF_{01} = 2.33$). The interaction between the previous congruency, the previous self-referential information, and current self-referential information was not significant, $F(1, 29) = 3.67$, $p = .065$, $\eta_p^2 = 0.11$, $BF = 0.63$ ($BF_{01} = 1.59$). The interaction between the current congruency, the previous self-referential information, and current self-referential information was significant, $F(1, 29) = 8.47$, $p = .007$, η_p^2 $= 0.23$, $BF = 4.50$.

The four-factor repeated-measures ANOVA on the RT data did not reveal a significant interaction, $F(1, 29) = 3.20$, $p =$ .084, $\eta_p^2 = 0.10$, $BF = 0.99$ ($BF_{01} = 1.01$). Furthermore, we employed paired-samples t tests to examine the differences in reduced CE between experiencing congruent and incongruent trials. The results revealed a significant difference, $t(29)$ $= 2.49$, $p = .019$, $d = 0.72$, $BF = 2.64$, indicating that the reduction in CE resulting from self-referential information after congruent trials (46.02 ms) was significantly larger than after incongruent trials (9.00 ms). However, the Bayesian factor ($BF = 2.64$) provided only anecdotal evidence, which indicated a relatively weak support for the t tests.

After controlling for self-referential information across trials (see Fig. 3), the results suggested that a typical CSE

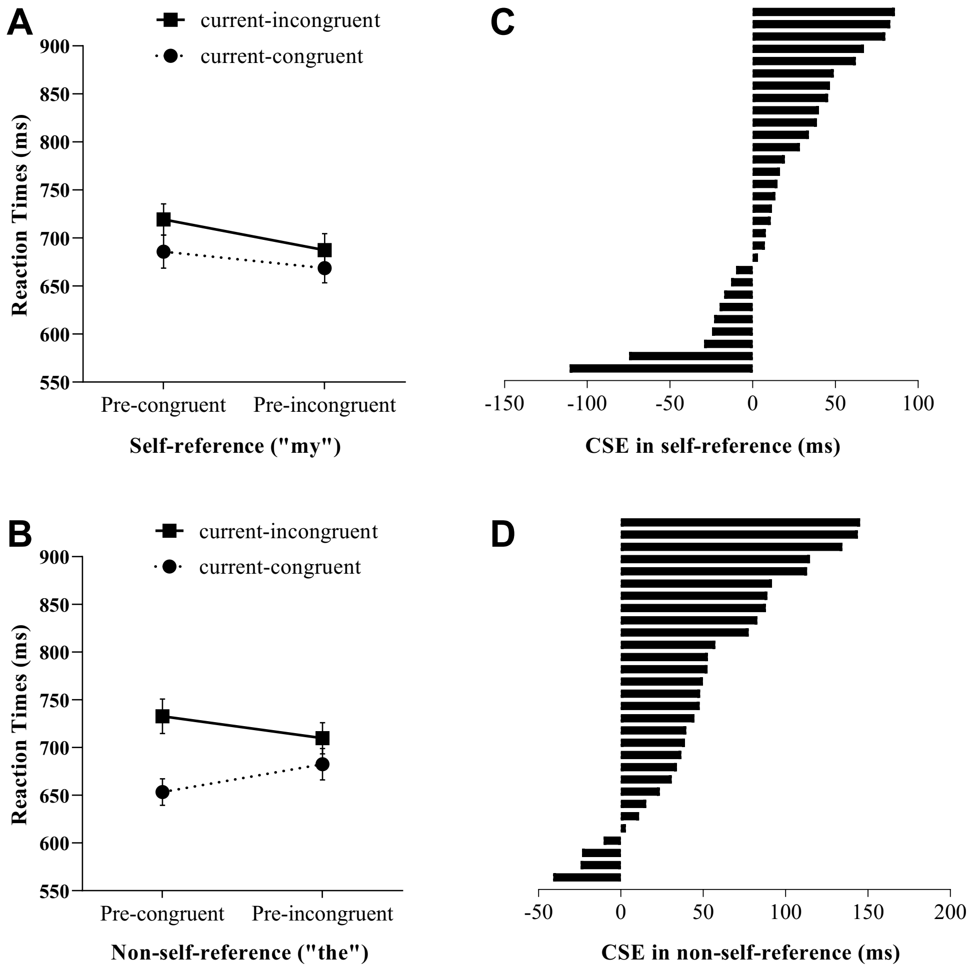

Fig. 2 Behavioral conflict adaptation effects. The conflict adaptation effects in (**A**) the self-reference and (**B**) the non-self-reference conditions. Individual conflict adaptation effects were found in (**C**) self-reference condition and (**D**) non-self-reference condition

Table 1 Response times (ms) for Experiments 1–3

	Experiment 1		Experiment 2			Experiment 3	
	Self	Non-self	Self	Non-self		Self	Non-self
cc	686(17)	653(14)	672(16)	672(15)	MCc	660(12)	671(14)
ci	719(16)	733(18)	720(18)	758(20)	MCi	714(18)	761(22)
ci-cc	33	80	48	86	MCi-c	54	90
ic	669(15)	682(16)	672(15)	678(16)	MIc	672(12)	677(14)
ii	687(17)	710(16)	691(16)	713(19)	MIi	703(15)	718(20)
ii-ic	18	28	19	35	MIi-c	32	41
CSE	15	52	29	51	LWPCE	22	49

Note. cc = congruent-congruent; ci = congruent-incongruent; ic = incongruent-congruent; ii = incongruent-incongruent; MCc = congruent in mostly congruent condition; MCi = incongruent in mostly congruent condition; MIc = congruent in mostly incongruent condition; MIi = incongruent in mostly incongruent condition; CSE = congruency sequence effect; LWPCE = list-wide proportion congruency effect; Self = self-reference condition; Non-self = non-self-reference condition

(31.30 ms) was found between the previous non-self-reference condition and current self-reference condition, $F(1, 29) = 6.33$, $p = .018$, $\eta_p^2 = 0.18$, $BF = 1.20$ (see Fig. 3B). Moreover, a typical CSE (73.03 ms) was found between the previous non-self-reference condition and current non-self-reference condition, $F(1, 29) = 24.51$, $p < .001$, $\eta_p^2 = 0.46$,

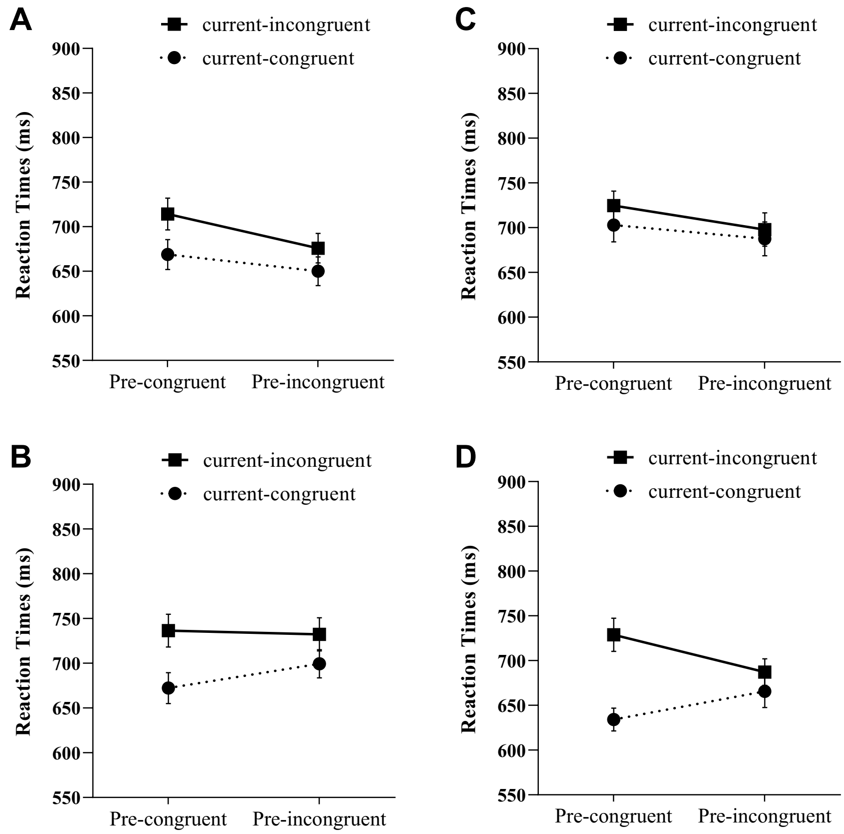

Fig. 3 Behavioral conflict adaptation effects. The conflict adaptation effects of self-referential information in the previous and current trials. **A** Previous self-reference condition and current self-reference condition. **B** Previous non-self-reference condition and current self-reference condition. **C** Previous self-reference condition and current non-self-reference condition. **D** Current non-self-reference condition and current non-self-reference condition

BF > 100 (see Fig. 3D). No CSE was observed in other conditions (see Figs. 3 A and C).

Discussion

It is worth noting that certain dissociations between F-values and BF10 may arise, leading to opposite way for both main effects and interactions. This discrepancy can be attributed to the influence of prior knowledge in Bayesian statistics, which can be especially pronounced in cases where prior knowledge is strong or when dealing with small sample sizes. When prior knowledge strongly supports certain hypotheses, Bayesian results may diverge from the findings obtained through traditional inferential statistics. For example, compared with the interaction between the previous congruency and the previous self-referential information, the interaction between the current congruency and the previous self-referential information should have stronger prior knowledge. Self-referential information reduced the CSE compared with the non-self-reference condition. However, self-referential information did not reduce the CEs in the current trials. This might be attributed to the repetition and alternation of stimuli that can affect the CEs (Hazeltine & Mordkoff, 2014; Hommel et al., 2004). Importantly, the translation between previous and current-trial self-referential information affected the CSE (see Fig. 3). To eliminate the cost of self-referential information in the translation, the block design in Experiment 2 was used. Specifically, this presented self-reference and non-self-reference conditions in separate blocks of trials.

Experiment 2

Method

Participants

We used a priori power analysis. For our experiment, we utilized a three-factor repeated measures ANOVA involving eight measurements. These factors encompassed 2 levels of previous congruency (congruent vs. incongruent), 2 levels of current congruency (congruent vs. incongruent), and 2 levels of self-referential information (self-reference condition “my” vs. non-self-reference condition “the”). We also incorporated a correlation estimate of 0.5 and assumed a non-sphericity correction coefficient of 1. The desired power was set at 0.95, and the significance level was 0.05. We chose the same effect size of $f = 0.25$, as determined in the previous analysis. The power analysis indicated an estimated sample size of approximately 23 participants. Experiment 2 finally included 35 healthy volunteers from China (28 females and seven males; age: $M = 20.2$ years, range: 18–24). All the participants were right-handed, with normal or corrected-to-normal vision. None took part in the other experiments here.

Stimuli and procedure

As indicated in Fig. 1B, the stimuli, material, and procedure are identical to those in Experiment 1. To yield a pure effect of self-reference on conflict adaptation, another design was used. We employed a 2 (previous congruency: congruent vs. incongruent) × 2 (current congruency: congruent vs. incongruent) × 2 (self-referential information: the self-reference condition “my” vs. the non-self-reference condition “the”) design. Prior to the formal experiment, participants completed a practice block consisting of 32 trials. Only when their average accuracy rate exceeded 90% were they permitted to proceed to the formal experiment. The formal experiment comprised six blocks in total, with three blocks assigned to the self-reference condition and three blocks assigned to the non-self-reference condition. To counterbalance the order of the blocks, we employed the ABBA procedure. Specifically, the blocks of the self-reference condition presented as the first, fourth, and fifth blocks while the blocks of the non-self-reference condition were presented as the second, third, and sixth blocks.

Data analyses and results

Initially, this study excluded the first trial of each block (0.9%), trials with RTs exceeding 3 standard deviations that were above or below the mean RT (1.0%), any response error trials (5.7%), and post-error trials (4.9%) from further analyses. The outcomes of the experiment were analyzed using repeated-measures ANOVA and Bayesian ANOVA.

Error rates A three-factors (self-referential information, previous congruency and current congruency) repeated-measures ANOVA yielded a significant main effect of current congruency, $F(1, 34) = 22.10$, $p < .001$, $\eta_p^2 = 0.39$, $BF > 100$, indicating that the incongruent condition had higher error rates (7.0%) than the congruent condition (4.4%). The main effect of previous congruency was not significant, $F(1, 34) = 3.02$, $p = .091$, $\eta_p^2 = 0.08$, $BF = 0.38$ ($BF_{01} = 2.63$). The main effect of self-referential information was significant, $F(1, 34) = 6.72$, $p = .014$, $\eta_p^2 = 0.17$, $BF = 3.56$. The error rates were higher in the non-self-reference condition (6.2%) than in the self-reference condition (5.1%).

The interaction between previous congruency and current congruency was significant, $F(1, 34) = 8.33$, $p = .007$, $\eta_p^2 = 0.20$, $BF = 5.45$, indicating the presence of the typical CSE (1.8%). The interaction between current congruency and self-referential information was significant, $F(1, 34) = 4.64$, $p = .038$, $\eta_p^2 = 0.12$, $BF = 1.61$. The Bayesian factor ($BF = 1.61$) indicated a relatively weak support for the interaction between current congruency and self-referential information. The interaction between previous congruency and self-referential information was not significant, $F(1, 34) < 1$, $BF = 0.60$ ($BF_{01} = 1.67$). The interaction between self-referential information, previous congruency and current congruency was significant, $F(1, 34) = 5.03$, $p = .032$, $\eta_p^2 = 0.12$, $BF = 5.52$, indicating a smaller CSE for the self-reference condition (0.55%) compared with the non-self-reference condition (3.06%).

RTs A three-factors (self-referential information, previous congruency and current congruency) repeated-measures ANOVA yielded a significant main effect of current congruency, $F(1, 34) = 105.83$, $p < .001$, $\eta_p^2 = 0.75$, $BF > 100$. The current congruent trials ($M = 673.53$ ms) were responded faster than the current incongruent trials ($M = 720.33$ ms). The main effect of previous congruency was significant, $F(1, 34) = 33.91$, $p < .001$, $\eta_p^2 = 0.50$, $BF > 100$. The previous congruent trials ($M = 688.42$ ms) were responded slower than the incongruent trials ($M = 705.44$ ms). The main effect of self-referential information was significant, $F(1, 34) = 8.11$, $p = .007$, $\eta_p^2 = 0.19$, $BF = 5.81$. The self-reference trials ($M = 688.71$ ms) were responded faster than the non-self-reference trials ($M = 705.14$ ms).

The interaction between the previous congruency and the current congruency was significant, $F(1, 34) = 70.60$, $p < .001$, $\eta_p^2 = 0.68$, $BF > 100$, indicating the presence of the typical CSE (39.62 ms). The interaction between the previous congruency and the self-referential information was not significant, $F(1, 34) < 1$, $BF = 0.43$ ($BF_{01} = 2.33$). A significant interaction between current congruency and self-referential information was found, $F(1, 34) = 22.01$, $p < .001$, $\eta_p^2 = 0.39$, $BF > 100$. The CE was reduced for the self-reference condition (33.74 ms) than the non-self-reference condition (59.86 ms). Importantly, this study found a significant interaction between self-referential information, previous congruency and current congruency, $F(1, 34) = 9.28$, $p = .004$, $\eta_p^2 = 0.21$, $BF = 10.42$. As illustrated in Fig. 4 and

Table 1, the CSE was reduced for the self-reference condition (28.56 ms), $F(1, 34) = 30.98$, $p < .001$, $\eta_p^2 = 0.48$, compared with the non-self-reference condition (50.67 ms), $F(1, 34) = 57.73$, $p < .001$, $\eta_p^2 = 0.63$.

Additionally, we utilized paired-samples *t* tests to explore the differences in reduced CE between experiencing congruent and incongruent trials. The results showed a significant difference, $t(34) = 3.05$, $p = .004$, $d = 0.56$, $BF = 8.56$, suggesting that the reduction in CE caused by self-referential information following congruent trials (37.18 ms) was significantly larger than following incongruent trials (15.07 ms).

Discussion

The current results replicated the findings of Experiments 1. The CSE for the self-reference condition ("my") was smaller than in the non-self-reference condition ("the"). Importantly, self-referential information reduced the CEs in the current trials replicating the findings by Dignath et al. (2022). Particularly, self-referential information is fully expressed when self-referential information existed constantly in a block. In contrast to Experiment 1, self-referential information was fully expressed in the block design, potentially reducing the smaller CEs. To investigate the impact of self-referential information in LWPCE, Experiment 3 comprised a block-level manipulation expressing the percentage of congruent and incongruent trials in the task.

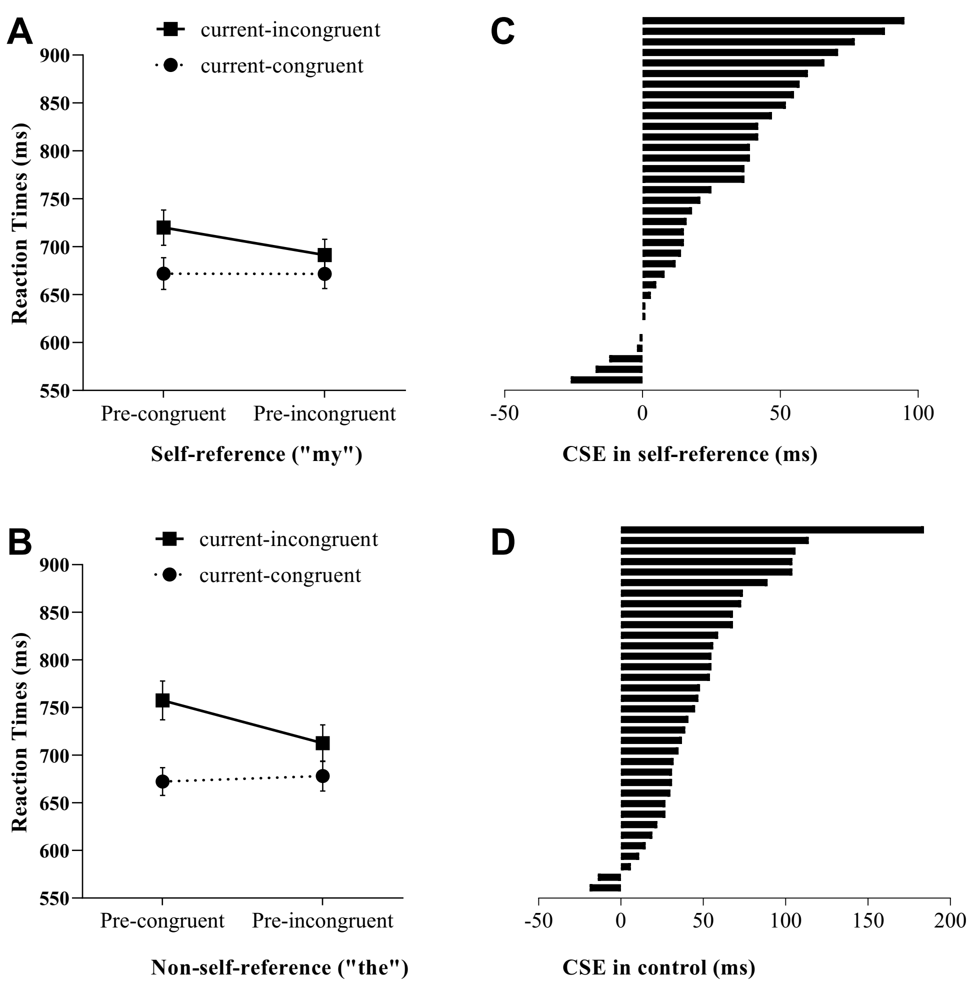

Fig. 4 Behavioral conflict adaptation effects. The CSE in (**A**) the self-reference and (**B**) the non-self-reference conditions. Individual CSE in (**C**) self-reference and (**D**) non-self-reference condition

Experiment 3

Method

Participants

We also used a priori power analysis. For our experiment, we utilized a three-factor repeated-measures ANOVA involving 12 measurements. These factors encompassed 3 levels of list type (MI vs. Neutral vs. MC), 2 levels of current congruency (congruent vs. incongruent), and 2 levels of self-referential information (self-reference condition "my" vs. non-self-reference condition "the"). We also incorporated a correlation estimate of 0.5 and assumed a non-sphericity correction coefficient of 1. For a three-way ANOVA, the desired power was set at 0.95, and the significance level was 0.05. We chose the same effect size of $f = 0.25$, as determined in the previous analysis. The power analysis indicated an estimated sample size of approximately 18 participants. Experiment 3 was finally completed by 34 healthy volunteers from China (26 females and eight males; age: $M = 20.9$ years, range: 19 –25). All participants were right-handed and had a normal or corrected-to-normal vision. The participants in this study did not participate in the other experiments conducted in this study.

Stimuli and procedure

The current study used the same stimuli and materials used in Experiment 2 as shown in Fig. 1B. The main procedure comprised 10 blocks each with 96 trials. The blocks were divided into three types based on the congruency proportion. In mostly congruent (MC) blocks, 75% of the trials were congruent; in neutral blocks, the congruent trials had a proportion of 50% each; In mostly incongruent (MI) blocks, only 25% of the trials were congruent. The participants were divided into two groups. The first group performed all four MC blocks first, followed by two neutral blocks, and then four MI blocks. The second group performed these block types in the reverse order. Within the four MC blocks, two blocks were assigned to the self-reference condition, and the other two blocks were assigned to the non-self-reference condition. The order of the MC blocks followed an ABBA sequence. The two neutral blocks included both self-reference and non-self-reference condition. The requirements of the MI blocks were the same as those for the MC blocks.

Data analyses and results

Initially, this study discarded the first trial of each block (0.7%), trials where RTs exceeded 3 SDs either above or below the mean RT (0.9%), any response error trials (4.1%), and post-error trials (4.0%) from further analyses. The experimental results were analyzed using repeated-measures ANOVA and Bayesian ANOVA.

Error rates A repeated-measures ANOVA, with 2 (list type: MI vs. MC) ×2 (current congruency: congruent vs. incongruent) × 2 (self-referential information: the self-reference condition "my" vs. the non-self-reference condition "the"), yielded a significant main effect of current congruency, $F(1, 33) = 19.75$, $p < .001$, $\eta_p^2 = 0.37$, $BF > 100$, indicating that the congruent condition (3.2%) had lower error rates than the incongruent condition (5.6%). The main effects of other factors were not significant. Moreover, a significant interaction was found between congruency and list type, $F(1, 33) = 5.45$, $p = .026$, $\eta_p^2 = 0.14$, $BF = 2.83$. The Bayesian factor ($BF = 2.83$) indicated a relatively weak support for the interaction between congruency and list type. The interaction between self-referential information and congruency was not significant, $F(1, 33) = 3.86$, $p = .058$, $\eta_p^2 = 0.11$, $BF = 0.60$ ($BF_{01} = 1.67$).

RTs To investigate the effects of self-referential information in LWPCE, a repeated-measures ANOVA, with 2 (list type: MI vs. MC) × 2 (congruency: congruent vs. incongruent) × 2 (self-referential information: the self-reference condition "my" vs. the non-self-reference condition "the"), yielded a significant main effect of congruency, $F(1, 33) = 65.26$, $p < .001$, $\eta_p^2 = 0.66$, $BF > 100$. The responses were faster in congruent trials ($M = 670.15$ ms) than in incongruent trials ($M = 723.92$ ms). The main effect of list type was not significant, $F(1, 33) = 1.03$, $p = .318$, $\eta_p^2 = 0.030$, $BF = 0.54$ ($BF_{01} = 1.85$). The main effect of self-referential information was significant, $F(1, 33) = 13.18$, $p = .001$, $\eta_p^2 = 0.29$, $BF = 35.94$. The responses were faster in self-reference trials ($M = 687.42$ ms) than in non-self-reference trials ($M = 706.66$ ms).

The interaction between congruency and list type was significant, $F(1, 34) = 15.76$, $p < .001$, $\eta_p^2 = 0.32$, $BF = 91.01$, indicating the presence of the typical LWPCE (35.87 ms). The interaction between list type and self-referential information was significant, $F(1, 33) = 4.57$, $p = .040$, $\eta_p^2 = 0.122$, $BF = 1.77$. The Bayesian Factor ($BF = 1.77$) provides indicated a relatively weak support for the interaction between list type and self-referential information**.** The interaction between congruency and self-referential information was significant, $F(1, 33) = 12.87$, $p = .001$, $\eta_p^2 = 0.281$, $BF = 20.66$, indicating that, the CEs for self-referential information (42.3 ms) were smaller than for the non-self-reference conditions (65.25 ms). Importantly, the interaction of three factors was significant, $F(1, 33) = 9.49$, $p = .004$, $\eta_p^2 = 0.22$, $BF = 6.71$. The size of the list-wide proportion congruency effect (MI congruency effect – MC congruency effect) was reduced for the self-reference condition (22.44 ms), $F(1, 33) = 4.60$, $p = .040$, $\eta_p^2 = 0.12$, compared with the non-self-reference condition (49.27 ms), $F(1, 33) = 26.55$, $p < .001$, $\eta_p^2 = 0.45$, as displayed in Fig. 6 and Table 1. Specifically, an interaction between congruency and self-referential information in the MC list was significant, $F(1, 33) = 18.98$, $p < .001$, $\eta_p^2 = 0.365$, $BF > 100$, indicating that, in MC list, the CEs for self-referential information (53.52. ms) were smaller than for the non-self-reference conditions (89.88 ms, in Fig. 5).

Moreover, we utilized paired-samples *t* tests to investigate the differences in reduced CE between the MC and MI lists. The results demonstrated a significant difference, $t(33) = 3.08$, $p = .004$, $d = 0.59$, $BF = 9.21$, indicating that the reduction in CE caused by self-referential information in MC list (36.36 ms) was significantly larger than that in MI list (9.53 ms).

Discussion

The result replicated and extended Experiment 2's findings. In contrast to the non-self-reference conditions, self-referential information reduced CE regardless of three list-type circumstances (i.e., MC, Neutral, and MI). Moreover, self-referential information yielded a lower LWPCE than the non-self-reference conditions.

General discussion

The present study aimed to investigate the role of self-referential information as a cue in modulating conflict adaptation. A color-word Stroop task was utilized, with manipulation

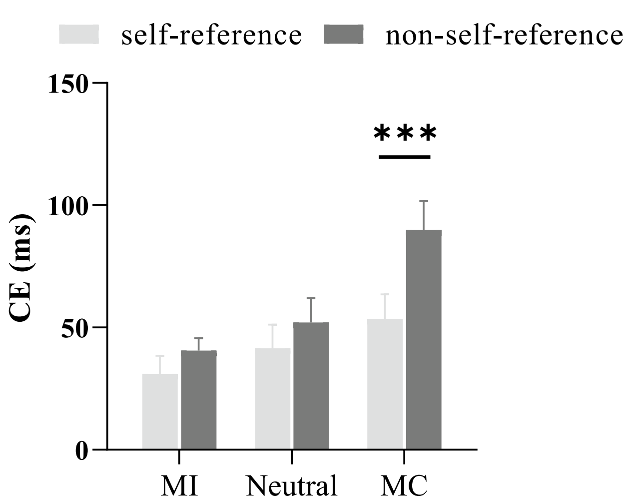

Fig. 5 The congruency effects (CE) in the self-reference and the non-self-reference conditions

of possessive pronouns or definite articles to represent self-referential information. The present study replicated and extended the results of Dignath et al. (2022), indicating that self-referential information significantly reduced the CEs in Experiments 2 and 3. Furthermore, self-referential information led to a reduction in conflict adaptation (the CSE in Experiments 1 and 2; the LWPCE in Experiment 3), compared with the non-self-reference condition.

This study has controlled priming, repetition, and contingency learning effects in Experiments 1 and 2, which may invalidate the interpretation of CSE (Schmidt & Weissman, 2014). The typical CSE was replicated in the non-self-reference condition (stimuli: the definite articles and color word; e.g., the green). Following an incongruent trial, participants exhibited increased attentional control toward the target on the subsequent trial, leading to a greater reduction in CE compared with following a congruent trial. The phenomenon was known as CSE (Egner, 2007; Gratton et al., 1992). In Experiment 3, we observed the typical LWPCE in the non-self-reference condition, which was also known as an important marker to measure conflict adaptation (Logan & Zbrodoff, 1979). The MI list, characterized by a focused attention state, exhibited reduced CE compared with the MC list, which reflected a more relaxed attention state (Spinelli & Lupker, 2023). The presence of definite article (the) yielded no effect on the CSE or the LWPCE. These findings suggested that self-referential information changed conflict adaptation rather than word presence.

Our research manipulated self-referential information and found that it reduced the conflict adaptation in all the three experiments. Our study did not only manipulate the CE following incongruent trials, but also the CE following congruent trials. Self-referential information reduced the CSE in Experiments 1 and 2 (see Figs. 2, 4 and Table 1). We speculated that self-reference enhanced cognitive control after congruent trials (from low control to relatively high control), leading to a smaller CE than the control condition. Self-reference also reduced the CE after incongruent trials. However, the reduction of CE (ii-ic) was smaller than that of CE (ci-cc), resulting in a smaller CSE. We also tested the effect of self-referential information on the LWPCE in Experiment 3 (see Fig. 6 and Table 1), a broader measure of conflict adaptation. Additionally, the PC paradigm supported the conflict adaptation function of the control system (Spinelli & Lupker, 2023). Self-reference might act as a cue to enhance attention intensity, increased control (i.e., focused attention) and led to a smaller CE in the MC list than control condition. Self-reference also reduced the CE in MI list. Similarly, the reduction of CE (MIi-c) was smaller than that of CE (MCi-c), resulting in a smaller LWPCE.

Our results suggest that self-referential information consistently influences both proactive and reactive control mode. This observation may indicate that CSE and LWPCE

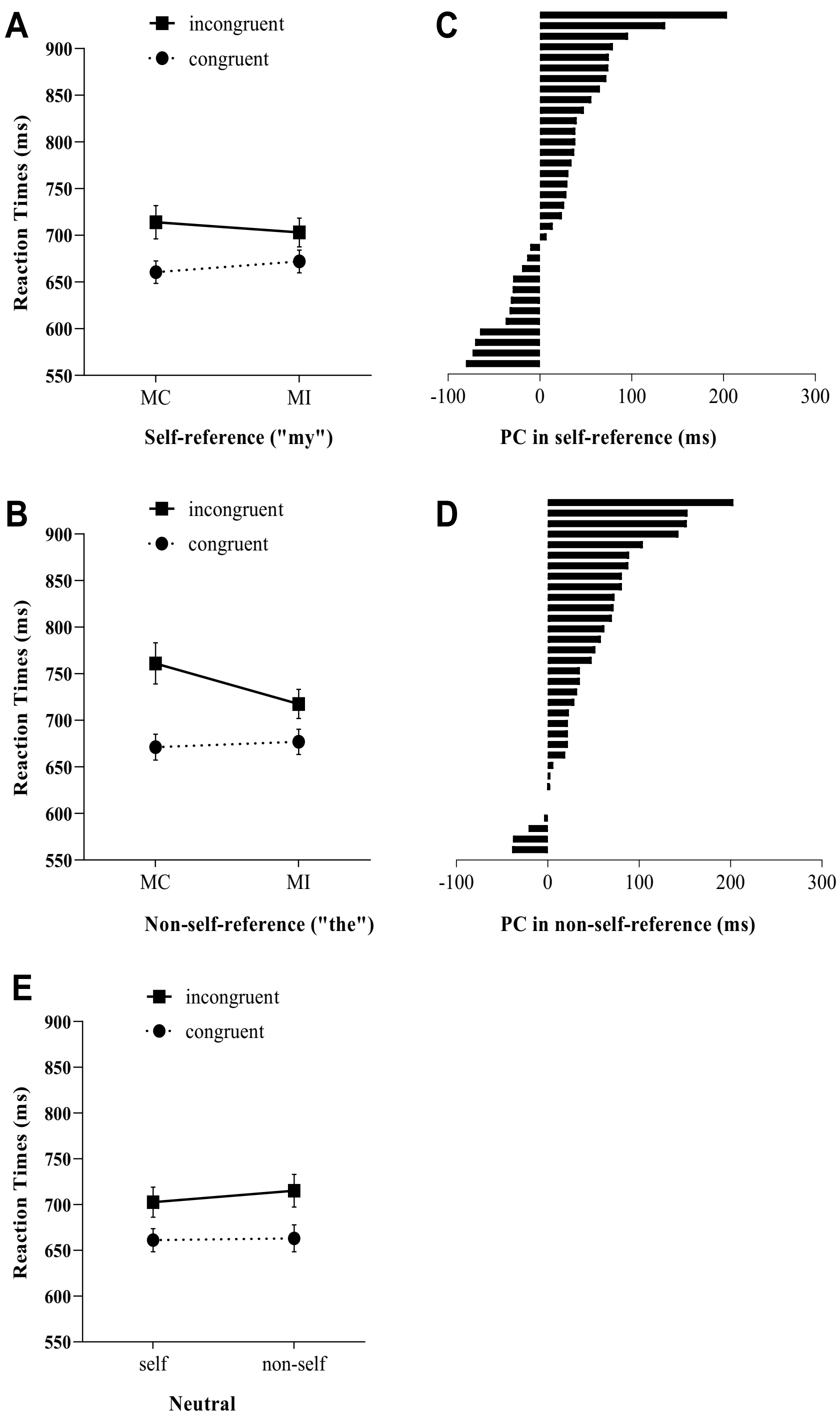

Fig. 6 Behavioral list-wide proportion congruency effects. The proportion effects in (**A**) the self-reference and (**B**) non-self-reference conditions. Individual proportion effects in (**C**) the self-reference and (**D**) non-self-reference condition. **E** The RT in the self-referential information and congruency conditions

reflect the same control mode (Botvinick et al., 2001). However, it is important to note that our study does not definitively rule out the possibility of two separate control mode (De Pisapia & Braver, 2006; Dosenbach et al., 2008). Specifically, self-referential information may enhance conflict alertness in the proactive control mode. Participants were better able to detect conflict trials and respond more quickly during the relaxed attention state (MC) when self-referential information was present. This suggests that self-referential cues may facilitate the anticipation and preparation for potential conflict, enabling participants to allocate cognitive resources more efficiently. In the reactive control mode, self-referential information may serve as a cue to signal the need for control. Following congruent trials, participants exhibited stronger need for control when self-referential information was present, suggesting that self-referential cues prompted the engagement of cognitive control to overcome the potential interference. Overall, our findings suggest that self-referential information influences both proactive and reactive control mechanisms, indicating a consistent impact on conflict processing. While our results support the notion of a single control mode underlying CSE and LWPCE, further research is needed to fully understand the nature and potential interactions between proactive and reactive control modes in the context of self-referential information.

The current results indicated that self-referential information can enhance cognitive control (smaller CE) and reduce the conflict adaptation (smaller CSE and LWPCE; see Table 1), which aligns with previous studies that the conflict strength of the previous trial affected the size of the conflict adaptation (Forster et al., 2011; Wendt et al., 2014; Zhang et al., 2021), with larger CE implying higher conflict in previous trials and leading to higher control in current trials. In this case, stronger conflicts led to higher control and the difference between high and low control increased (Botvinick et al., 2001). Self-referential information greatly improved low control, thereby narrowing this difference and resulting in smaller conflict adaptation. In our study, even when we removed the priming (i.e., self-referential information was presented only with a Stroop stimulus), self-referential information still reduced the CE. This supported the hypothesis that self-referential information acted as a cue to signal the need for increased control (Dignath et al., 2022). However, it was worth noting that the impact of self-referential information as a cue may be subject to interference. Li et al. (2022) argued that attentional functions can be modulated by self-referential information in conflict situations. Under low-control conditions, self-referential information as a signal may be fully expressed, effectively signaling the need to enhance control. But under high-control conditions, the presence of conflict itself may act as a competing signal, potentially interfering with this enhancement process triggered by self-referential information. Another possibility to consider is the presence of a marginal effect. In this case, the high-control state may already be operating at near-optimal levels, making it difficult to further enhance performance. This could explain why the impact of self-referential information on conflict adaptation was more pronounced under low-control conditions. In summary, the current findings demonstrate that self-referential information can act as a cue to enhance cognitive control and reduce conflict adaptation. However, the relationship between self-referential information, conflict, and cognitive control is complex and may be influenced by factors such as the level of control, the presence of competing signals, and potential marginal effects. Further research is needed to fully understand the underlying mechanisms and boundary conditions of self-referential information's influence on conflict adaptation.

Interestingly, our study also indicates that cognitive control processes may not be unified, but rather multifaceted and diverse. Although the effects of self-referential information on cognitive control were consistent across different paradigms associated with proactive (LWPCE) and reactive (CSE) control, this does not imply that the underlying mechanisms are identical. Previous research has shown dissociations between different forms of cognitive control, suggesting that they may be supported by distinct neural bases or psychological mechanisms (Dosenbach et al., 2008; Hommel et al., 2004). Therefore, while our results demonstrate the general influence of self-relevant stimuli on cognitive control, they also highlight the need for further investigation into the underlying mechanisms of different control processes. The crucial question is how self-relevant stimuli specifically influence different forms or levels of cognitive control. It is possible that various factors, such as individual differences, task difficulty, and emotional states, may moderate the impact of self-relevant stimuli on cognitive control.

Our study aligns with previous research suggesting that the change in cognitive control plays a crucial role in conflict adaptation (Botvinick et al., 2001; Kerns et al., 2004; Spinelli & Lupker, 2023). Dignath et al. (2022) proposed the control priming hypothesis, which suggests that self-referential information serves as a cue to enhance cognitive control. Based on this hypothesis, we tested it in a conflict adaptation paradigm and found that it reduced conflict adaptation. This may indicate that the modulation of cognitive control affects conflict adaptation, but it is also premature to claim that this result supports the conflict monitoring theory. First, self-referential information did not only affect the trials after incongruent trials and the blocks with mostly incongruent trials, but also more prominently affected the congruent trials and the blocks with mostly congruent trials, which cannot be fully explained by the conflict monitoring theory. Second, even in the study by Dignath et al. (2022), they did not rule out other possibilities, such as the influence of memory, emotion, and other non-conflict factors. Therefore, the mechanism of self-referential information on conflict adaptation is complex and requires further investigation to pinpoint its exact role. It is noteworthy that our study only used one type of self-referential information (i.e., “my”), which limited the scope and complexity of self-referential processing. Future studies should incorporate more types of self-relevant stimuli, such as names, faces, genders, and others, to explore a broader range of self-referential effects. Moreover, our investigation solely focused on the Stroop task as a measure of conflict, and its generalizability to other tasks involving different cognitive processes may be limited. Given the potential drawbacks of using the Stroop task as a conflict task (Algom et al., 2022), it would be beneficial for future studies to explore alternative conflict tasks, such as the flanker task, and assess their compatibility with the observed self-referential effects. By broadening the scope of self-referential stimuli and employing diverse conflict tasks, we can gain a more comprehensive understanding of the interplay between self-referential information and conflict adaptation.

In conclusion, this study revealed that self-referential information can act as a cue to reduce the conflict adaptation. This study provided a new perspective on self-reference processing, emphasizing the role of self-referential information in cognitive control adjustments. By shedding light on the influence of self-referential information on cognitive control, this study deepens our understanding of the complexities involved in conflict resolution.

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Data availability The data will be made available upon request to the corresponding author with a formal data sharing agreement. The software and code used in the study are open-source and publicly available.

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