Disentangling Sequential Effects of Stimulus- and Response-related Conflict and Stimulus–Response Repetition using Brain Potentials

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Abstract

■ Conflict monitoring theory holds that detection of conflicts in information processing by the anterior cingulate cortex (ACC) results in processing adaptation that minimizes subsequent conflict. Applying an Eriksen flanker task with four stimuli mapped onto two responses, we investigated whether such modulation occurs only after response-related or also after stimulus-related conflict, focusing on the N2 component of the event-related potential. Contrasting with previous findings, both stimulus- and response-related conflict elicited enhancement of the N2, suggesting that the ACC is sensitive to conflict at both the stimulus and the response level. However, neither type of conflict resulted in reduced conflict effects on the following trial when stimulus–response (S-R) sequence effects were controlled by excluding identical S-R repetition trials. Identical S-R repetitions were associated with facilitated processing, thus demonstrating that inclusion of these trials in the analysis may mimic results predicted by the conflict adaptation hypothesis. ■

INTRODUCTION

A question in the focus of current research on cognitive control concerns the mechanisms by which the human information processing system ensures coherent, goal-oriented behavior in the presence of external stimuli (or stimulus features) that are associated with an incorrect response. Under such conditions, performance is usually impaired—a finding attributed to conflict between the processing of such stimulus features and goal-relevant processing. Whereas, traditionally, studies have mainly tried to identify the precise mechanisms that underlie conflict-related performance decrements (thereby developing sophisticated models regarding different types of conflict, e.g., De Jong, Liang, & Lauber, 1994; Cohen, Dunbar, & McClelland, 1990; Kornblum, Hasbroucq, & Osman, 1990), recent theoretical developments emphasize a functional role of conflicts with regard to goal achievement. Specifically, it has been assumed that detection of cognitive conflict is responded to by increased focusing on task-relevant stimulus features, thereby minimizing subsequent conflict effects and, thus, the risk of performance failure (Botvinick, Braver, Barch, Carter, & Cohen, 2001).

Consistent with this *conflict adaptation hypothesis*, a number of effects that are assumed to index the degree of processing of an irrelevant stimulus dimension (e.g., interference in different versions of the Stroop or Simon paradigm) have been found to be reduced *after conflict on the directly preceding trial* (e.g., Kerns et al., 2004; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). Most relevant to the current study, Gratton, Coles, and Donchin (1992) and Botvinick, Nystrom, Fissell, Carter, and Cohen (1999) demonstrated such sequential interference modulation in the Eriksen flanker task (Eriksen & Eriksen, 1974). In that task, a predesignated target stimulus is presented embedded in a number of irrelevant stimulus objects (flankers), which are identical among each other, such as the letter H with a pair of same or different letters on either side (e.g., HHHHH or SSHSS). In the above studies, target and flanker characters were either identical (henceforth, stimulus congruent, SC) or different from each other and mapped onto different responses (henceforth, response incongruent, RIC). As expected from the conflict adaptation hypothesis, flanker interference effects (i.e., worse performance on RIC as compared to SC trials) were substantially reduced after an RIC as compared to after an SC predecessor trial.

This interpretation of the sequential modulation of the flanker effect bears important implications regarding the assumed functional role of the anterior cingulate

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cortex (ACC), a brain structure shown to be associated with increased activity by various manipulations thought to evoke cognitive conflict. Whereas an earlier view held that the ACC is actively involved in the resolution of such conflicts (e.g., Posner & Rothbart, 1998; Pardo, Pardo, Janer, & Raichle, 1990; Posner, Petersen, Fox, & Raichle, 1988), more recently, the ACC has been viewed predominantly as a mere conflict detector, signaling conflict occurrence to the prefrontal cortical areas, which in turn increase processing selectivity by amplifying relevant or inhibiting irrelevant S-R translation routes, or both (Kerns et al., 2004; Carter et al., 2000; MacDonald, Cohen, Stenger, & Carter, 2000; Botvinick et al., 1999). This shift in view has strongly been motivated by findings of ACC activation being positively correlated with conditions assumed to involve different degrees of conflict while being negatively correlated to conditions assumed to involve different degrees of focusing on target information (see, however, Ruff, Woodward, Laurens, & Liddle, 2001, for a different result). Most notably, as regards the current study, using functional magnetic resonance imaging (fMRI) in a flanker task, Botvinick et al. (1999) found ACC activation to be lower under conditions when focusing on the target was assumed to be high and conflict was assumed to be low (i.e., on RIC trials following an RIC trial) than under conditions when focusing on the target was assumed to be low and conflict was assumed to be high (i.e., on RIC trials following an SC trial).

Recent studies tried to identify the specific stage(s) of processing at which conflict occurrence results in ACC activation and subsequent processing adaptation. In the model of Botvinick et al. (2001), conflict is quantified as an abstract measure of the activation of multiple responses, thus suggesting that it is the simultaneous activation of incoherent action tendencies by which processing adjustments are called into play. Some evidence consistent with this suggestion was obtained in an fMRI study by Van Veen, Cohen, Botvinick, Stenger, and Carter (2001). These authors applied a four-to-two mapping between stimuli and responses, which allowed them to present trials in which target and flankers differed from each other but shared the same response category (henceforth, stimulus incongruent, SIC) in addition to SC and RIC target–flanker pairings. Whereas ACC activation did not differ between SC and SIC trials, it was clearly enhanced on RIC trials as compared to both response-congruent conditions, thus suggesting that the ACC is sensitive to late, response-related conflict, but not to early, stimulus-related conflict. Van Veen and Carter (2002) corroborated this finding by assessing the frontocentral N2, a component of the event-related potential (ERP) that had previously been shown to be increased on RIC trials as compared to both SC trials and ''neutral'' trials, in which the flankers are not associated with a response (Kopp, Rist, & Mattler, 1996). Dipole source localization suggested an origin of the N2 within (or in the vicinity of) the ACC (Van Veen & Carter, 2002). Similar to the fMRI findings, N2 enhancement was confined to RIC trials and did not occur on SIC trials.

Assuming that conflict adaptation is triggered by an ACC conflict signal, these findings suggest that flanker processing should be reduced after RIC but not after SIC trials. Contrasting with this view, however, Notebaert and Verguts (2006) recently suggested that conflict at the stimulus level rather than at the response level triggers adaptation in the flanker task (see also Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006). Using digits from 1 to 9 as target and flanker stimuli (each digit mapped onto a separate response), these authors found a gradual reduction of flanker interference after trials with greater numerical distance between target and flankers, a condition assumed to be characterized by high conflict at the stimulus level and low conflict at the level of responses. Given the lack of an ACC conflict signal on SIC trials in the studies of Van Veen et al. (2001) and Van Veen and Carter (2002), however, this interpretation is clearly at odds with the idea of ACC-based conflict adaptation. To clarify this issue we followed the work of Van Veen et al. and Van Veen and Carter and applied a flanker task with a four-to-two mapping between stimuli and responses that enabled us to investigate N2 enhancement and subsequent flanker processing regarding both SIC and RIC trials.

An important aspect concerning sequential analysis in the flanker task refers to the role of *identical S-R repetitions*, that is, trials in which both target (and thus also the response) and flankers are repeated from the directly preceding trial. In classical choice reaction time (RT) tasks (in which the target stimulus is presented without any distracting stimulus dimension such as flankers), identical S-R repetitions have long been considered to constitute a special case of facilitated processing. Such trials are usually associated with particularly fast responses, which is assumed to reflect reemission of the most recent response on detection of an exact stimulus reoccurrence, thereby bypassing response selection proper (Hommel & Colzato, 2004; Pashler & Baylis, 1991; Bertelson, 1963). Considering that what has so far been described as a reduced flanker congruence effect after conflict trials may also be referred to as a *congruence-level repetition advantage* (e.g., performance on RIC trials is better after RIC as compared to after SC trials), it becomes apparent that inclusion of identical S-R repetitions, which are always associated with repetition of the congruence level, may yield results that mimic conflict adaptation. Following Mayr, Awh, and Laurey (2003), we therefore excluded identical S-R repetitions from the analysis of sequential conflict effects.[1] That said, although identical repetitions should be excluded from the sequential conflict analysis to achieve an accurate estimate of conflict adaptation, separate analysis of these trials may be valuable with regard to

characterizing more precisely the assumed response selection shortcut mechanism. Specifically, comparing flanker-related conflict effects on S-R repetition and nonrepetition trials should be informative as regards the question of whether response decisions are less affected by flanker processing under such conditions.

To summarize, in the current study we used behavioral and electrophysiological methods to investigate sequential effects in a flanker task with a four-to-two mapping between stimuli and responses. Specifically, we set out to answer the following questions: (1) Is processing selectivity enhanced only after response-related or after stimulus-related flanker conflict, even under conditions of control of S-R repetition effects? This question was addressed by comparing flanker congruence effects and the N2 after RIC versus after SIC predecessor trials while discarding identical S-R repetitions from the analyses. (2) Do flanker-related conflict effects also occur on trials with identical S-R repetitions? This question was addressed by comparing flanker congruence effects and the N2 on trials with versus without identical S-R repetitions.

METHODS

Participants

Twenty-three neurologically healthy students (12 women; aged 20–30 years, mean age 23.3 years) of the University of Magdeburg gave informed consent to participate. All subjects were right-handed, had normal or corrected-to-normal vision, and were naive to the purpose of this study. Because of overall error rates greater than 20%, 3 subjects were excluded from the statistical analysis.

Stimuli and Procedure

All procedures have been approved by the local institutional review board. Stimuli were shown in white letters against a black background on a 19-in. CRT monitor using Presentation software. Viewing distance was 80 cm; size of the stimuli was 2.5° visual angle in the horizontal and vertical direction. Target and flanker stimuli were created from letters K, L, N, and P. Each stimulus comprised five letters: the target letter was located in the center and the flanker letters (all identical) were presented to the left and to the right of and above and below the target letter, respectively. Stimuli were shown for 100 msec with a fixed stimulus onset asynchrony (SOA) of 900 msec. The participants' task was to respond as fast as possible to the target letter by pressing a mouse button with the index finger of the left or the right hand. Half of the participants had to give a left-hand response for target letters K and L and a right-hand response for N and P. For the other half of subjects the stimulus response mapping was reversed. SC, SIC, and RIC trials were presented in one third of the trials each. The whole session comprised 20 blocks of 120 trials separated by breaks of at least 20 sec. The session started with 30 test trials to ensure that subjects used the correct stimulus–response mapping.

Electroencephalogram Recording and Analysis

The electroencephalogram (EEG) was recorded from 28 tin electrodes, referenced against the left mastoid, mounted in an elastic cap, and placed according to the international 10-20 system. The EEG was re-referenced offline to the mean activity at the left and right mastoid. To allow comparison with previous data (Van Veen & Carter, 2002), we also obtained waveforms referenced to the common average reference. To enable the offline rejection of eye movement artifacts, horizontal and vertical electrooculograms (EOGs) were recorded using bipolar montages. All channels were amplified (band-pass 0.05–30 Hz) and digitized with 4 msec resolution. Using individualized amplitude criteria on the eye channels, we excluded trials with eye movement artifacts from the analysis. Stimulus-locked ERPs were averaged for epochs 700 msec long, starting 100 msec prior to each stimulus presentation. For statistical analyses, we calculated for each condition and each subject the mean amplitude for electrodes Fz and Cz, where the N2 effect is maximal, in the time window 240–280 msec. Baseline was −100 to 0 msec.

Statistical Analysis

With regard to the behavioral results, we report RTs and error rates. Trials following errors were excluded. The statistical analyses of the ERPs were based on data from trials with correct responses only. Again, we excluded all trials following an erroneous response. All analyses of variance (ANOVAs) reported subsequently were calculated as full-factorial repeated measurement ANOVAs. Significance levels of the two-factorial ANOVAs were Huynh–Feldt corrected. Post hoc contrasts following one-factorial ANOVAs were tested with Tukey's HSD. To adjust the significance level of post hoc t tests for multiple comparisons after two-factorial ANOVAs, α was set to .05, and an improved Bonferroni procedure based on the ordered p values was applied (Simes, 1986). According to Simes (1986), let $p_{(1)} \leq p_{(2)} \leq \ldots \leq p_{(j)}$ be the ordered p values for testing $H_0 = \{H_1, H_2, \ldots, H_i\}$. H_0 will be rejected whenever $p_i < i \times \alpha/j$ for $i = 1 \ldots j$.

RESULTS

Reaction Time Analysis

The mean RTs for SC, SIC and RIC conditions are shown in Figure 1A. A repeated measures ANOVA with the factor Congruence Level (SC, SIC, RIC) revealed a clear main effect, $F(2,38) = 63.8$, $p < .001$. Post hoc contrasts

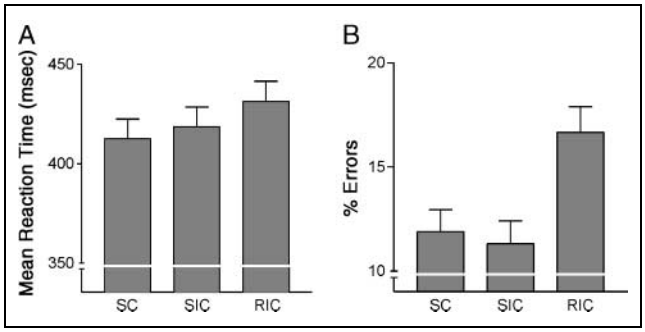

Figure 1. (A) Mean RTs and *SEM*s in milliseconds for the conditions stimulus congruent (SC), stimulus incongruent (SIC), and response incongruent (RIC). (B) Mean error rates and *SEM*s in percent.

indicated that subjects responded reliably faster to SC trials than to SIC ($p < .01$) or RIC trials ($p < .001$) and also faster to SIC than to RIC trials ($p < .001$).

To test for conflict adaptation effects a repeated measures ANOVA with the factors Congruence Level of the Current Trial (SC, SIC, RIC) and Congruence Level of the Preceding Trial (SC, SIC, RIC) was performed. For the reasons given above, trials involving identical S-R repetition were excluded from this analysis. The resulting mean RTs for all conditions are depicted in Figure 2A. The main effect Congruence Level of the Current Trial, $F(2,38) = 62.8$, $p < .001$, as well as the interaction of both factors, $F(4,76) = 7.25$, $p < .001$, was significant, whereas the main effect, Congruence of the Preceding Trial, failed to reach significance, $F(2,38) = 2.18$, $p = .12$. Inspection of Figure 2A suggests that the interaction was brought about by slowed responding to SC trials following (nonidentical) SC trials.

To analyze the influence of congruence-level repetition in contrast to identical S-R repetition, an ANOVA with repeated measures on the factors Congruence Level (SC, SIC, RIC) and Repetition (identical S-R repetition vs. congruence level repetition) was performed. Both main factors Congruence Level, $F(2,38) = 74.3$, $p < .001$, and Repetition, $F(1,19) = 4.59$, $p = .045$, as well as their interaction reached significance, $F(2,38) = 14.0$, $p < .001$. In order to disentangle this interaction, we calculated post hoc comparisons between identical S-R repetition and their corresponding congruence-level repetition for each condition. Furthermore, contrasts between identical S-R repetitions of different congruence levels were performed. Therefore, we adjusted α for six post hoc contrasts. In all conditions, identical S-R repetitions were significantly faster than their corresponding congruence-level repetition (SC[ID] vs. SC[SC], SIC[ID] vs. SIC[SIC], and RIC[ID] vs. RIC[RIC]; nomenclature: current trial [preceding trial]; see Table 1 for details). The comparison of identical S-R repetitions indicated fastest response times for the SC[ID] condition (SC[ID] vs. SIC[ID], SC[ID] vs. RIC[ID]) and slowest for RIC[ID] (SIC[ID] vs. RIC[ID]).

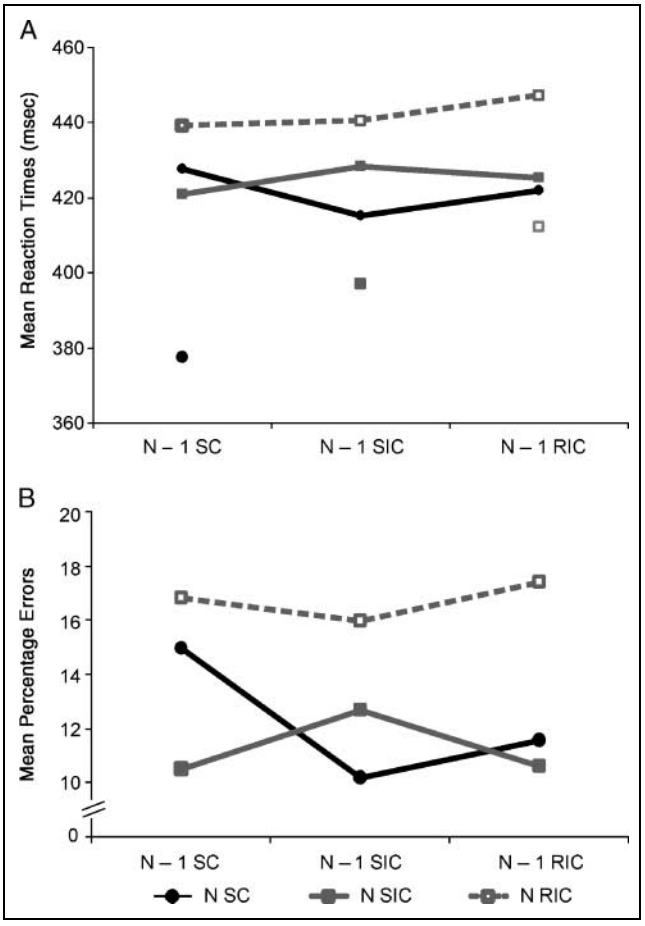

Figure 2. (A) Sequential effects on mean RT. Unconnected symbols represent the identical S-R repetitions in the current and preceding trial for each congruence level. N − 1 SC/SIC/RIC = congruence level in the preceding trial; N SC/SIC/RIC = congruence level in the current trial. (B) Sequential effects on mean error rates (in percent).

Performance Errors

Figure 1B shows mean error rates for SC, SIC, and RIC conditions. Calculating a repeated measures ANOVA with the factor Congruence Level (SC, SIC, RIC), the main effect was highly significant, $F(2,38) = 39.2$, $p < .001$. Post hoc contrasts revealed that subjects made more response errors for RIC than for SC ($p < .001$) or

Table 1. Post Hoc Comparisons in Reaction Time Analysis

Order	*Contrast*	*t*	p_{emp}	p_{crit}
1	SC[SC] vs. SC[ID]	7.79	<.001	.008
2	RIC[ID] vs. SC[ID]	7.26	<.001	.017
3	RIC[RIC] vs. RIC[ID]	5.99	<.001	.025
4	SIC[SIC] vs. SIC[ID]	5.12	<.001	.033
5	SC[ID] vs. SIC[ID]	−3.75	.001	.042
6	RIC[ID] vs. SIC[ID]	2.99	.007	.050

SIC ($p < .001$) trials, whereas there was no difference between SC and SIC trials ($p = .19$).

To test the influence of conflict adaption on error rates, a repeated measures ANOVA, similar to the analysis of RTs, with the factors Congruence Level of the Current Trial (SC, SIC, RIC) and Congruence Level of the Preceding Trial was performed. Both main effects of the factors Congruence Level of the Current Trial, $F(2,38) = 31.37$, $p < .001$, and Congruence Level of the Preceding Trial, $F(2,38) = 3.89$, $p = .029$, as well as their interaction, $F(4,78) = 8.39$, $p < .001$, were significant (see Figure 2B). Similar to the results of the corresponding RT analysis, conflict effects were not reduced after stimulus- or response-based conflict on the preceding trial. Because of the low error rates for identical S-R repetitions, this effect was not compared to identical congruence-level repetition.

Event-related Potentials

Figure 3 shows the stimulus-locked grand averages for conditions SC, SIC, and RIC at midline electrode sites Fz, Cz, and Pz. Compared to the SC condition, a pronounced N2, peaking around 260 msec at frontocentral electrode sites (for topographical distribution, see Figure 3, right column), was observed for the RIC as well as for the SIC condition. This effect was present regardless of the reference used, that is, common average reference (cf. Van Veen & Carter, 2002) or mastoid reference. The latter was used for all statistical analyses.

A repeated measures ANOVA with the factor Congruence Level (SC, SIC, RIC) yielded a significant main effect, $F(2,38) = 35.8$, $p < .001$. Post hoc comparisons revealed highly significant differences between SC and SIC ($p < .001$) as well as between SC and RIC ($p < .001$) conditions. In contrast, the comparison SIC against RIC was not significant ($p = .34$).

To assess the influence of congruence level in the preceding trial a repeated measures ANOVA with the factors Congruence Level of the Current Trial (SC, SIC, RIC) and Congruence Level of the Preceding Trial (SC, SIC, RIC) was performed. The corresponding mean amplitudes are shown in Figure 4. As for the related RT analysis, the main effect Congruence Level of the Current Trial, $F(2,38) = 35.15$, $p < .001$, and the interaction of both factors, $F(4,76) = 3.73$, $p = .008$, were significant, whereas the main effect Congruence Level of the Preceding Trial was not significant, $F(2,38) = 0.8$, $p = .455$. As can be seen in Figure 4, the N2 amplitude is more negative going at Fz and Cz if SC trials were preceded by SC trials as well. This N2 amplitude for the SC[SC] condition was significantly different from the SC[SIC] and SC[RIC] conditions (see Figure 5 and Table 2 for details).

To assess the influence of identical S-R repetition on the N2 a two-factorial repeated measures ANOVA with factors Congruence Level (SC, SIC, RIC) and Repetition (identical S-R repetition, congruence-level repetition) was conducted. Although the congruence level main effect was significant, $F(2,38) = 4.35$, $p = .023$, neither the

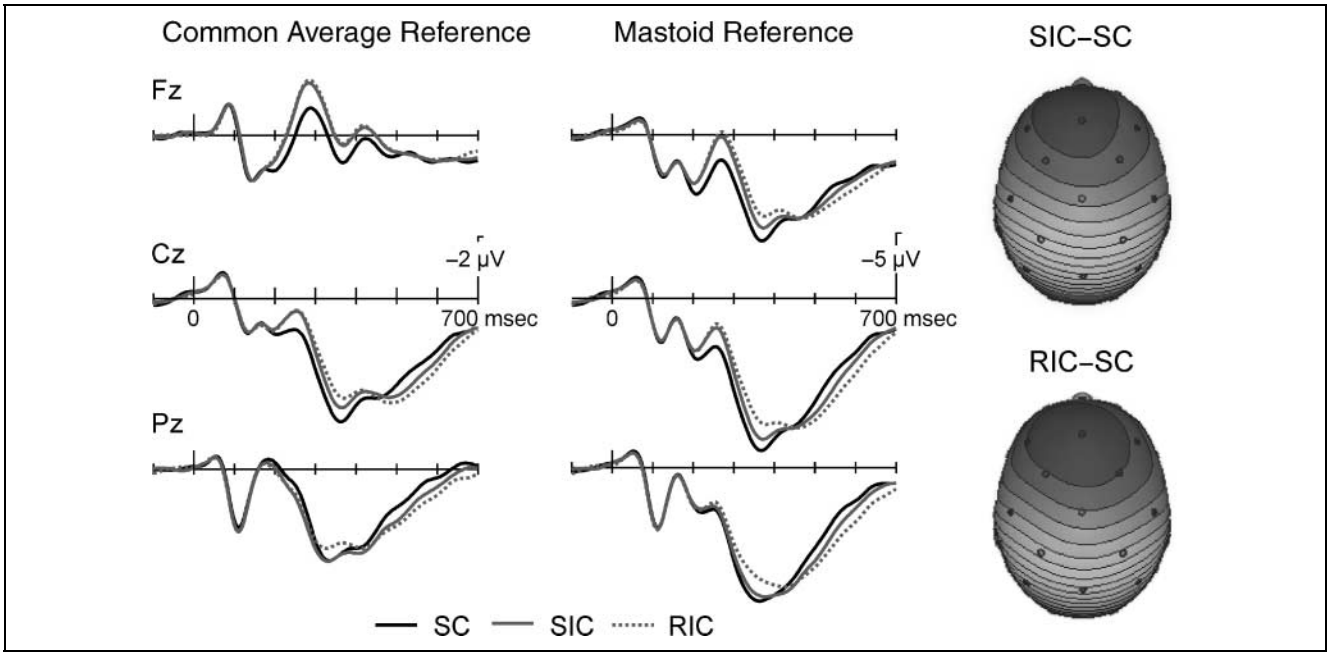

Figure 3. Left and middle columns: Stimulus-locked grand averages for conditions stimulus congruent (SC), stimulus incongruent (SIC), and response incongruent (RIC) for midline electrodes Fz, Cz, and Pz. Baseline used is −100 to 0 msec. Grand averages in the left column were derived using a common average reference; for grand averages in the middle column the mean of the activity at the two mastoid processes was used as a reference. The displayed waveforms were filtered with a 12-Hz low-pass filter. Right: Topographies for difference waveforms. Grayscales are changing in steps of 0.16 μV; brighter shades represent more positive values.

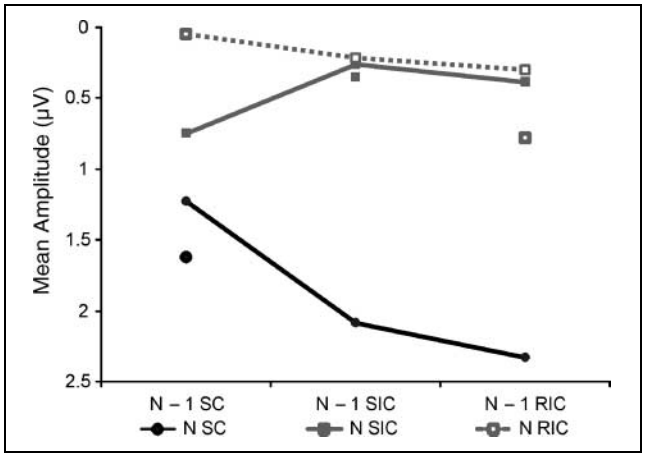

Figure 4. Mean amplitude of the ERP in the time window 240–280 msec (averaged over Fz and Cz electrodes). Unconnected symbols represent the identical S-R repetitions in the current and the preceding trial for each congruence level. N − 1 SC/SIC/RIC = congruence level in the preceding trial; N SC/SIC/RIC = congruence level in the current trial.

repetition main effect, $F(1,19) = 0.49$, $p = .49$, nor the interaction, $F(2,38) = 0.03$, $p = .96$, reached significance. Post hoc contrasts (see Figure 6 for corresponding ERPs) indicated no significant difference between the numerically smaller N2 amplitude of the SC[ID] condition and the SIC[ID] and RIC[ID] conditions, respectively.[2]

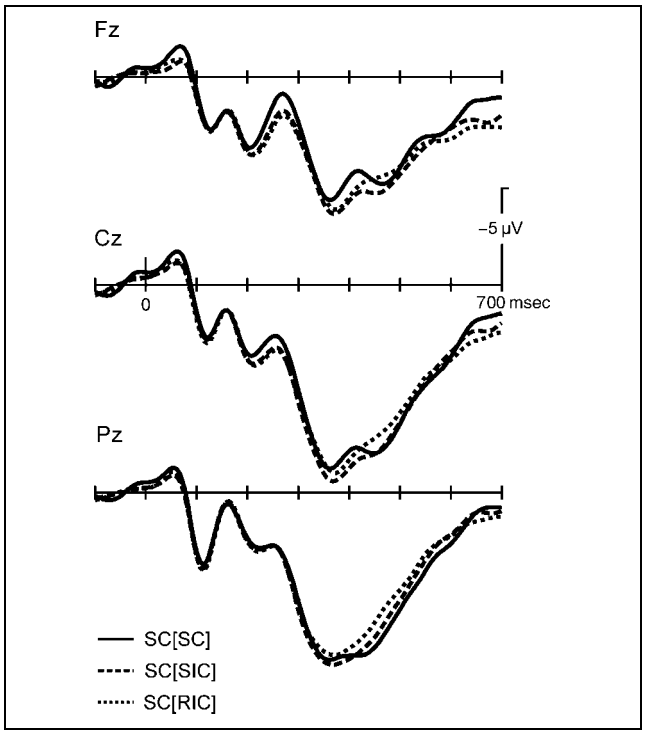

Figure 5. Stimulus congruent trials with different congruence levels in the preceding trials for midline electrodes Fz, Cz, and Pz (mastoid reference, baseline −100 to 0 msec). Trial type on current trial is given before, trial type of preceding trial within the bracket. SC = stimulus congruent, SIC = stimulus incongruent, RIC = response incongruent. Grand averages were filtered with a 12-Hz low-pass filter.

Table 2. Post Hoc Comparisons in ERP Analysis

Order	*Contrast*	*t*	p_{emp}	p_{crit}
1	SC[SC] − SC[SIC]	−3.43	.003	.0125
2	SC[SC] − SC[RIC]	−2.61	.017	.025
3	SIC[SC] − SIC[SIC]	1.99	.061	.0375
4	SIC[SC] − SIC[RIC]	1.40	.177	.05

DISCUSSION

Although previous results of best performance on SC trials, worst performance on RIC trials, and intermediate performance on SIC trials (Van Veen & Carter, 2002; Van Veen et al., 2001; Eriksen & Eriksen, 1974) could be replicated, ERP results in the current experiment were clearly different from prior findings. Specifically, whereas Van Veen and Carter (2002) found enhancement of the N2 component selectively on RIC trials and no difference between SC and SIC trials, in the current study N2 enhancement occurred to the same degree on SIC and RIC trials. Although the basic designs of the Van Veen and Carter study and the current experiment are rather similar, there are a number of procedural differences. For instance, whereas Van Veen and Carter used a variable SOA of about 1000–2500 msec,[3] we have used a fixed SOA of 900 msec. Second, target and flanker letters were presented simultaneously in the present experiment, whereas flanker letters preceded the target letter by 100 msec in the earlier study. Third, the spatial arrangement of target and flanker letters was different (Van Veen and Carter used two flankers to the left and two flankers to the right of the target; the current study used one flanker each to the left and right and above and below the target). Finally, whereas in the current

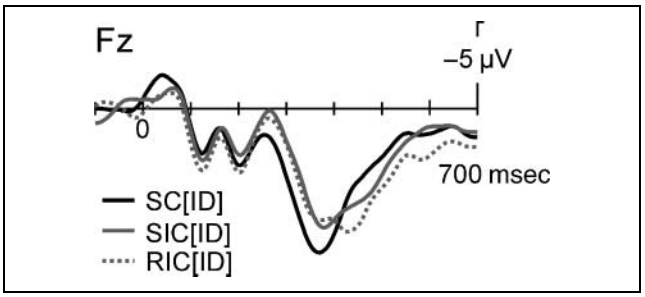

Figure 6. Stimulus-locked grand averages for conditions with identical S-R repetitions: stimulus congruent repetition (SC[ID]), stimulus incongruent repetition (SIC[ID]), and response incongruent repetition (RIC[ID]) for midline electrodes Fz, Cz, and Pz (mastoid reference, baseline −100 to 0 msec). Grand averages were filtered with a 12-Hz low-pass filter.

study the three congruence conditions (SC, SIC, and RIC) were administered with equal probability, Van Veen and Carter presented SC stimuli on 50% of the trials and SIC and RIC stimuli on 25% of the trials each. To what extent these differences in design could be responsible for the differences in the N2 effect is unclear at present. In any case, however, given the dependency of the N2 pattern on specific procedural factors it seems premature to view the ACC as a selective response-conflict detector.

Although increased ACC activation on both SIC and RIC trials, as indicated by our N2 findings, fits well with recent suggestions that conflict at the stimulus level rather than at the response level triggers adaptation of processing selectivity (Notebaert & Verguts, 2006; Verbruggen et al., 2006), the current study provides no further support for this notion because reduction of flanker interference occurred neither after SIC nor after RIC trials. Likewise, we observed no reduction in conflict-related N2 enhancement after stimulus- or response-related conflict on the preceding trial. That is, previously found sequential effects attributed to conflict adaptation mechanisms could not be replicated in the current study. Importantly, because identical S-R repetitions were clearly associated with facilitated processing, inclusion of such trials in the sequential conflict analysis may have mimicked results predicted by the conflict adaptation hypothesis.

In line with these findings, Mayr et al. (2003) failed to obtain reliable interference reduction after conflict in a flanker paradigm with only two stimuli and responses (see also Nieuwenhuis et al., 2006; Stürmer, Seiss, & Leuthold, 2005). These authors separately analyzed trials with repetition of the target/response (in which repetitions of the congruence level consisted of identical S-R repetitions) and trials with alternation of the target/response (which did not involve identical S-R repetitions). Whereas, on target/response repetition trials, reduction of flanker interference after conflict occurred, target/response alternations were associated with the same amount of interference regardless of preceding conflict. Contrary to these results, however, Ullsperger, Bylsma, and Botvinick (2005) observed interference reduction after conflict with both repetition and alternation of the target/response. To account for the discrepancy in findings, these authors conjectured that negative priming effects (i.e., performance decrements on trials in which the target is identical to the previous trial's distractor) may mask conflict adaptation under certain conditions. To control for this possibility with regard to the lack of conflict adaptation effects in the current study, we reanalyzed our RT data, excluding all trials that involved flanker-to-target repetitions (i.e., all trials in which negative priming might have occurred). The Current Trial (SC, SIC RIC) × Preceding Trial (SC,SIC,RIC) ANOVA revealed main effects for both current trial, $F(2,38) = 65.8$, $p < .001$, and preceding trial, $F(2,38) = 4.15$, $p = .023$; interaction, $F(4,76) = 3.61$, $p = .01$. Therefore, it appears that our results cannot be explained by negative priming.

Another aspect of the current experiment that might have relevance regarding the lack of conflict adaptation effects is that behavioral conflict effects were overall comparably low. It may thus be argued that a higher degree of conflict than realized in our experiment is needed to trigger the adaptation mechanism. This possibility seems unlikely, however, because the marked increase in the N2 on conflict trials (i.e., almost 2 μV [linked mastoid reference] and 0.9 μV [common average reference] difference between RIC and SC trials, cf. Figures 3 and 4, compared to 0.5 μV in the Van Veen & Carter, 2002, study) clearly suggests that a conflict signal was emitted by the ACC. Nevertheless, to gain further insight into the role of conflict strength regarding sequential interference modulation, we assessed sequential effects separately for participants with overall high conflict versus overall low conflict effects (see Footnote 2). Importantly, there were no significant differences in the N2 amplitude when testing for sequential flanker effects. Thus, although the enhancement of the frontocentral N2 on conflict trials suggests that ACC-based conflict detection took place, the lack of a conflict adaptation effect precludes attributing a functional role to this effect. It is noteworthy that doubts about a functional role of the ACC in conflict processing have recently been put forward by Fellows and Farah (2005), who obtained normal conflict-related adaptation effects in a group of four patients with damage to the ACC.

As noted earlier, the comparison of identical S-R repetitions with corresponding congruence level repetitions, which were not exact replicas of their predecessor trials, revealed a general processing advantage, thereby demonstrating the importance of controlling S-R sequence when examining conflict adaptation effects. Despite this general RT facilitation, however, flanker-related conflict effects were not reduced on trials involving identical S-R repetitions, thereby demonstrating that the assumed response selection shortcut (Hommel & Colzato, 2004; Pashler & Baylis, 1991; Bertelson, 1963) does not shield performance against parallel flanker processing. Consistent with this finding, identical S-R repetitions of conflict trials were associated with a numerically increased N2. This difference failed to reach significance, however, because of the low number of trials in this comparison. Note that dissociations between overall performance on the one hand and interference evoked by parallel processing of (formally) irrelevant stimuli (or stimulus features) on the other are not unusual findings. For instance, in most task-switching studies that varied the length of a preparation interval, increased preparation was associated with markedly improved task performance, whereas response congruence effects from the competitor task remained unchanged (e.g., Meiran, 1996; Rogers & Monsell, 1995;

Fagot, 1994; see, e.g., Lamb & Robertson, 1989, for a similar dissociation in processing global and local aspects of hierarchical stimuli). With regard to the flanker task used in the current study, Coles, Gratton, Bashore, Eriksen, and Dochin (1985) and Gratton, Coles, Sirevaag, Eriksen, and Donchin (1988) observed that the impact of flanker congruence on performance was larger for responses determined at early than at late processing stages. Given the particular fast response determination with identical S-R repetitions, the nonreduction of flanker conflict effects on these trials is not surprising.

An unexpected result of the current study is the increase in RTs and N2 on SC (nonidentical) repetition trials, which resulted in an interaction between the congruence levels of the current and the preceding trial. Because we replicated this result in another, yet unpublished behavioral experiment (which differed from the experiment of the current study in several aspects, such as the frequency of SC, SIC, and RIC trials and the timing of events), this cannot be considered a singular finding. Although at the moment we can only speculate regarding the cause of this performance disadvantage, the fact that it was associated with an increase in the N2 points to the involvement of some form of cognitive conflict. This type of conflict may be related to recent findings regarding so-called partial feature repetition costs, that is, performance decrements when a given stimulus or response feature repeats across consecutive trials, whereas another feature alternates, as compared to conjoined repetitions or alternations (Hommel & Colzato, 2004; Hommel, 1998). In light of the fact that SC stimuli differ from both SIC and RIC stimuli in that they consist of an array of identical letters, such stimulus homogeneity may be a particularly salient feature. It might thus be particularly problematic if this feature repeats, whereas other features (i.e., target, flankers, or response) alternate, as is the case on SC nonidentical repetition trials. More importantly, given the N2 increase in this condition, identifying the cause of the SC repetition disadvantage may provide further information regarding the range of conflict types the ACC is sensitive to. Future research is needed for this endeavor.

In summary, the current study demonstrates that in the Eriksen flanker task enhancement of the frontocentral N2 may be evoked by conflict at either the stimulus or at the response level, but this enhancement is not necessarily followed by subsequent conflict adaptation, thereby suggesting that at least under certain circumstances the ACC responds to a broader range of cognitive conflict and raising doubts about boundary conditions of conflict adaptation.

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Notes

1. Rather than excluding identical S-R repetition trials, Mayr et al. (2003) analyzed target/response repetition trials and target/response alternation trials separately and found the conflict adaptation effect on target/response repetition trials, which included identical S-R repetitions, but not on target/response alternation trials, in which identical S-R repetitions were absent. We will come back to this issue in the Discussion.
2. In addition, we tested the influence of conflict strength on N2 amplitude. Using the difference between mean RTs of SC and RIC trials, we made a median split to divide our subjects into a low- and a high-conflict group. With respect to the N2 analysis of the overall group, the pattern of results remained the same in both groups. Most importantly, there were no significant differences in the N2 amplitude when testing for sequential flanker effects (SIC[SIC] vs. SIC[RIC] and RIC[SIC] vs. RIC [RIC]).
3. Their experiment was programmed such that a variable time (500–1500 msec) between the button press and the onset of the next trial occurred. As the mean RT was about 500 msec, an SOA of about 1000–2500 msec resulted.

REFERENCES

Bertelson, P. (1963). S-R relationships and reaction time to new versus repeated signals in serial tasks. *Journal of Experimental Psychology, 65,* 478–484.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624–652.

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for action in anterior cingulate cortex. *Nature, 402,* 179–181.

Carter, C. S., Macdonald, A. M., Botvinick, M., Ross, L. L., Stenger, V. A., Noll, D., et al. (2000). Parsing executive processes: Strategic vs. evaluative functions of the anterior cingulate cortex. *Proceedings of the National Academy of Sciences, U.S.A., 97,* 1944–1948.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97,* 332–361.

Coles, M. G. H., Gratton, G., Bashore, T. R., Eriksen, C. W., & Dochin, E. (1985). A psychophysical investigation of the continuous flow model of human information processing. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 529–553.

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus–response correspondence. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 731–750.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143–149.

Fagot, C. (1994). *Chronometric investigations of task switching.* PhD Dissertation, University of California, San Diego.
Fellows, L. K., & Farah, M. J. (2005). Is anterior cingulate cortex necessary for cognitive control? *Brain, 128,* 788–796.
Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General, 121,* 480–506.
Gratton, G., Coles, M. G. H., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and post-stimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 331–344.
Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus–response episodes. *Visual Cognition, 5,* 183–216.
Hommel, B., & Colzato, L. (2004). Visual attention and the temporal dynamics of feature integration. *Visual Cognition, 11,* 483–521.
Kerns, J. G., Cohen, J. D., MacDonald, A. W., III, Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science, 303,* 1023–1026.
Kopp, B., Rist, F., & Mattler, U. (1996). N200 in the flanker task as a neurobehavioral tool for investigating executive control. *Psychophysiology, 33,* 282–294.
Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility—A model and a taxonomy. *Psychological Review, 97,* 253–270.
Lamb, M. R., & Robertson, L. C. (1989). Do response time advantage and interference reflect the order of processing of global- and local-level information? *Perception & Psychophysics, 46,* 254–258.
MacDonald, A. W., III, Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of dorsolateral prefrontal and anterior cingulated cortex in cognitive control. *Science, 288,* 1835–1838.
Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience, 6,* 450–452.
Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1423–1442.
Nieuwenhuis, S., Stins, J. F., Posthuma, D., Polderman, T. J. C., Boomsma, D. I., & de Geus, E. J. (2006). Accounting for sequential trial effects in the flanker task: Conflict adaptation or associative priming? *Memory & Cognition, 34,* 1260–1272.
Notebaert, W., & Verguts, T. (2006). Stimulus conflict predicts conflict adaptation in a numerical flanker task. *Psychonomic Bulletin & Review, 13,* 1078–1084.
Pardo, J. V., Pardo, P. J., Janer, K. W., & Raichle, M. E. (1990). The anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm. *Proceedings of the National Academy of Sciences, U.S.A., 87,* 256–259.
Pashler, H., & Baylis, G. (1991). Procedural learning: 2. Intertrial repetition effects in speeded-choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 33–48.
Posner, M. I., Petersen, S. E., Fox, P. T., & Raichle, M. E. (1988). Localization of cognitive operations in the human brain. *Science, 240,* 1627–1631.
Posner, M. I., & Rothbart, M. K. (1998). Attention, self-regulation and consciousness. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences, 353,* 1915–1927.
Rogers, R., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207–231.
Ruff, C. C., Woodward, T. S., Laurens, K. R., & Liddle, P. F. (2001). The role of the anterior cingulated cortex in conflict processing: Evidence from reverse Stroop interference. *Neuroimage, 14,* 1150–1158.
Simes, R. J. (1986). An improved Bonferroni procedure for multiple tests of significance. *Biometrika, 73,* 751–754.
Stürmer, B., Leuthold, H., Soetens, E., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 1345–1363.
Stürmer, B., Seiss, E., & Leuthold, H. (2005). Executive control in the Simon task: A dual-task examination of response priming and its suppression. *The European Journal of Cognitive Psychology, 17,* 590–618.
Ullsperger, M., Bylsma, L. M., & Botvinick, M. M. (2005). The conflict-adaptation effect: It's not just priming. *Cognitive, Affective, and Behavioral Neuroscience, 5,* 467–472.
Van Veen, V., & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience, 14,* 593–602.
Van Veen, V., Cohen, J. D., Botvinick, M. M., Stenger, V. A., & Carter, C. S. (2001). Anterior cingulate cortex, conflict monitoring, and levels of processing. *Neuroimage, 14,* 1302–1308.
Verbruggen, F., Notebaert, W., Liefooghe, B., & Vandierendonck, A. (2006). Stimulus- and response-conflict-induced cognitive control in the flanker task. *Psychonomic Bulletin & Review, 13,* 328–333.