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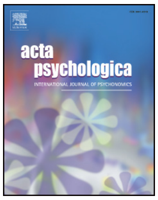

Conflict adjustment devoid of perceptual selection☆,☆☆

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ABSTRACT

Task performance suffers when an aspect of a stimulus is associated with an incorrect response, thereby evoking cognitive conflict. Such impairment is reduced after recent or frequent conflict occurrence, suggesting attentional adjustment. We examined adjustment to conflict evoked by a temporarily irrelevant S–R rule when participants frequently switched between two semantic classification tasks by manipulating the proportion of conflict trials in one of them. Controlling stimulus-specific presentation frequencies, we found reduced conflict effects under conditions of a higher proportion of conflict trials in the task to which the manipulation was applied, whereas there was no such effect in the other task. Additional analyses demonstrated task-specificity regarding trial-to-trial conflict adjustment. Because conflict was evoked in the absence of perceptually distinct target and distractor stimulus features, these adjustment effects cannot be attributed to perceptual selection.

1. Introduction

Conflict paradigms have yielded abundant evidence for cognitive processing of stimulus aspects which are irrelevant to a current task (i.e., which contain only information not necessary for correct task performance), even if participants have full knowledge about this irrelevance and are instructed to ignore them. Prominent demonstrations of this can be seen in relative performance impairment when a distractor stimulus feature, such as a word in the Stroop task (Stroop, 1935), a stimulus object adjacent to the target stimulus in the Eriksen flanker task (Eriksen & Eriksen, 1974), or the stimulus location in the Simon task (Simon & Small, 1969), is associated with an incorrect response, suggesting distractor-related response activation that interferes with responding to the target stimulus feature.

Such response conflict effects are reduced after recent or frequent processing of conflict stimuli (i.e., stimuli involving a distractor feature associated with an incorrect response) (e.g., Fernandez-Duque & Knight, 2008; Gratton, Coles, & Donchin, 1992; Wendt & Luna-Rodriguez, 2009). These modulations have been ascribed to attentional adjustment, that is, variations of the degree of dominance of processing target over distractor stimulus information, as a consequence of conflict experience (Botvinick, Braver, Barch, Carter, & Cohen, 2001) or, more generally, as a function of distractor utility (Gratton et al., 1992).

So far, little attempts have been made to specify the stages of processing which are affected by conflict adjustment. In paradigms as the ones mentioned above, in which target and distractor stimulus information is presented in the form of physically distinct stimulus features, perceptual selection, that is, re-distributing attentional weights assigned to the processing of these features, seems a likely means of adjustment. Support for this assumption has been obtained by using a visual search task, intermixed into blocks of flanker task trials, to probe the processing weights given to target- and flanker-related perceptual features. More precisely, Wendt, Luna-Rodriguez, and Jacobsen (2012) administered a traditional version of the flanker task (Experiment 1), in which a target letter was presented at the center of the screen, flanked on either side by identical copies of the same or of a different letter. On intermixed search task trials, participants had to detect a target digit in a string of three digits which occurred at the same locations as the letters in the flanker task. The location of the search task target varied randomly among the three possible locations. Search task reaction times (RTs) were generally shorter when the target was presented at the central location (i.e., at the location of the target of the flanker task) than when it was presented at one of the flanker locations. Crucially, this center-to-periphery gradient was more pronounced when the proportion of flanker task trials associated with

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response conflict was higher. A similar result was obtained in another experiment (Experiment 2) with a modified flanker task, in which target and distractor were defined by their colors rather than their locations, and a correspondingly adjusted search task was used (i.e., a search task in which the target and the distractor digits were randomly assigned to the two colors of the flanker task stimuli).

Although these findings demonstrate conflict-induced enhancement of selection based on perceptual target- and distractor-related features, inferring conflict adjustment at the stage of stimulus encoding may be premature because Wendt et al.'s (2012) data do not allow to dismiss the possibility that perceiving the distractor-related stimulus feature elicits retrieval of “don't respond tags”, attached to this feature on previous flanker task trials, which may interfere with current response demands (Neill, Valdes, Terry, & Gorfein, 1992). Noteworthily, the two interpretations differ regarding the functionality attributed to the mechanism underlying the performance pattern found in the search task. Whereas perceptual filtering could be regarded as a strategic measure, serving to reduce conflict emergence on future occasions, the episodic memory view would consider the pattern of search task results to be a by-product of automatic integration and retrieval processes.

However, other possible non-perceptual mechanisms of conflict adjustment than episodic retrieval of response information are conceivable. Firstly, it could be assumed that processing weights assigned to conceptual rather than perceptual categories are modified as a result of conflict occurrence. Putting larger weight on task-relevant conceptual categories may be assumed to reduce the build-up of conflict in an analogous manner to enhanced perceptual selection. Secondly, later processes of conflict resolution may gain efficiency through previous application, thereby possibly facilitating responding in conflict trials after recent or frequent conflict processing, even if early stimulus–response translation processes and conflict build-up remain unaffected.

In the current study, we looked for evidence for conflict adjustment devoid of perceptual selection, presumably taking place at a post-perceptual processing stage. To this end, we set up conflict conditions in which target and distractor information is not presented in terms of perceptually distinct stimulus features. This can be achieved by asking participants to alternate between two different classification tasks comprising semantic judgments, such as classifying a stimulus digit as odd or even on some trials and as smaller or larger than 5 on other trials, while using the same set of responses for both tasks.[1] With such an arrangement (e.g., pressing a key on the left side for *odd* and *smaller*, and pressing a key on the right side for *even* and *larger*) some stimuli are associated with the same response in both tasks (henceforth *congruent*, e.g., for the above S–R assignment, 1 or 6), whereas other stimuli are associated with different responses regarding the two tasks (henceforth *incongruent*, e.g., 2 or 7). By consequence, congruency effects (i.e., the performance difference between responding to a congruent and an incongruent stimulus) reflect some form of application of the S–R rules of the currently irrelevant task (see e.g., Kiesel et al., 2010, for a review of conflict effects in task switching studies).

Preliminary evidence for non-perceptual conflict adjustment was obtained by Kiesel, Kunde, and Hoffmann (2006). Applying a task switching paradigm as described (i.e., parity vs. magnitude judgments on digit stimuli), these authors found a reduced congruency effect after an incongruent as compared to a congruent predecessor trial when the task repeated from the preceding trial (thereby replicating the above mentioned trial-to-trial modulation found in single-task conflict paradigms). In contrast, the congruency effect was unaffected by the congruency level of the preceding trial when the task alternated, suggesting that conflict adjustment takes place in a task-specific manner.[2]

This task-specificity accords with other demonstrations of context-dependency of conflict adjustment effects. For instance, Spapé and Hommel (2008) using an auditory Stroop-like task found a reduced congruency effect after an incongruent predecessor trial if the voice in which the distractor stimulus was presented remained the same between trials but not if the voice switched between trials, suggesting that attentional settings can be bound to task-irrelevant contextual features. Regarding adjustment to conflict frequency, several studies in which the ratio of congruent and incongruent trials was correlated with an additional task-irrelevant stimulus feature (e.g., two stimulus locations, associated with different congruent/incongruent ratios) found a smaller congruency effect in trials with the contextual feature associated with a lower ratio (e.g., Corballis & Gratton, 2003; Crump, Gong, & Milliken, 2006; Crump & Milliken, 2009; Crump, Vaquero, & Milliken, 2008; King, Korb, & Egner, 2012; Wendt & Kiesel, 2011; Wendt, Kluwe, & Vietze, 2008).

Although some models of cognitive control attribute the trial-to-trial modulation and the congruency ratio-based modulation to the same mechanism (e.g., Botvinick et al., 2001; Gratton et al., 1992; Verguts & Notebaert, 2008, 2009), some recently reported dissociations between the two effects support the notion that they are brought about by different types of adjustment (e.g., Fernandez-Duque & Knight, 2008; Funes, Lupiáñez, & Humphreys, 2010; Purmann, Badde, & Wendt, 2009; Torres-Quesada, Funes, & Lupiáñez, 2013; Wendt et al., 2012). For instance, Funes et al. (2010) manipulated the proportion of Simon conflict trials in a combined Simon and Spatial Stroop task and found reductions of both the Simon effect and the spatial Stroop effect under conditions of a higher (Simon) conflict proportion in the absence of any trial-to-trial modulation between the two types of conflict, thus suggesting conflict-type-specific adjustment to individual conflict events and generalized adjustment across conflict types to a list-wide conflict manipulation.

Some framework conceptions of cognitive control emphasize a distinction of transient and more sustained control implementations, brought about by different types of processes and neural correlates (e.g., Braver, 2012; see also Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008), and this distinction has been linked to the two phenomena of trial-to-trial and congruency ratio modulations of the congruency effect in conflict tasks (De Pisapia & Braver, 2006; Funes et al., 2010). Specifically, Braver (2012) assumed, on the one hand, a reactive control mechanism to resolve interference after its onset, recruited by the detection of high interference events (e.g., through the engagement of conflict monitoring brain regions), and associated with transient activation of lateral prefrontal cortex and other brain areas. On the other hand, he proposed a mechanism of proactive control, reflecting active maintenance of goal-relevant information and characterized by sustained activation of lateral prefrontal cortical areas. Consistent with the idea of a sustained nature of the congruency ratio modulation of the congruency effect, Torres-Quesada et al. (2013) demonstrated transfer to subsequent blocks of trials (i.e., a larger congruency effect after practice with a higher congruent/incongruent ratio).

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[1] Although it is theoretically possible that participants cope with such demands by focusing on different perceptual aspects of one and the same stimulus, depending on the current task, we deem such ad-hoc generation of perceptual dimensions unlikely.

[2] Unlike the congruency effect, task switch costs (i.e., worse performance on task alternation trials than on task repetition trials) were affected by the congruency level of the preceding trial. More precisely, responding on task alternation trials was selectively impaired after an incongruent predecessor trial whereas there was no corresponding effect on task repetition trials. This pattern of results had earlier been observed when participants switched between tasks which were afforded by different perceptual stimulus dimensions (i.e., letter vs. color identification, Goschke, 2000). Assuming inhibited processing of a (previously) conflicting stimulus dimension, Goschke labeled the effect dimension negative priming. The fact that the effect also occurs in make-ups such as Kiesel et al.'s (2006), in which tasks are not associated with distinct perceptual features, demonstrates that it might also be accounted for in terms of inhibition of non-perceptual task-set components.

When investigating conflict adjustment, care must be taken to control effects of stimulus and response repetition. In particular, inclusion of trials associated with repetition of the directly preceding trial's target stimulus is liable to yield a data pattern which mimics trial-to-trial conflict adjustment. This is because stimulus repetitions have been found to be associated with particularly fast responses, possibly resulting from bypassing time-consuming response selection stages (e.g., Pashler & Baylis, 1991). Given that stimulus repetitions are perfectly confounded with repetition of the congruency level, inclusion of these trials should facilitate responding on congruency level repetition trials, thus yielding a conflict adjustment pattern (i.e., smaller congruency effect after incongruent than after congruent trials; cf. Mayr, Awh, & Laurey, 2003). Moreover, in task switching paradigms, this shortcutting strategy would produce frequent erroneous responses when the task switches and may therefore only be applied on task repetition trials. In fact, Hübner, Kluwe, Luna-Rodriguez, and Peters (2004) found a stimulus repetition advantage on task repetition trials but not on task alternation trials. As stimulus repetitions were not excluded from the analyses in the study of Kiesel et al. (2006), it is likely that the obtained data pattern was caused, in part, by stimulus repetition benefits rather than conflict adjustment.

Regarding adjustment to the frequency or ratio of congruent and incongruent trials, additional experimental control is needed. For illustration, consider manipulating the congruent-to-incongruent ratio in the above mentioned task switching paradigm involving parity and magnitude judgments. Presenting a larger proportion of incongruent stimuli, in the parity task, say, implies that the incongruent stimuli receive more task-specific practice than the congruent stimuli, thereby presumably gaining strengthened associations to their responses (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wendt & Luna-Rodriguez, 2009). As a consequence, incongruent digits should be facilitated compared to a condition involving a higher proportion of congruent trials, thereby mimicking the result expected on the assumption of conflict adjustment. Detailed accounts of this idea, assuming episodic retrieval of response information from previous trials have been put forward by Schmidt (2013) and Schmidt, De Houwer, and Besner (2010). Furthermore, processing of frequently presented S–R events may be facilitated by expectation (see e.g., Logan & Zbrodoff, 1979; Schmidt & Besner, 2008, for accounts of the congruency ratio modulation in terms of strategic use of S–R contingencies). In a task switching context, as realized in the current study, enhanced presentation frequency may, in addition, have detrimental effects on performance. Specifically, practice-based task-specific strengthening of an S–R association—and also S–R expectancies, provided they develop in a task-unspecific manner—may, in the case of an incongruent stimulus, impair responding when the stimulus occurs in the context of the other task because a different response is required. Such impairment might mask conflict adjustment, possibly leading one to erroneously infer adjustment only in the task in which the congruent/incongruent ratio was manipulated.

Support for a conflict adjustment account of the congruency ratio modulation was obtained by Bugg, Jacoby, and Chanani (2011) by use of a picture-word Stroop task, in which participants name the pictures and ignore congruent or incongruent words. Bugg and colleagues presented a subset of pictures predominantly together with a congruent word and another subset predominantly together with an incongruent word and found a smaller congruency effect for the latter subset. Because the assignment of pictures to different congruent/incongruent ratios was not associated with differential S–R contingencies (because pictures, being the target dimension, had the same response assignment in both conditions), this modulation was considered evidence for stimulus-specific attentional adjustment to conflict frequency (see, however, Schmidt, in press, for a failure to obtain a stimulus-specific congruency ratio modulation with a different method of controlling S–R contingency).

The notion of stimulus-specific attentional adjustment effects (as well as adjustment based on contextual features which vary on a trial-by-trial basis, mentioned above) raises the possibility that congruency ratio modulations, in general, reflect episodic retrieval of attentional sets on a given trial rather than sustained control operations. On the other hand, there is evidence that modulations of the congruency effect depending on the global congruent/incongruent ratio cannot be accounted for in terms of stimulus- or context-specific effects alone: To disentangle conflict frequency and S–R contingency, several studies used only a subset of the stimuli to manipulate the congruent/incongruent ratio and confined the analysis of conflict adjustment to a different subset of stimuli, associated with a constant congruent/incongruent ratio. Dismissing a pure S–R contingency account, modulations of the congruency effect by the overall congruent/incongruent ratio were found not only for the subset of stimuli associated with the manipulation but also for the constant ratio subset (Bugg & Chanani, 2011; Crump & Milliken, 2009; Fernandez-Duque & Knight, 2008, Experiment 2B; Wendt & Luna-Rodriguez, 2009; see also Bugg, McDaniel, Sculli, & Braver, 2011). Both stimulus/context-specific and generalized conflict adjustment effects are nicely predicted by a connectionist model put forward by Verguts and Notebaert (2008, 2009). According to this account, stimulus-specific conflict adjustment results from a Hebbian learning mechanism which strengthens the connection between a unit representing the currently present target stimulus feature (such as a specific color in a Stroop task) and an attention unit, biasing attention towards the target stimulus dimension, as a result of conflict evoked by an incongruent stimulus. Because the strengthening of connections depends on the activity of a given unit and because units representing target stimulus features currently not presented are associated with some baseline activity, conflict adjustment generalizes, to some extent, across the whole set of possible target stimulus features. Despite these suggestions of stimulus-specific adjustment, the precise consequences of S–R contingency are currently unclear, thus necessitating careful control.

In summary, conflict adjustment phenomena may be brought about by various mechanisms, depending on the precise task and other context conditions. Whereas in classical interference tasks, conflict adjustment appears to involve selection based on perceptual features, (trial-to-trial) modulation of conflict effects has also been found in conditions lacking a perceptual distinction between target and distractor information, suggesting transient non-perceptual conflict adjustment that operates in a task-specific manner. The current study aims at corroborating and extending such findings. Our primary goal was to assess non-perceptual adjustment—and task-specificity thereof—to the ratio of congruent to incongruent trials, controlling stimulus-specific practice and expectation effects. To this end, we asked participants to switch between parity and magnitude classifications of digit stimuli, and manipulated the congruent/incongruent ratio for only one of the tasks. To control for stimulus-related practice or expectancy effects, we manipulated the congruency ratio by presenting only half of the stimuli of a congruency level with enhanced frequency (henceforth referred to as *induction digits*) and assessed conflict adjustment by analyzing performance regarding the other subset of stimuli (henceforth referred to as *test digits*). In light of the distinction regarding transient and sustained adjustment we also looked at trial-to-trial adjustment effects, controlling for stimulus sequence effects by discarding all trials from the analyses in which the digit was repeated from the preceding trial.

2. Experiments 1A and 1B

In Experiment 1A, we varied the ratio of congruent and incongruent trials in the parity task between 25/75 and 75/25, whereas the congruent/incongruent ratio in the magnitude task was kept constant (at 50/50) throughout the experimental session. Whereas one half of the participants experienced infrequent conflict in the first half of the experimental trials and frequent conflict in the second half, this assignment was reversed for the other half of the participants. Assuming sustained, task-specific non-perceptual conflict adjustment, we expected reduced congruency effects (on trials involving test digits) in the parity task, but not in the magnitude task, for the 25/75 congruent/incongruent ratio condition compared to the 75/25 congruent/incongruent ratio condition. Assuming transient task-specific non-perceptual conflict adjustment, we expected reduced congruency effects after an incongruent predecessor trial on task repetition trials but not on task alternation trials, despite removal of data from trials associated with digit repetition from the analyses.

Experiment 1B was run to corroborate the results of Experiment 1A, accounting for the fact that the congruency effect tends to be smaller in the magnitude task than in the parity task (provided the latter involves the mapping of small digits to a left-sided response and large digits to a right-sided response, e.g., Otten, Sudevan, Logan, & Coles, 1996; Sudevan & Taylor, 1987). To control the confound of congruency ratio manipulation and overall susceptibility to S–R congruency, Experiment 1B replicated Experiment 1A with the ratio manipulation being applied to the magnitude task.

2.1. Method

2.1.1. Participants

Eleven female and 13 male students of the Helmut-Schmidt-University/University of the Federal Armed Forces Hamburg, ranging in age from 22 to 28 years, participated in Experiment 1A in exchange for partial fulfillment of course requirements. All reported to have normal or corrected-to-normal vision. Ten female and 14 male students of the University of Hamburg, ranging in age from 20 to 29 years, participated in Experiment 1B in exchange for partial fulfillment of course requirements. All reported to have normal or corrected-to-normal vision.

2.1.2. Apparatus and stimuli

Stimulus presentation and reaction time measurement were performed with a PC. The digits *1* to *9* except *5* were used as stimuli; these were displayed on a 19-in. monitor with a refresh rate of 60 Hz, viewed from a distance of about 90 cm. All digits were presented in white color on a dark gray background, in the center of the screen. The digits were 13 mm high (0.83°) and a maximum of 9 mm wide (0.57°). A rectangular white frame (98 × 64 mm), centered on the screen center, was continuously shown. Filled with red color, this frame acted as cue for the parity task, filled with cyan color as cue for the magnitude task.

Responses were given by pressing one of two response keys which were mounted on an external rectangular keyboard (10 cm × 18 cm) providing 0.1 ms timing accuracy. The response keys extended 1.0 × 1.0 cm and were separated by 8.0 cm (parallel to the keyboard's long axis). Participants pressed the response keys with the index or middle fingers of their left and right hands (hands uncrossed). In the magnitude task, participants pressed the left key to indicate smaller than 5 and the right key to indicate larger than 5. In the parity task only, the S–R assignment was counterbalanced across participants.

2.1.3. Procedure

At the start of the experiment, participants were instructed on the parity task, and given a 20-trial practice block. This was followed by the instructions for the magnitude task, a 20-trial practice block, and then a mixed block, in which the task was chosen randomly on each trial, of 30 trials. Finally, 10 experimental blocks of 99 trials each were administered. (The first three trials of each block were considered warm-up trials and were not entered into the statistical analyses.) Between blocks, participants were allowed to rest for some time. A trial started with the presentation of the task cue for 1000 ms, followed immediately by the presentation of the digit which remained on the screen until a response was given. After an incorrect response, the German word "falsch" ("incorrect") was displayed for 800 ms slightly below the screen center. Then the trial was repeated with an identical stimulus. Such repetitions of incorrect trials were not counted as trials. The next task cue was displayed 500 ms after a correct response and 1300 ms after an incorrect response.

The task was chosen randomly on each trial. In Experiment 1A, the congruent/incongruent ratio for the parity task was 75/25 in one half of the experiment (either the first or the second 5 successive blocks, counterbalanced across participants), and 25/75 in the other half. To achieve these ratios, two congruent or two incongruent induction digits had a 5 times higher probability to be chosen than the other digits. These induction digits were either 1, 2, 8, and 9 (i.e., extreme digits), or 3, 4, 6, and 7 (i.e., medial digits), counterbalanced across participants. Thus, with a total of 960 trials per participant (i.e., 10 blocks of 99 trials minus the three warm-up trials each), the expected frequency of presentation for an induction digit in the parity task was 75 during the part of the experimental session in which the proportion of the corresponding congruency level was high, and 15 during the other half, whereas the expected frequency of a test digit in the parity task was 15 for the first as well as for the second half (see Table 1 for an example). Considering the whole experimental session, each induction and test digit was thus associated with an expected frequency of 90 and 30, respectively, in the parity task. On magnitude task trials, the digit was chosen randomly on each trial without any constraints, thereby yielding an expected 50/50 ratio of congruent and incongruent trials as well as equal proportions of test digits and induction digits. The expected frequency for each digit was therefore 30 per half of the experimental session. The identical procedure was applied in Experiment 1B, with the only difference that the magnitude task was subject to the ratio manipulation, whereas the parity task was associated with a constant 50/50 congruent/incongruent ratio.

3. Results

Reaction time and error data of the experimental blocks were subjected to statistical analyses. Data from the first three trials of each block, from trials associated with repetition of the stimulus digit from the preceding trial, from trials following an erroneous response (as well as from the identical stimulus repetitions following an incorrect response, which were not counted as trials), and RTs below 200 ms or exceeding 2000 ms, were discarded from the analyses. RT outlier exclusion resulted in the loss of 1.4% of the data of Experiment 1A and of 1.1% of the data of Experiment 1B. Using stricter outlier criteria of 1500 ms or 1200 ms did not produce substantively different results.

Table 1
Example of the expected presentation frequencies of digit stimuli in the parity task and in the magnitude task in each half of the experimental session for a participant who responds to odd digits with a left-sided key press and to even digits with a right-sided key press. In this example, medial digits are used as induction stimuli (shaded), and the congruent/incongruent ratio of the parity task equals 75/25 during the first half of the session and 25/75 during the second half.

Digit	Parity task		Magnitude task	
	First half	Second half	First half	Second half
1 (congruent)	15	15	30	30
2 (incongruent)	15	15	30	30
3 (congruent)	75	15	30	30
4 (incongruent)	15	75	30	30
6 (congruent)	75	15	30	30
7 (incongruent)	15	75	30	30
8 (congruent)	15	15	30	30
9 (incongruent)	15	15	30	30

3.1. Experiment 1A

An Analysis of Variance (ANOVA) with repeated measures on the factors Congruent/Incongruent Ratio (in the parity task; 75/25, 25/75), Task (parity, magnitude), Task Sequence (repetition, alternation), Stimulus Type (test, induction), and Congruency (congruent, incongruent) on the mean RTs yielded significant main effects of Task, Task Sequence, and Congruency, $F(1,23) = 4.5$, $p < .05$, $MSE = 9931.4$, $F(1,23) = 42.2$, $p < .01$, $MSE = 23706.9$, and $F(1,23) = 31.0$, $p < .01$, $MSE = 34338.3$, respectively, revealing that magnitude task trials were responded to faster than parity task trials (627 ms vs. 642 ms), task repetition trials were responded to faster than task alternation trials (598 ms vs. 671 ms), and congruent trials were responded to faster than incongruent trials (597 ms vs. 672 ms).

Congruency effects were larger on parity task trials than on magnitude task trials, $F(1,23) = 6.7$, $p < .02$, $MSE = 9393.1$ (92 ms vs. 56 ms), and on task alternation than on task repetition trials, $F(1,23) = 7.4$, $p < .02$, $MSE = 4321.4$ (87 ms vs. 61 ms). Furthermore, task switch costs were reduced for induction digits compared to test digits, $F(1,23) = 5.6$, $p < .03$, $MSE = 3555.9$ (82 ms vs. 62 ms).

Of more importance regarding our research question, congruency effects were affected by the congruent/incongruent ratio, differentially for the two tasks, thus yielding a significant three-way interaction, $F(1,23) = 19.5$, $p < .01$, $MSE = 5972.3$. Whereas in the parity task the congruency effect was lower under conditions of increased conflict proportion, the congruency effect in the magnitude task was hardly affected. As can be seen in Fig. 1, the ratio modulation in the parity task was stronger with induction digits than with test digits, yielding a four-way interaction with stimulus type, $F(1,23) = 9.4$, $p < .01$, $MSE = 3603.4$. Planned comparisons, involving test digit trials only, confirmed the ratio modulation of the congruency effect in the parity task, $F(1,23) = 5.0$, $p < .04$, $MSE = 7813.8$ (unaffected by task sequence, $F(1,23) < 1$), and the absence thereof in the magnitude task, $F(1,23) < 1$.

Of minor interest for our purpose, there were significant three-way interactions involving Congruent/Incongruent Ratio, Task, and Stimulus Type, $F(1,23) = 5.9$, $p < .03$, $MSE = 6819.1$, and Congruency, Task, and Stimulus Type, $F(1,23) = 4.6$, $p < .05$, $MSE = 8220.7$, which are shown in Fig. 1. Finally, all factors entered into a significant five-way interaction $F(1,23) = 4.5$, $p < .05$, $MSE = 2537.7$.

An analogous ANOVA of the mean error proportions yielded significant main effects of Congruent/Incongruent Ratio, Task, Task Sequence, and Congruency, $F(1,23) = 26.7$, $p < .01$, $MSE = .00329$, $F(1,23) = 16.4$, $p < .01$, $MSE = .00626$, $F(1,23) = 15.2$, $p < .01$, $MSE = .00476$, and $F(1,23) = 64.7$, $p < .01$, $MSE = .01394$, respectively, reflecting that the error proportion was lower in the low congruent/incongruent condition than in the high congruent/incongruent condition (4.5% vs. 6.6%), on magnitude task trials than on parity task trials (4.5% vs. 6.6%), on task repetition trials than on task alternation trials (4.6% vs. 6.5%), and on congruent trials than on incongruent trials (2.1% vs. 9.0%).

A two-way interaction involving congruent/incongruent ratio and task, $F(1,23) = 15.2$, $p < .01$, $MSE = .00433$, indicated that response accuracy in the two tasks differed more strongly when the parity task involved predominantly congruent digits. Congruency effects were, again, larger on parity task trials than on magnitude task trials, $F(1,23) = 19.4$, $p < .01$, $MSE = .00805$ (9.7% vs. 4.0%), and on task alternation trials than on task repetition trials, $F(1,23) = 8.6$, $p < .01$, $MSE = .00573$ (10.6% vs. 5.2%). Moreover, there was a three-way interaction, involving Congruency, Task and Stimulus Type, $F(1,23) = 6.8$, $p < .02$, $MSE = .00870$, indicating that in the parity task congruency effects were larger for test digits than for induction digits, whereas in the magnitude task congruency effects were larger for induction digits than for test digits.

Most importantly, a three-way interaction involving Congruent/Incongruent Ratio, Task, and Congruency, $F(1,23) = 24.8$, $p < .01$, $MSE = .00444$, indicated that in the parity task congruency effects were larger when parity task trials were predominantly congruent rather than predominantly incongruent, whereas there was no ratio modulation in the magnitude task. In contrast to the RT analysis, the three-way interaction was not further modulated by Stimulus Type, $F(1,23) < 1$. Planned comparisons, involving test digit trials only, confirmed the ratio modulation of the congruency effect in the parity task, $F(1,23) = 21.0$, $p < .01$, $MSE = .00565$ (unaffected by task sequence, $F(1,23) < 1$), and the absence thereof in the magnitude task, $F(1,23) < 1$.

3.2. Experiment 1B

An ANOVA with repeated measures on the factors Congruent/Incongruent Ratio (in the magnitude task; 75/25, 25/75), Task (parity, magnitude), Task Sequence (repetition, alternation), Stimulus Type (test, induction), and Congruency (congruent, incongruent) on the mean RTs yielded significant main effects of Task Sequence and

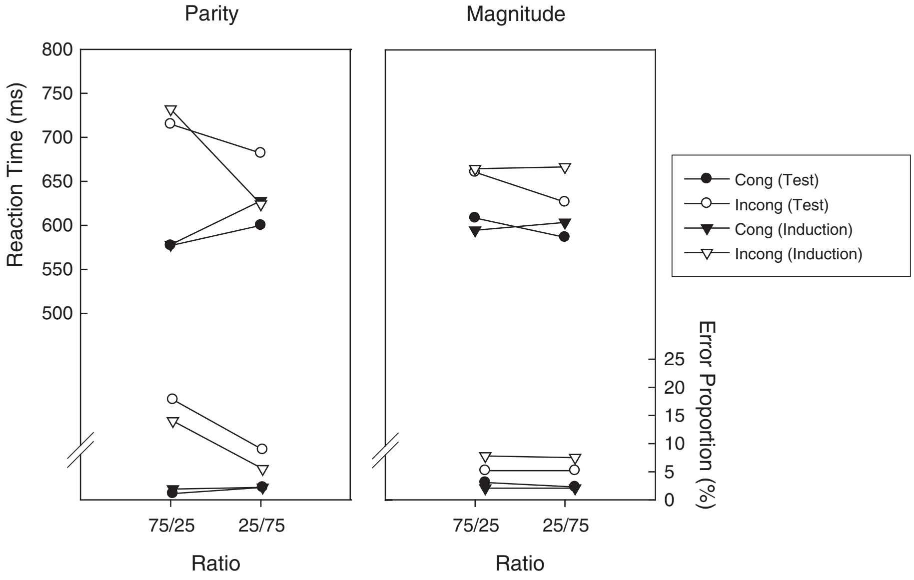

Fig. 1. Mean reaction times and error proportions in Experiment 1A as a function of task, congruency ratio in the parity task, congruency, and stimulus type (test, induction).

Congruency, $F(1,23) = 43.5$, $p < .01$, $MSE = 28294.6$, and $F(1,23) = 51.4$, $p < .01$, $MSE = 30953.5$, respectively, because task repetition trials were responded to faster than task alternation trials (600 ms vs. 680 ms), and congruent trials were responded to faster than incongruent trials (595 ms vs. 686 ms).

Congruency effects were larger on task alternation than on task repetition trials, $F(1,23) = 17.6$, $p < .01$, $MSE = 3586.8$ (109 ms vs. 73 ms), and larger for induction digits than for test digits, $F(1,23) = 5.8$, $p < .03$, $MSE = 7475.2$ (107 ms vs. 76 ms).

As in Experiment 1A, the congruency effect of the two tasks was differentially affected by the congruent/incongruent ratio, yielding a significant three-way interaction, $F(1,23) = 11.8$, $p < .01$, $MSE = 5091.3$. Whereas in the magnitude task the congruency effect was lower under conditions of a higher proportion of incongruent trials, the congruency effect in the parity task was hardly affected. As can be seen in Fig. 2, the ratio modulation in the magnitude task was stronger with induction digits than with test digits, yielding a four-way interaction with stimulus type, $F(1,23) = 5.1$, $p < .04$, $MSE = 4061.4$. Planned comparisons involving only test digit trials showed no significant ratio modulation of the congruency effect, neither in the magnitude task nor in the parity task, $F(1,23) = 1.5$, $p = .23$, $MSE = 8946.3$, and $F(1,23) < 1$, respectively. Of minor importance for our purpose, Stimulus Type entered into two-way interactions with Congruent/Incongruent Ratio, $F(1,23) = 5.9$, $p < .03$, $MSE = 5226.0$, and with Task, $F(1,23) = 8.1$, $p < .01$, $MSE = 9510.8$, as well as into a three-way interaction involving both these factors, $F(1,23) = 13.0$, $p < .01$, $MSE = 3436.5$ (see Fig. 2). There was also a three-way interaction involving Stimulus Type, Task, and Task Sequence, $F(1,23) = 5.7$, $p < .03$, $MSE = 3228.2$, indicating that in the parity task induction digits were responded to more slowly than test digits (somewhat more so on task alternation than on task repetition trials), whereas in the magnitude task responses to induction digits were made slightly faster on task repetition trials and substantially faster on task alternation trials than responses to test digits.

An analogous ANOVA on the mean error proportions yielded significant main effects of Task Sequence and Congruency, $F(1,23) = 27.2$, $p < .01$, $MSE = .00493$, and $F(1,23) = 49.5$, $p < .01$, $MSE = .05065$, respectively, reflecting that the error proportion was lower on task repetition trials than on task alternation trials (8.2% vs. 10.8%), and on congruent trials than on incongruent trials (3.8% vs. 15.2%). Task switch costs were larger for the parity task than for the magnitude task (4.4% vs. 0.9%), $F(1,23) = 8.1$, $p < .01$, $MSE = .00692$. The congruency effect was once more larger on task alternation trials than on task repetition trials (12.8% vs. 10.0%), $F(1,23) = 7.9$, $p < .01$, $MSE = .00501$, and entered into a three-way interaction with Task and Stimulus Type, $F(1,23) = 6.9$, $p < .02$, $MSE = .01157$, indicating that in the parity task congruency effects were larger for induction digits than for test digits, whereas in the magnitude task congruency effects were larger for test digits than for induction digits.

Most importantly, a three-way interaction involving Congruent/Incongruent Ratio, Task, and Congruency, $F(1,23) = 32.9$, $p < .01$, $MSE = .00495$, indicated that in the magnitude task congruency effects were larger when magnitude task trials were predominantly congruent, whereas there was no corresponding ratio modulation in the parity task (see Fig. 2). Deviating from the RT analysis, the three-way interaction was not further modulated by Stimulus Type, $F(1,23) = 2.1$, $p = .16$, $MSE = .00593$. Planned comparisons, involving test digit trials only, confirmed a ratio modulation of the congruency effect in the magnitude task, $F(1,23) = 8.7$, $p < .01$, $MSE = .01049$ (which was unaffected by task sequence, $F(1,23) < 1$), and the absence thereof in the parity task, $F(1,23) < 1$. Of minor importance for our purpose, Stimulus Type entered into two-way interactions with Congruent/Incongruent Ratio, $F(1,23) = 12.3$, $p < .01$, $MSE = .00164$, and with Task, $F(1,23) = 6.2$, $p < .03$, $MSE = .01682$, as well as into a three-way interaction involving both these factors, $F(1,23) = 15.5$, $p < .01$, $MSE = .00322$ (see Fig. 2.) Finally, there was a five-way interaction involving all factors, $F(1,23) = 4.5$, $p < .05$, $MSE = .00391$. The easiest way to describe this seems to be that in the magnitude task, congruency effects were always reduced by a congruent/incongruent ratio of 25/75 (regardless of task sequence and stimulus type), whereas in the parity task this was only the case for task alternation trials involving test digits and all other combinations of task sequence and stimulus type were associated with a larger congruency effect when the majority of trials was incongruent as compared to congruent.

3.3. Combined analysis

Given that the RT analysis of Experiment 1B only descriptively but not significantly revealed a ratio modulation on congruency effects in test trials, we re-conducted our analyses of data from trials involving a test digit on the combined data sets of both experiments. Regarding RTs, an ANOVA with repeated measures on the factors Congruent/Incongruent Ratio (in the manipulated task; 75/25, 25/75), Task (manipulated, non-manipulated), Task Sequence (repetition, alternation), and Congruency (congruent, incongruent), and the between-subjects

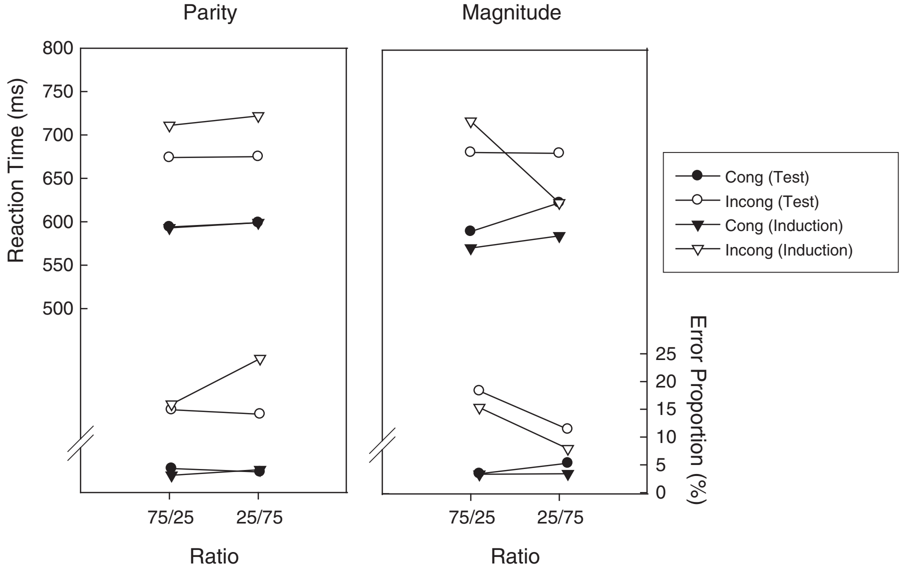

Fig. 2. Mean reaction times and error proportions in Experiment 1B as a function of task, congruency ratio in the magnitude task, congruency, and stimulus type (test, induction).

factor Experiment, confirmed that the ratio manipulation had a differential effect on the congruency effect in the task to which it was applied than in the other task, $F(1,46) = 3.7$, $p = .06$, $MSE = 4585.8$. Planned comparisons showed a significant ratio modulation of the congruency effect in the manipulated task, and the absence thereof in the other task, $F(1,46) = 5.9$, $p < .02$, $MSE = 8380.0$, and $F(1,46) < 1$, respectively. There was no further modulation by Experiment, Task Sequence, or both these factors (all Fs < 1).

The three-way interaction involving Congruent/Incongruent Ratio, Task, and Congruency was replicated in the corresponding error analysis, $F(1,46) = 20.2$, $p < .01$, $MSE = .00546$. Contrasting with the RT analysis, it was further modulated by Task Sequence, $F(1,46) = 3.6$, $p = .06$, $MSE = .00381$, and by Task Sequence and Experiment, thus yielding a five-way interaction, $F(1,46) = 3.9$, $p = .05$, $MSE = .00381$.This was because regarding the manipulated task, a ratio modulation of the congruency effect (i.e., a reduced congruency effect when the majority of trials was incongruent) occurred irrespective of the task sequence in both experiments, whereas regarding the non-manipulated task, the congruency effect was reduced when the majority of trials was incongruent on task alternation trials but enhanced on task repetition trials of Experiment 1B, and unaffected by the ratio of congruent and incongruent trials on both task repetition and task alternation trials of Experiment 1A.

To check for trial-to-trial adjustment effects, we conducted an additional analysis on the combined data sets of both experiments, including the congruency level of the directly preceding trial. (To obtain a reasonable amount of data per cell of the design, we averaged across congruent/incongruent ratios.) More precisely, RT and error data from test digit trials were subjected to ANOVAs with repeated measures on the factors Task (manipulated, non-manipulated), Task Sequence (repetition, alternation), Congruency on Current Trial (congruent, incongruent), and Congruency on Preceding Trial (congruent, incongruent), and the between-subjects factor Experiment. The same criteria for data exclusion were applied as in the preceding analyses. In particular, we excluded data from trials associated with repetition of the stimulus digit. The mean RTs and error proportions of the relevant conditions are displayed in Table 2. The RT analysis yielded a marginally significant three-way interaction of Task Sequence, Congruency on Current Trial, and Congruency on Preceding Trial, $F(1,46) = 3.0$, $p = .09$, $MSE = 5064.7$, which was not modulated by Experiment, Task, or the combination of these factors (all Fs < 1). Planned comparisons showed a reduction of the congruency effect following an incongruent trial when the task repeated but not when the task switched, $F(1,46) = 6.0$, $p < .02$, $MSE = 5026.8$, and $F(1,46) < 1$, respectively. In the corresponding error analysis, the three-way interaction of Task Sequence, Congruency on Current Trial, and Congruency on Preceding Trial, reached significance, $F(1,46) = 9.2$, $p < .01$, $MSE = .00375$. Again, there was no further modulation by Experiment, Task, or the combination of these factors (all Fs < 1). Planned comparisons replicated the RT results by showing a reduction of the congruency effect following an incongruent trial when the task repeated but not when the task switched, $F(1,46) = 39.2$, $p < .01$, $MSE = .00338$, and $F(1,46) = 2.2$, $p = .14$, $MSE = .00455$.

Table 2
Mean RTs and error percentages (in parentheses) of trials with test digits in Experiment 1A and Experiment 1B as a function of task sequence, congruency on the current trial, and congruency on the previous trial.

	Experiment 1A		Experiment 1B	
	Task Rep	Task Alt	Task Rep	Task Alt
Previous cong				
Current Cong	547 (2.0)	630 (1.6)	553 (2.1)	633 (3.3)
Current Incong	632 (9.2)	723 (9.8)	634 (16.2)	722 (17.4)
Congruency Effect	85 (7.2)	93 (8.2)	81 (14.1)	89 (14.1)
Previous Incong				
Current Cong	569 (2.3)	632 (2.8)	575 (4.6)	643 (5.9)
Current Incong	614 (4.8)	720 (12.1)	623 (8.5)	736 (14.9)
Congruency Effect	45 (2.5)	88 (9.3)	48 (3.9)	93 (9.0)

Note. Rep = repetition, Alt = alternation, Cong = congruent, Incong = incongruent.

4. Discussion

The primary purpose of the experiments of the current study was to examine evidence for conflict-frequency-dependent attentional adjustment that takes place at a post-perceptual processing stage. To this end, participants frequently switched between two perceptually identical semantic classification tasks, one of which was associated with a manipulation of the ratio of congruent to incongruent trials. To deconfound conflict adjustment from (task-specific) S–R contingency, the ratio manipulation was implemented by presenting, in different parts of the experimental session, a subset of congruent or incongruent stimuli with increased frequency (i.e., the induction digits), whereas conflict adjustment was inferred from performance involving the other subset of the stimuli (i.e., the test digits). Regarding the congruency ratio manipulation, we found a reduced congruency effect under conditions of higher conflict frequency not only for the induction digits but also, albeit smaller, for the test digits, and this modulation was confined to the task to which the manipulation was applied.

Regarding the induction digits, the confound of congruent/incongruent ratio and stimulus-specific frequency precludes a decision about whether the modulation reflects stimulus-specific control (i.e., adoption of a more or of a less selective attentional set based on stimulus identity) or (non-attentional) S–R-based practice or expectancy. An interesting aspect of our data, in this connection, refers to the particularly high error rate for incongruent induction digits presented in the non-manipulated task under conditions of a low congruent/incongruent ratio in Experiment 1B (see Fig. 2). Such reversal of the congruency ratio effect would be expected on the assumption that, for incongruent stimuli, practice-based strengthening of S–R associations in one of the tasks resulted in corresponding interference in the other task, in which a different response is required. Although it seems less likely that a similar interference effect is brought about by stimulus expectation, the fact that a reversed congruency ratio modulation in the non-manipulated task was found only in Experiment 1B and only in the error analysis, necessitates to be cautious in drawing conclusions from this result.

Contrasting with the induction stimuli, the results obtained in test digit trials provide unequivocal support for the notion of stimulus-unspecific, non-perceptual attentional adjustment. (Although the congruency ratio modulation in the manipulated task was not significant in the RT analysis of Experiment 1B, significance was obtained in the error analysis. In addition, even in the RT data no difference was found between the experiments.) Additional analyses replicated the previously found task-specificity of trial-to-trial conflict adjustment, that is, the selective reduction of the congruency effect on task repetition trials. Because we excluded all data from trials associated with a repetition of the digit of the preceding trial from our analyses, this finding cannot be attributed to particularly facilitated processing on trials which were identical to the preceding trial. Given that a global increase of the proportion of trials of a given congruency level is associated with a corresponding increase regarding direct predecessor trials, the occurrence of a trial-to-trial modulation makes it conceivable that the ratio modulation found for the manipulated task can be completely accounted for in terms of transient trial-to-trial adjustment. Although it was not feasible to include both congruency ratio and sequence in a single analysis—owed to the highly frequent presentation of induction digits which did not leave a sufficient number test digit trial data per condition—, the fact that the trial-to-trial modulation was confined to task repetition trials (with the exception of the error rates analysis of Experiment 1B, see Table 2) whereas the ratio modulation in the manipulated task did not interact with task sequence argues against this notion.

Although the independence of the congruency ratio modulation from execution of the same task on the preceding trial is consistent with the notion of sustained (task-specific) top-down biasing of attention, trial-by-trial retrieval and implementation of the attentional set is also conceivable, for instance, as part of task-set reconfiguration processes triggered by the task cue. Interestingly, findings from previous studies that investigated context-specific congruency ratio modulations, differ regarding the role of context sequence. Whereas some studies found no interaction with the sequence of a contextual feature associated with a high vs. with a low congruent/incongruent ratio (e.g., Crump et al., 2006), a recent study of King et al. (2012) did so. In this study, a modified Eriksen flanker task was used with target and flanker stimuli occurring, in each trial, at one of two possible locations, associated with differential congruent/incongruent ratios. Results revealed a reduced congruency effect in the context (i.e., the location) associated with high conflict frequency, yet only in trials in which the location was repeated from the preceding trial, suggesting that the context-specific attentional set was implemented during processing of the context-switch trial. A crucial factor regarding the time of implementation of a context-specific attentional set might be constituted by the availability of context-disambiguating information. The comparably long cue-target interval used in the current study might have favored set implementation in advance of task processing in both task repetition and task switch trials.

Taken together with the evidence for conflict-induced perceptual selection (Wendt et al., 2012), the findings of the current study corroborate the idea of multiple mechanisms of conflict adjustment that depend on the particular task and context conditions. At least two different kinds of non-perceptual adjustment, redistributed processing weights given to task-relevant and task-irrelevant conceptual categories (analogous to attentional adjustment assumed to occur regarding perceptual features, e.g., Botvinick et al., 2001) and modified conflict resolution efficiency, appear to be plausible options. The lacking impact of the congruent/incongruent ratio on the congruency effect in the non-manipulated task and of the preceding congruency level on the congruency effect on a task switch trial may be informative here. Any shifting of attentional weights towards the currently relevant S–R mapping might not only reduce the congruency effect evoked by the currently irrelevant task-set but also enhance the congruency effect exerted by the currently relevant task-set on performance in the currently irrelevant task at a later time (i.e., after a task switch). Consistent with this reasoning, connectionist modeling applied to tasks in which target and distractor information is presented via different perceptual stimulus features, demonstrated a larger congruency effect after incongruent than after congruent predecessor trials when the task switched (Verguts & Notebaert, 2008). This pattern of task switch performance apparently occurred (although statistical significance was not reported) in a study of Brown, Reynolds, and Braver (2007, see also Notebaert & Verguts, 2008), in which participants switched between a number and a letter classification task and conflict was manipulated by presenting a character of the currently irrelevant task at the side of the target character. Judging from Fig. 4B of that study, the congruency effect on task switch trials was larger after an incongruent than after a congruent predecessor trial.

The fact that we did not observe such a modulation of the congruency effect might indicate that the control settings responsible for the conflict adjustment effects in the task context we used operate in a strictly task-specific manner. On the other hand, it must be considered that enhanced strength of the competitor task's S–R mapping may be masked by an additional task-unspecific improvement in conflict resolution efficiency, which would work in the opposite direction (i.e., minimizing the influence of the competitor task's S–R assignment). Given that digits and letters, which were used as stimuli in the study of Brown, Reynolds, and Braver (2007), differ regarding their constituent perceptual features, the discrepancy between the pattern of task switch performance in that study and the results of the sequential analyses of the current study and the study of Kiesel et al. (2006) may point to differences in conflict resolution and adjustment based on perceptual and non-perceptual selection. Further research comparing conflict-related performance in task switching conditions for combinations of tasks afforded by the same vs. by different perceptual features is needed to clarify these issues.

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