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No evidence for the reduction of task competition and attentional adjustment during task-switching practice

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ABSTRACT

Performance in task switching experiments is worse when the current stimulus is associated with different responses in the two tasks (i.e., incongruent condition) than when it is associated with the same response (i.e., congruent condition). This congruency effect reflects some sort of application of the irrelevant task's stimulus-response translation rules. Manipulating the recency and the proportion of congruent and incongruent trials results in a modulation of the congruency effect (i.e., Congruency Sequence Effect, CSE, and Proportion Congruency Effect, PCE, respectively), suggesting attentional adjustment of processing weights. Here, we investigated the impact of task switching practice on the congruency effect and the modulation thereof by (a) reanalyzing the data of a task switching experiment involving six consecutive sessions and (b) conducting a novel four-session experiment in which the proportions of congruent and incongruent trials were manipulated. Although practice appeared to reduce the reaction times overall and the task switch costs (i.e., slower reaction times after task switches than after task repetitions) to an asymptotic level, the congruency effect as well as its modulations remained remarkably constant. These findings thus do not provide evidence that conflict effects between tasks and attentional adjustment are affected by task switching practice.

1. Introduction

Conflict paradigms have yielded ample evidence for cognitive processing of stimulus aspects which are irrelevant to a current task, i.e. aspects which contain information not necessary for the currently correct task performance. Prominent examples of this processing of irrelevant information can be seen in relative performance impairments 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 Jr, 1969), is associated with an incorrect response in comparison to conditions without features of incorrect response information. For instance, when participants have to respond to the ink color of Stroop color words, performance is impaired under incongruent conditions (i.e., ink and word meaning do not match such as in RED) in comparison to congruent conditions (i.e., ink and word meaning match such as in BLACK) generally resulting in a congruency effect in form of the prominent Stroop effect in this task (i.e., slower responses and/or high error rates in incongruent than in congruent conditions). Such result patterns suggest distractor-related response activation that interferes with responding to the target stimulus feature. Here, we investigated the impact of practice on the congruency effect and the modulation thereof. We do so by using task switching contexts presenting two different tasks, in contrast to conflict paradigms that present only one task.

1.1. Attentional adjustments in conflict paradigms

It has been shown that the size of congruency effects depends, among others, on the *recency* and *frequency* of congruent and incongruent trials in conflict paradigms. More precisely, when focusing on recency of congruent and incongruent trials, congruency effects are reduced in a current trial after experiencing an incongruent stimulus in a previous trial in comparison to these effects after a congruent stimulus in a previous trial (the Congruency Sequence Effect, CSE; e.g., Gratton, Coles, & Donchin, 1992; Mayr & Awh, 2009). Further, interference decreases when the block-wise frequency of incongruent trials (i.e., trials with stimuli involving a distractor feature associated with an incorrect response) is increased and the frequency of congruent trials is decreased in the Stroop task (e.g., Mayr & Awh, 2009), the Eriksen flanker task (e.g., Gratton et al., 1992; Wendt & Luna-Rodriguez, 2009), and the Simon task (e.g., Hommel, 1994; Stürmer, Leuthold, Soetens,

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Schröter, & Sommer, 2002); this modulation of the congruency effect is referred to as the Proportion Congruency Effect (PCE; for an overview, see Bugg & Crump, 2012). These modulations of the congruency effect by recency (i.e., the CSE) and frequency (i.e., the PCE) have been ascribed to *attentional adjustment*. This adjustment refers to variations of the degree of attentional dominance of processing target information (e.g., the ink in the Stroop task) over processing distractor information (e.g., the word meaning in the Stroop task). These variations are a consequence of conflict experience and strategic attentional control (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Kerns et al., 2004) or, more generally, are a function of distractor utility and expectations built-up by participants in the context of conflict experiments (Brown, Reynolds, & Braver, 2007; Gratton et al., 1992; Wendt, Luna-Rodriguez, & Jacobsen, 2014).

In paradigms such as the Stroop task, the Eriksen flanker task and the Simon task, 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. Some previous studies, however, observed a CSE (Kiesel, Kunde, & Hoffmann, 2006; Wendt, Luna-Rodriguez, Kiesel, & Jacobsen, 2013) and a PCE (Schneider, 2015; Wendt et al., 2013) when participants switched between semantic classification tasks even in the absence of perceptually distinct target and distractor stimulus features. For instance, Wendt et al. (2013) asked participants to alternate between classifying a stimulus digit as odd or even (parity task) on some trials and as smaller or larger than 5 on other trials (magnitude task), while using the same set of responses for both tasks (e.g., Sudevan & Taylor, 1987). 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 (i.e., congruent; e.g., 1 or 6 for the above task assignments), whereas other stimuli are associated with different responses regarding the two tasks (i.e., incongruent; e.g., 2 or 7 for the above task assignments). Similar to the congruency effects observed in the conflict tasks mentioned above, responses in incongruent trials are typically slower and more error-prone than responses in congruent trials, reflecting some form of application of the stimulus-response (S-R) mapping rules of the currently irrelevant task.

When investigating attentional adjustment, care must be taken to experimentally control possible confounds (see Schmidt, 2013, for an overview). For example, inclusion of trials associated with identical stimulus repetitions may yield a CSE as these repetitions likely constitute a special case of facilitated processing (e.g., Pashler & Baylis, 1991) and only occur when the congruency level repeats from the preceding trial (e.g., a congruent trial before a congruent trial) while these repetitions do not occur when the congruency levels change (e.g., a congruent trial before an incongruent trial). Concerning the PCE, manipulations of the proportion of congruent and incongruent trials must be deconfounded from the presentation frequency of individual stimuli to avoid processing advantages, brought about by associative S-R learning. For illustration, consider a distractor, such as the word RED in a Stroop task. Lacking control of stimulus-specific presentation frequency this distractor will occur more frequently in red color—and thus together with the "red" response—if the proportion of congruent trials is higher. Likewise, it will occur more frequently in a different color—and thus together with a different response—when the proportion of incongruent trials is higher (e.g., Wendt & Luna-Rodriguez, 2009). Assuming associative distractor-response learning, these contingencies might facilitate congruent trials when the proportion of congruent trials is high and incongruent trials when the proportion of incongruent trials is high. As a result of these potential confounds, recent studies investigating attentional adjustments in the context of the CSE excluded all trials with stimulus repetitions from the presentation procedure or the analysis (e.g., Kim & Cho, 2014; Schmidt & Weissman, 2014; Weissman, Jiang, & Egner, 2014; Wendt et al., 2013). Similarly, recent studies investigating the PCE presented a subset of stimuli for which distractror-response contingencies were controlled (e.g., Abrahamse, Duthoo, Notebaert, & Risko, 2013; Wendt et al., 2013). We applied these control procedures in the experiment of the current study.

1.2. Investigating attentional adjustment with practice

There exists a number of studies focusing on practice effects in experimental paradigms tapping on conflict processing. For example, color Stroop task practice results in an increased practice-related reduction of reaction times (RTs) in incongruent trials versus RTs in congruent trial and thus a reduction of the color Stroop effect (e.g., Davidson, Zacks, & Williams, 2003; Dotson, Sozda, Marsiske, & Perlstein, 2013; Dulaney & Rogers, 1994; Edwards, Brice, Craig, & Penri-Jones, 1996; Ellis, Woodley-Zanthos, Dulaney, & Palmer, 1989; Flowers & Stoup, 1977; Macleod, 1998; MacLeod & Dunbar, 1988; Reisberg, Baron, & Kemler, 1980; Roe, Wilsoncroft, & Griffiths, 1980; Rogers & Fisk, 1991; Wilkinson & Yang, 2012). A comparable pattern of results (i.e., increased practice-related reduction of incongruent trial RTs than on congruent trial RTs) was also evident in a number version of the Stroop task (Bush et al., 1998). This is consistent with the assumption that practice facilitates interference processing by improving the suppression of response activation that interferes with responding to the target stimulus feature, besides the build-up of a color-response association.

To the best of our knowledge, there exists, however, only a single study investigating the effects of practice on attentional adjustment in the context of conflict paradigms. In detail, this study applied the Stroop task and investigated the development of the CSE and the PCE over the course of several blocks within one experimental session (Mayr & Awh, 2009). Using a six-choice version of the Stroop task and eliminating data from trials associated with stimulus repetitions from the analyses, Mayr and Awh (2009, Experiment 2) obtained a CSE only in the first two blocks of the experimental session. However, the CSE and thus the adjustment pattern was not present in the remaining eight blocks. This result is compatible with the idea that attentional adjustment might be a conscious, explicit process that occurs during early, deliberate phases of practice with a new situation. However, this adjustment is abandoned as a result of experience. By contrast, manipulating the proportions of congruent and incongruent stimuli in ratios of 30/70, 50/50, and 70/30, in three different groups of participants, resulted in a PCE throughout the experimental session. As the presentation frequency of individual stimuli was not controlled, however, non-attentional accounts of the PCE, such as associative distractor-response priming (see above), cannot be dismissed.

The findings of Mayr and Awh (2009) are thus consistent with the notion that a strategy of dynamic adjustment might be abandoned once a state of processing associated with a satisfactorily low level of interference is reached, which can be "kept in check" by adoption of a permanent attentional setting. In conflict tasks involving perceptually distinct target and distractor features, such as the Stroop task, this might be possible after some initial practice by means of sustained suppression of distractor processing. This interpretation is plausible since processing distractor information is constantly irrelevant.

However, such control measures may not be feasible in a task switching context, in which conflict is evoked by the S-R translation rules of the (temporarily) irrelevant task. This irrelevant task cannot be suppressed in a sustained manner but is regularly "freshed up" when constantly switching between tasks and by the execution of the task in trials in which it is relevant. Support for this reasoning can be seen in demonstrations of remarkably stable congruency effects during practice, observed in some task switching studies (Cepeda, Kramer, & Gonzalez de Sather, 2001; Meiran, Chorev, & Sapir, 2000; Wendt, Klein, & Strobach, 2017). In the task switching practice study of Wendt et al. (2017) the authors even failed to observe a reduction of the congruency effect when they compared performance in the first and the sixth session. This stability of the congruency effects between tasks may relate to suggestions of an exogenous component of task reconfiguration, that is, a control process assumed to be triggered by the stimulus of a task switch trial which needs to be completed before the stimulus can be processed according to the demands of the task. Specifically, Rubinstein, Meyer, and Evans (2001) put forward a task switching model in which task switch trials involve two distinct executive processes, one of which (i.e., goal shifting) can be completed during the preparation interval, while the other one (i.e. activation of the task's stimulus-response translation rule) does not occur before encoding of the task stimulus.[1] Relating this account to the fact that task switching practice tends to reduce the switch cost mainly in trials associated with short preparation time — suggesting a practice gain for task preparation processes (e.g., Wendt et al., 2017) — a straightforward explanation of the lack of a reduction of the congruency effect after practice is to assume that practice hardly affects rule activation time, leaving sufficient room for interference exerted by processing the task stimulus according to the still activated S-R rules of the irrelevant task.

Attentional adjustment in task switching pertains to the frequently discussed question of context-specificity of attentional adjustment, that is, to the question whether adjustment evoked in a particular context transfers to another, unrelated context (e.g., Funes, Lupiáñez, & Humphreys, 2010; Torres-Quesada, Funes, & Lupiáñez, 2013; Wendt et al., 2013). Of importance for our research question, previous task switching studies suggest task-specific adjustment as indicated by selective occurrence of the CSE in task repetition trials, but not in task switch trials (e.g., Kiesel et al., 2006; Schneider, 2015; Weissman, Colter, Grant, & Bissett, 2017; Wendt et al., 2013). Moreover, Wendt et al. (2013), manipulating the proportion of congruent and incongruent trials for only one of two tasks while keeping them constant for the other task, found the PCE to be confined to the task to which the manipulation was applied.

In the current study, we set out to investigate the effect of practice on attentional adjustments in the context of CSE and PCE under conditions of frequent reactivation of the interfering processes. That is, we investigated in the task switching context. Investigating practice effects on the CSE and the PCE in a task switching context allowed us to examine not only possible disappearance of attentional adjustment during extended practice but also possible change concerning the task-specificity of the adjustment effects.

2. Experiment 1

Experiment 1 includes a reanalysis of the data of the Wendt et al. (2017) study on task switching practice on digit classification tasks (i.e., parity and magnitude tasks) across six consecutive experimental sessions. As mentioned above, this study demonstrated remarkable stability of the congruency effect across practice sessions, despite a substantial reduction of the overall RT level and the switch costs (see also Berryhill & Hughes, 2009; Strobach, Liepelt, Schubert, & Kiesel, 2012). Congruency of the predecessor trial, as needed to assess the CSE, was not included as a factor in the analysis of the original article, however. Although the CSE in task switching studies has repeatedly found to be confined to task repetition trials (e.g., Brown et al., 2007; Kiesel et al., 2006; Schneider, 2015; Wendt et al., 2013), task switch trials may not be unaffected by the congruency level of the predecessor trial. Specifically, task switch costs tend to be increased after an incongruent compared to after a congruent predecessor trial (e.g., Kiesel et al., 2006; Monsell, Sumner, & Waters, 2003; Wendt et al., 2013). This increase in switch costs presumably reflects a carry-over of enhanced inhibition of the previous competitor task-set (which is the currently relevant task-set) or of extra-activation of the previously relevant task-set (which is the current competitor), to meet particularly high demands of controlling task-set competition in incongruent trials.

Re-analyzing the data, including congruency of the preceding trial allowed us to investigate practice-related changes of attentional adjustment (i.e., the CSE) and its task-specificity (i.e., the CSE in task repetition trials versus in task switch trials). The former would be reflected by an interaction of a session factor with congruency in the previous trials and congruency in the current trials while the latter would be reflected by an additional modulation of task switching costs by this interaction (i.e., the interaction of a session factor, congruency in the current trial and congruency in the previous trials differs in trials with task repetitions and task switches). Further, we focus on a practice-related carry-over of inhibition or competitor priming of task set (i.e., larger task switch costs after incongruent than after congruent trials) reflected by an interaction of a session factor and the congruency in the previous trial and the task switch costs in the current trials. The stability of the congruency effect across six sessions as demonstrated by Wendt et al. (2017) would be consistent with a lacking interaction of a session factor and the congruency in the current trials. For reasons unrelated to the aims of the current study, the first and the last experimental session of the Experiment of Wendt et al. involved trials of an Eriksen flanker task in addition to the digit classification tasks. These trials will not be considered in our re-analysis.

2.1. Method

2.1.1. Participants

Twenty students of the Medical School Hamburg (17 female) participated in the experiment in exchange for course credit. They ranged in age from 21 years to 31 years. All participants had normal or corrected to normal vision by self-report.

2.1.2. Apparatus and stimuli

Stimulus presentation and RT measurement were performed with a PC. The digits *1* to *9* except *5* were used as stimuli for the magnitude and the parity task. They were displayed in the center of a 22-inch monitor with a refresh rate of 60 Hz, viewed from a distance of about 60 cm. All digits were presented in white color on a black background. The digits extended 0.6 cm (approximately 0.6°) vertically and from 0.3 to 0.4 cm horizontally (approximately 0.3° – 0.4°). Colored discs with a diameter of 0.6 cm (approximately 0.6°), presented in the center of the screen, were used as task cues. A blue disc indicated the magnitude task, and a red disc indicated the parity task.

On flanker task trials, three arrows, extending in the horizontal dimension, were presented. One of the arrows (i.e., the target) was presented in the center of the screen, whereas the other two arrows (i.e., the flankers) surrounded the central arrow symmetrically in the vertical dimension. All three arrows were horizontally aligned. The two flanker arrows of a trial always pointed into the same direction and either in the same direction as the target arrow (i.e., compatible) or in the opposite direction as the target arrow (i.e., incompatible). A target-flanker ensemble extended 1.3 cm (approximately 1.2°) vertically and 0.7 cm (approximately 0.7°) horizontally.

Responses were given by pressing the Y key (left) and the M key (right) on a standard QWERTZ-keyboard with the index fingers of the left and the right hand, respectively. 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, participants pressed the left key to indicate even and the right key to indicate odd. In the flanker task, participants pressed the left key and the right key to indicate that the target arrow pointed to the left and the right, respectively.

2.1.3. Procedure

There were 6 experimental sessions. One of the participants failed to attend the final session and the data were not included into the final data set. The interval between 2 consecutive sessions ranged from 1 day

[1] We are grateful to an anonymous reviewer for drawing our attention to this point.

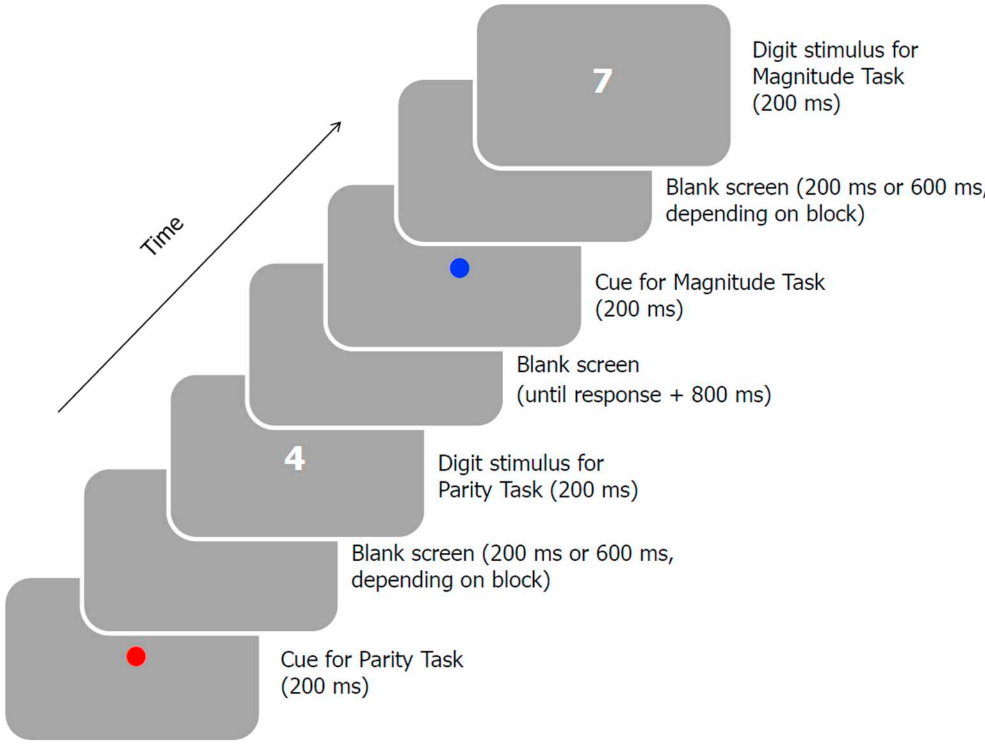

Fig. 1. Schematic of a sequence of a Parity task trial and a Magnitude task trial of the experimental blocks of the practice sessions in Experiment 1.

to 6 days (mean: 2.63 days). The initial and the final session were structurally identical. In these sessions, participants first received a practice block of 16 flanker task trials. Then, a practice block involving 48 trials of the magnitude and parity task was administered. A third practice block included trials of all three tasks (16 trials of the magnitude and parity task, each, and 8 flanker task trials). A fourth practice block was structurally identical to the subsequent experimental blocks. This block was composed of 96 trials (32 trials of each of the three tasks).

On each trial, the task was chosen randomly without replacement and the stimulus was chosen randomly, without replacement, out of the set of possible stimuli of the current task (Fig. 1). Flanker task trials were presented with a cue indicating the magnitude task or the parity task with equal probability. Each task cue, digit, and target-flanker ensemble were displayed for 200 ms. The CTI was set to 800 ms in the practice blocks (with the exception of the first practice block, in which no cues were presented). In the experimental blocks the CTI alternated between 400 and 800 ms from block to block, starting with a 400 ms block. In case of a correct response, the cue of the subsequent trial occurred 800 ms after the response. In case of an incorrect response the message “FALSCHE ANTWORT” (‘*incorrect response*’) was displayed after a delay of 500 ms in white color for 1000 ms. In case no response was given within 5600 ms (in blocks with a short CTI of 400 ms) or 5200 ms (in blocks with a long CTI of 800 ms) the message “ZU LANGSAM” (‘*too slow*’) was displayed in white color for 1000 ms. In both cases, the cue of the subsequent trial occurred 800 ms after the offset of the feedback. Instructions stressed to respond as quickly as possible while attempting to achieve a high level of accuracy. Nine experimental blocks were administered. Between blocks, the participants were allowed to rest for some time.

The practice sessions (Sessions 2–5) were identical to the initial and final sessions with the following exceptions. In these sessions the participants were administered only the magnitude task and the parity task. On each trial, each of the two tasks occurred with equal probability and the target digit was chosen randomly from the set of possible digits. Two practice blocks involved 32 trials each (CTI = 800 ms). Then, 10 blocks of 64 trials each were administered. The CTI alternated between 400 and 800 ms from block to block, starting with 800 ms.

2.2. Results

RT data and proportion of error responses of the experimental blocks of the six sessions were subjected to statistical analyses. For these analyses in Sessions 2 to 5, data from the practice blocks, from the first trial of each block, from trials with stimulus repetitions (i.e., the same digit stimulus as the preceding and current trial), and from trials following a trial associated with an incorrect response (i.e., post-errors) were discarded from all analyses. The RT analyses were based only on data from trials with correct responses. Data analyses in the digit tasks were identical for the initial and the final sessions with the exception that trials following a flanker task trial were also discarded. Because of this way of analyzing the data, we did not investigate the flanker task because it did not include task switches or repetitions. As a consequence, Analyses of Variance (ANOVAs) with repeated measures on the factors Session (1 to 6), Task Sequence (repetition vs. switch), CTI (400 ms vs. 800 ms), Congruency Current Trial (congruent vs. incongruent), and Congruency Previous Trial (congruent vs. incongruent) were conducted on the mean RTs and proportions of error responses.

2.2.1. RTs

Fig. 2 displays the RT results obtained in trials associated with the digit tasks in all sessions. There were significant main effects of Session, $F(5, 90) = 16.41$, $p < .001$, $\eta_p^2 = 0.48$, Task Sequence, $F(1, 18) = 50.48$, $p < .001$, $\eta_p^2 = 0.73$, CTI, $F(1, 18) = 7.77$, $p = .012$, $\eta_p^2 = 0.30$, Congruency Current Trial, $F(1, 18) = 127.99$, $p < .001$, $\eta_p^2 = 0.87$, Congruency Previous Trial, $F(1, 18) = 20.637$, $p < .001$, $\eta_p^2 = 0.53$. RTs were reduced during practice from Session 1 to Session 6. During task repetitions, RTs were reduced compared to task switches and RTs were reduced after long CTIs in comparison to short CTIs. RTs were also reduced under congruent in comparison to RTs under incongruent conditions in current trials and they were reduced under congruent in comparison to RTs under incongruent conditions in

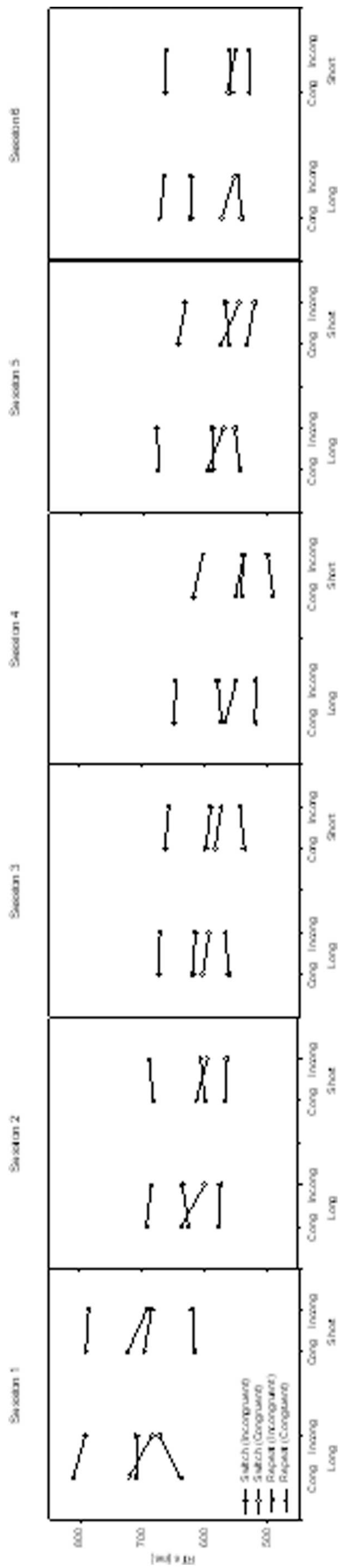

Fig. 2. Illustration of reaction times (RTs) in ms as a function of Session (Session 1–6), Task Sequence (Switch versus Repetition), Cue-Target-Interval (short interval versus long interval), Congruency Current Trial (congruent versus incongruent), and Congruency Previous Trial (congruent versus incongruent) in Experiment 1. C = (previously) congruent trial. I = (previously) incongruent trial. S = Short Cue-Target-Interval. L = long Cue-Target-Interval.

previous trials. The interaction of Session and Task Sequence, $F(5, 90) = 3.90$, $p = .003$, $\eta_p^2 = 0.18$, revealed that switch costs were reduced with practice; generally replicating findings of previous task switching studies (Berryhill & Hughes, 2009; Strobach et al., 2012). The interaction of Task Sequence and CTI, $F(1, 18) = 6.93$, $p = .017$, $\eta_p^2 = 0.28$, demonstrated that switch costs were increased after short CTIs in comparison with switch costs after long CTIs, demonstrating the *Reduction In Switch Cost (RISC) Effect* (Liefooghe, Demanet, & Vandierendonck, 2009). The interaction of Task Sequence and Congruency Current Trial, $F(1, 18) = 14.68$, $p < .001$, $\eta_p^2 = 0.45$, showed decreased switch costs in currently congruent trials in comparison to incongruent trials. The interaction of Task Sequence and Congruency Previous Trial, $F(1, 18) = 14.01$, $p < .001$, $\eta_p^2 = 0.44$, showed decreased switch costs in previously congruent trials in comparison to incongruent trials. This interaction was modulated by a three-way interaction of Task Sequence, Congruency Current Trial, and Congruency Previous Trial, $F(1, 18) = 4.57$, $p = .046$, $\eta_p^2 = 0.20$. This interaction demonstrated the CSE in repetition trials (i.e., Congruency Current Trial and Congruency Previous Trial interacted), $F(1, 18) = 20.04$, $p < .001$, $\eta_p^2 = 0.53$, with a smaller congruency effect after previously incongruent trials than after previously congruent trials. This CSE effect was not evident during switch trials, $F(1, 18) = 0.016$, $p = .90$, and very similar congruency effects were evident after previously incongruent trials and after previously congruent trials, suggesting that conflict adjustment occurs in a task-specific manner.

Importantly in this analysis, the lacking interaction of Session and Congruency Current Trial, $F(5, 90) = 1.76$, $p = .13$, is consistent with Wendt et al.'s (2017) finding of stability of the congruency effect across six sessions. The lacking interaction of Session, Congruency Current Trial, and Congruency Previous Trial, $F(5, 90) < 1$, provided no evidence for the modulations of the attentional adjustments during practice. That is the CSE remained rather stable across sessions. Further, there is no statistical evidence for differences between task repetitions and task switches in this stability of the CSE (or the lack of the CSE) in the combination of Session, Sequence, Congruency Current Trial, and Congruency Previous Trial, $F(5, 90) = 2.26$, $p = .06$. Finally, there is no evidence for a practice-related change of the carry-over of inhibition or competitor priming of task set (i.e., larger task switch costs after incongruent than after congruent trials) since the interaction of Session, Congruency Previous Trial, and Sequence was non-significant, $F(5, 90) < 1$. All remaining main effects and interaction effects were non-significant, $Fs < 2.23$, $ps > .058$.

2.2.2. Errors

The analysis of the proportion of error responses (Table 1) showed main effects for Task Sequence, $F(1, 18) = 18.80$, $p < .001$, $\eta_p^2 = 0.51$, and Congruency Current Trial, $F(1, 18) = 61.69$, $p < .001$, $\eta_p^2 = 0.77$. The proportion of errors was reduced in repetition trials in comparison to switch trials and there were reduced errors in currently congruent trials than in currently incongruent trials. The interaction of both factors, Task Sequence and Congruency Current Trial, was significant, $F(1, 18) = 22.12$, $p < .001$, $\eta_p^2 = 0.55$. Switch costs were significant for currently incongruent trials, but not for currently congruent trials. Also, the interaction of Task Sequence and Congruency Previous Trial was significant, $F(1, 18) = 27.88$, $p < .001$, $\eta_p^2 = 0.61$. Switch costs were increased for previously incongruent trials than for previously congruent trials. The three-way interaction of Task Sequence, CTI, and Congruency Current Trial, was also significant, $F(1, 18) = 5.45$, $p = .031$, $\eta_p^2 = 0.23$. The congruency effect was particularly high for repetition trials and short CTIs. The interaction of Congruency Current Trial and Congruency Previous Trial was significant, $F(1, 18) = 15.88$, $p < .001$, $\eta_p^2 = 0.47$, generally demonstrating the CSE effect: The congruency effect was smaller after incongruent trials than after congruent trials. This interaction was further qualified in an interaction with Task Sequence, $F(1, 18) = 13.88$, $p = .002$, $\eta_p^2 = 0.44$. Equivalent to the RTs, the CSE was evident in

Table 1
Percentage of errors in Experiment 1 including the factors (Session (1 to 6), Task Sequence (Repetition versus Switch), Cue-target interval (CTI; long versus short), Congruency Current Trials (congruent versus incongruent), and Congruency Previous Trials (congruent versus incongruent).

				Session					
Task sequence	CTI	Congruency current trial	Congruency previous trial	1	2	3	4	5	6
Repetition	Long	Congruent	Congruent	1.7	1.6	1.4	2.6	2.3	3.1
			Incongruent	3.4	3.1	2.8	4.3	4.1	2.4
		Incongruent	Congruent	15.0	10.2	11.4	12.4	10.9	15.5
			Incongruent	17.6	11.8	10.8	12.2	12.0	19.5
	Short	Congruent	Congruent	1.7	1.1	1.9	1.9	2.5	1.6
			Incongruent	3.9	2.1	2.4	2.6	2.6	3.1
		Incongruent	Congruent	13.8	13.2	11.9	12.1	12.7	13.5
			Incongruent	17.6	12.5	14.4	16.2	14.1	18.5
Switch	Long	Congruent	Congruent	2.3	0.9	0.9	2.8	2.4	2.9
			Incongruent	3.0	1.5	3.0	2.0	2.7	2.3
		Incongruent	Congruent	10.6	10.8	9.0	10.4	10.6	12.3
			Incongruent	6.7	6.0	7.3	6.3	6.3	9.3
	Short	Congruent	Congruent	2.6	1.7	0.5	2.0	1.7	2.6
			Incongruent	2.7	2.3	1.2	3.1	3.0	1.9
		Incongruent	Congruent	10.6	10.5	9.7	10.2	8.8	13.5
			Incongruent	3.7	5.5	5.8	5.2	7.0	3.9

repetition trials but was not evident during switch trials, suggesting again that attentional adjustment occurs in a task-specific manner.

Important for the present analysis, the factors Session and Congruency Current Trial interacted, $F(5, 90) = 2.76$, $p = .023$, $\eta_p^2 = 0.13$, indicating varying congruency effects over the practice sessions with highest effects in the first and the last session compared to the Sessions 2 to 5. This pattern thus does not show a linear practice-related reduction of these effects and is not arguing against the conclusions from the RTs. Further, the CSE effect was not modulated by practice since the combination of Session, Congruency Current Trial, and Congruency Previous Trial was non-significant, $F(5, 90) < 1$. Inconsistent with the RT analysis however, Session, Congruency Previous Trial, and Sequence interacted, $F(5, 90) = 2.54$, $p = .034$, $\eta_p^2 = 0.13$. However, similar to the interaction of Session and Congruency Current Trials, there was no clear linear trend of differences in switch costs between previously congruent and incongruent trials across practice sessions. All factors and factor combinations were not significant, $Fs < 3.99$, $ps > .06$.

2.2.3. Bayesian analysis

Because our conclusions are based on null hypothesis statistical testing, which only allows rejecting the null but not the alternative hypothesis, we repeated our analysis with a Bayesian approach. We restricted this analysis to the most critical conditions of our experiment, that is, we included only data from task repetition trials (i.e., the trials in which the CSE occurred) of the initial and the final session. The Bayes Factor was computed using the BayesFactor (v0.9.12–4.2, Morey & Rouder, 2018) package in RStudio. For the priors we used the default Cauchy priors (scaling factor $r = 0.707$) with 10.000 iterations. The Bayes Factor was calculated by comparing the model including the three-way interaction of Congruency Current Trial, Congruency Previous Trial, and Session (Congruency Current Trial + Congruency Previous Trial + Congruency Current Trial × Congruency Previous Trial + Session + Congruency Current Trial × Session + Congruency Previous Trial × Session + Congruency Current Trial × Congruency Previous Trial × Session + Subject) with the equivalent model excluding the three-way interaction and only including two-way interaction of Congruency Current Trial with Congruency Previous Trial (Congruency Current Trial + Congruency Previous Trial + Congruency Current Trial × Congruency Previous Trial + Session + Subject). For classification, a Bayes factor between 1 and 3 relates to anecdotal evidence, between 3 and 10 substantial evidence, between 10 and 30 strong evidence, between 30 and 100 very strong evidence, and for over 100 decisive evidence for the tested hypothesis (Jeffreys, 1961).

Concerning RTs, overall comparing the H0 (model including the three-way interaction: Congruency Current Trial × Congruency Previous Trial × Session) with the H1 (model only including the two two-way interaction: Congruency Current Trial × Congruency Previous Trial) yielded a Bayes Factor of $BF_{01} = 0.082$, with an inverse of $BF_{10} = 1/0.082 = 12.20$. This suggests that the data actually provide more support for the alternative Hypothesis (the model not including the three-way interaction), being 12 times more likely to occur under the alternative Hypothesis compared to the null hypothesis (model including the three-way interaction). Concerning error rates, overall comparing the H0 (model including the three-way interaction: Congruency Current Trial × Congruency Previous Trial × Session) with the H1 (model only including the two two-way interaction: Congruency Current Trial × Congruency Previous Trial) yielded a Bayes Factor of $BF_{01} = 0.071$, with an inverse of $BF_{10} = 1/0.071 = 14.08$. This suggests that the data actually provide more support for the alternative Hypothesis (the model not including the three-way interaction), being 14 times more likely to occur under the alternative Hypothesis compared to the null hypothesis (model including the three-way interaction). By adding a Bayesian analysis, we thus gathered stronger evidence that the CSE is independent of practice. The likelihood for a model containing two two-way interactions is 12 times more likely considering the RTs and 14 times more likely considering the error rates than the model containing the three-way interaction involving the factor Session.

2.3. Discussion

The present experiment provided evidence for the fundamental effects of previous task switching practice studies and studies investigating attentional adjustments. First, the task switch costs but not the congruency effect was reduced with practice based on the RT data (e.g., Berryhill & Hughes, 2009; Strobach et al., 2012; Wendt et al., 2017). Further, attentional adjustments were demonstrated in the RT and error data, showing reduced congruency effects after incongruent than after congruent trials. This CSE was however limited to repetition trials and was not evident in switch trials showing its task-specific character. Also, task switch costs were increased after incongruent trials, replicating previous results (analogous to attentional adjustment assumed to occur regarding perceptual features, e.g., Botvinick et al., 2001) Importantly, neither the CSE in task repetition trials nor the lack thereof in task switch trials or the increase of the switch cost after incongruent trials were significantly modulated by practice. These lacking modulations provided no evidence for practice-related changes of attentional adjustments in the present experimental set-up.

Our results thus strikingly contrast with the disappearance of the CSE after initial practice in the study of Mayr and Awh (2009). As there was neither a reduction of the congruency effect as such, suggesting a constantly high degree of conflict between the tasks, our findings are in agreement with our reasoning that abandoning a dynamic (trial-by-trial) adjustment strategy may be prevented by frequent re-activation of the interfering processes.

3. Experiment 2

To investigate executive control of task competition and conflict monitoring in a task-switching context, Wendt et al. (2013) manipulated the proportions of congruent and incongruent trials in one of the two digit classification tasks used in our Experiment 1. Keeping the proportions of congruent and incongruent trials in the other task at 50:50 allowed the authors to assess task-specificity of the PCE (i.e., transfer of the PCE to the non-manipulated task). To deconfound attentional adjustment from (task-specific) S-R contingency, the proportion 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 the adjustment was inferred from performance involving the other subset of the stimuli (i.e., the test digits), which were presented with the same frequency in high and low proportion congruency conditions. Consistent with the notion of task-specific attentional adjustment, Wendt et al. found a PCE not only for the induction digits but also, albeit smaller, for the test digits, which did not generalize to the non-manipulated task.

Experiment 2 extends our investigation of attentional adjustment to potential practice effects on the PCE. Replicating Experiment 1A of Wendt et al. (2013) across four consecutive practice sessions, we assessed whether a reduction of the PCE or transfer of the PCE to the other task would occur. A practice-related modulation would be indicated by an interaction of a session factor, the stimulus congruency as well as the ratio of congruent versus incongruent stimuli. Given the findings of Wendt et al. (2013) this interaction could be more pronounced for induction than for test stimuli.

It is worth noting that Experiment 2 of the study of Mayr and Awh (2009) also involved a manipulation of the proportions of congruent and incongruent Stroop task trials, yielding a PCE which, unlike the CSE, remained substantial during the course of the experimental session. Because in that study the presentation frequency of individual stimuli was not controlled, the PCE might reflect associative S-R learning rather than attentional adjustment, however.

3.1. Methods

3.1.1. Participants

Twenty students of the Helmut Schmidt University / University of the Federal Armed Forces Hamburg (10 female) participated in the experiment in exchange for course credit. They ranged in age from 20 years to 27 years. All participants had normal or corrected to normal vision by self-report.

3.1.2. Apparatus and stimuli

Stimulus presentation and RT measurements were performed with a Windows-compatible 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) was continuously shown on the screen center. This frame acted as cue for the parity task when filled with red color and it acted as a cue for the magnitude task when filled with cyan color.

Responses were given by pressing 1 of 2 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 hand. In the magnitude task, participants pressed the left key to indicate smaller than 5 and the right key to indicate larger than 5. Importantly, the S-R assignment was counterbalanced across participants in the parity task.

3.1.3. 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 of 30 trials, in which the task was chosen randomly on each trial. Finally, ten experimental blocks of 99 trials each were administered. Each 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 below the screen center. The trial was then 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. 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., the extreme digits), or 3, 4, 6, and 7 (i.e., the 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 half 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. Considering the whole experimental sessions, each induction and test digit was thus associated with an expected frequency of 90 and 30 in the parity task, respectively. 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. This procedure of each experimental session was repeated 4 times resulting in 4 practice sessions. These 4 sessions were conducted on separated days.

3.2. Results

Only RT and error data of the experimental blocks were subjected to a ANOVA with repeated measures on the within-subjects factors Session (Session 1 to 4), Congruent/Incongruent Ratio in the parity task (75/25 vs. 25/75), Task (parity vs. magnitude), Task Sequence (repetition vs. switch), Stimulus Type (test vs. induction), and Congruency (congruent vs. incongruent). The first three trials of each block were considered “warm-up” trials and not analyzed. In addition, trial-to-trial digit repetitions, data from trials following an erroneous response as well as the identical stimulus repetitions following an incorrect response, which were not counted as trials, were discarded from the analyses.

3.2.1. RTs

Mean RTs are displayed in Figs. 3, 4, and 5. The RT analysis yielded significant main effects of Session, $F(3, 57) = 37.62$, $p < .001$, $\eta_p^2 = 0.66$, Task, $F(1,19) = 5.86$, $p < .05$, $\eta_p^2 = 0.24$, Task Sequence,

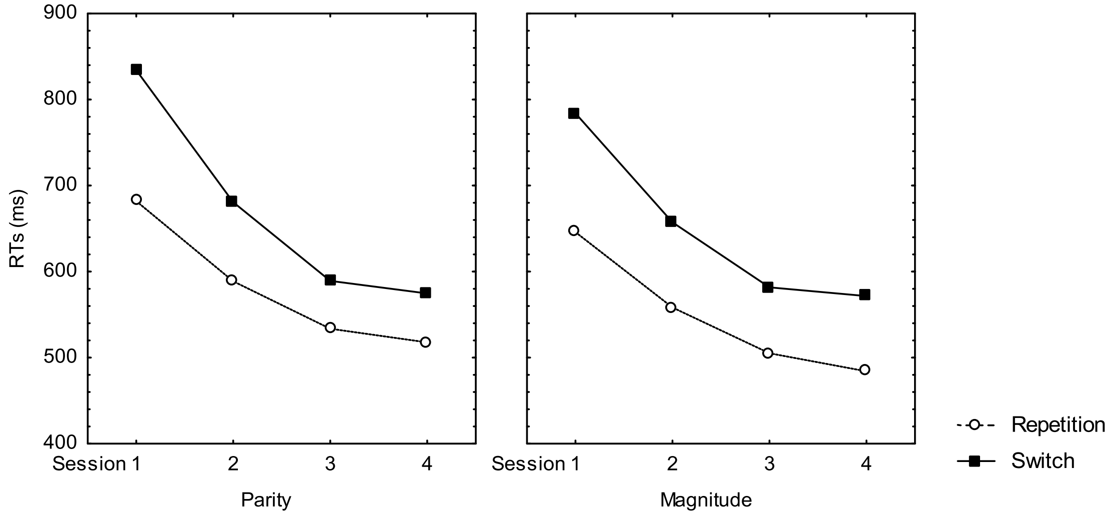

Fig. 3. Mean reaction times as a function of Session (Session 1–4), Task (parity versus magnitude), and Task Sequence (repetition versus switch) in Experiment 2.

$F(1,19) = 12.21$, $p < .01$, $\eta_p^2 = 0.39$, and Congruency, $F(1,19) = 61.84$, $p < .001$, $\eta_p^2 = 0.77$, revealing that RTs decreased with practice, were overall longer in trials of the parity task than in trials of the magnitude task, longer in task switch trials than in task repetition trials, and longer in incongruent than in congruent trials. Task switch costs decreased over the course of the four sessions, $F(3, 57) = 8.78$, $p < .001$, $\eta_p^2 = 0.32$. Planned comparisons demonstrated that the switch costs were significantly larger in the first session than in the second session, $F(1,19) = 6.08$, $p < .05$, and larger in the second session than in the third session, $F(1,19) = 4.68$, $p < .05$, but did not differ significantly between the third and the forth session, $F(1,19) < 1$. There was also a significant three-way interaction involving Congruency, Task Sequence, and Session, $F(3, 57) = 3.57$, $p < .05$, $\eta_p^2 = 0.16$, because the congruency effect tended to be larger in task switch trials than in task repetition trials in Session 1, 3, and 4, whereas this pattern was reversed in Session 2.

Replicating previous results of Wendt et al. (2013), the three-way interaction involving Congruency, Task, and Congruent/Incongruent Ratio, as well as the four-way interaction with Stimulus Type reached significance, $F(1,19) = 9.83$, $p < .01$, $\eta_p^2 = 0.34$, and $F(1,19) = 9.77$, $p < .01$, $\eta_p^2 = 0.34$, respectively. Inspection of Figs. 4 and 5 reveals that in the (manipulated) parity task the congruency effect was larger when the Congruent/Incongruent Ratio was low than when it was high, and this latter effect was more pronounced for induction stimuli than for test stimuli, whereas in the (non-manipulated) magnitude task the congruency effect did not seem affected by the Congruent/Incongruent Ratio. Most important for the present study, neither these interactions, both *F*s < 1, nor any other effect involving Congruency was modulated by Session, all *F*s < 1.9, all *p*s > .13. These findings thus provide no evidence for a practice-related modulation of attentional adjustments.

3.2.2. Errors

Mean error rates for all experimental conditions are displayed in Table 2. The corresponding ANOVA yielded a significant main effect of Session, $F(3, 57) = 4.30$, $p < .01$, $\eta_p^2 = 0.18$, reflecting that error rates displayed a U-shaped function across the four sessions (Fig. 5), as well as significant main effects of Congruent/Incongruent Ratio, $F(1, 19) = 20.88$, $p < .001$, $\eta_p^2 = 0.52$, Task, $F(1, 19) = 33.41$, $p < .001$, $\eta_p^2 = 0.64$, Task Sequence, $F(1, 19) = 8.64$, $p < .01$, $\eta_p^2 = 0.31$, and Congruency, $F(1, 19) = 75.82$, $p < .001$, $\eta_p^2 = 0.80$, reflecting that more errors were committed when the Congruent/Incongruent Ratio was high than when it was low, in parity task trials than in magnitude

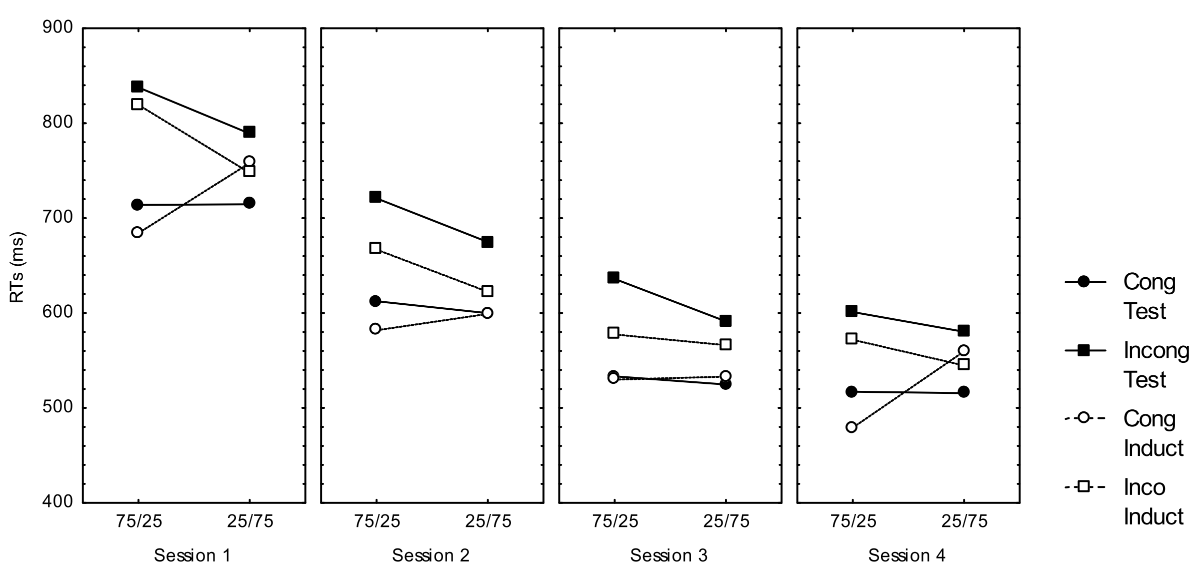

Fig. 4. Mean reaction times of the parity task as a function of Session (Session 1–4), Congruent/Incongruent Ratio (75/25 versus 25/75), Congruency (congruent versus incongruent), and Stimulus Type (induction, test) in Experiment 2. Cong = Congruent. Incong = Incongruent. Induct = Induction.

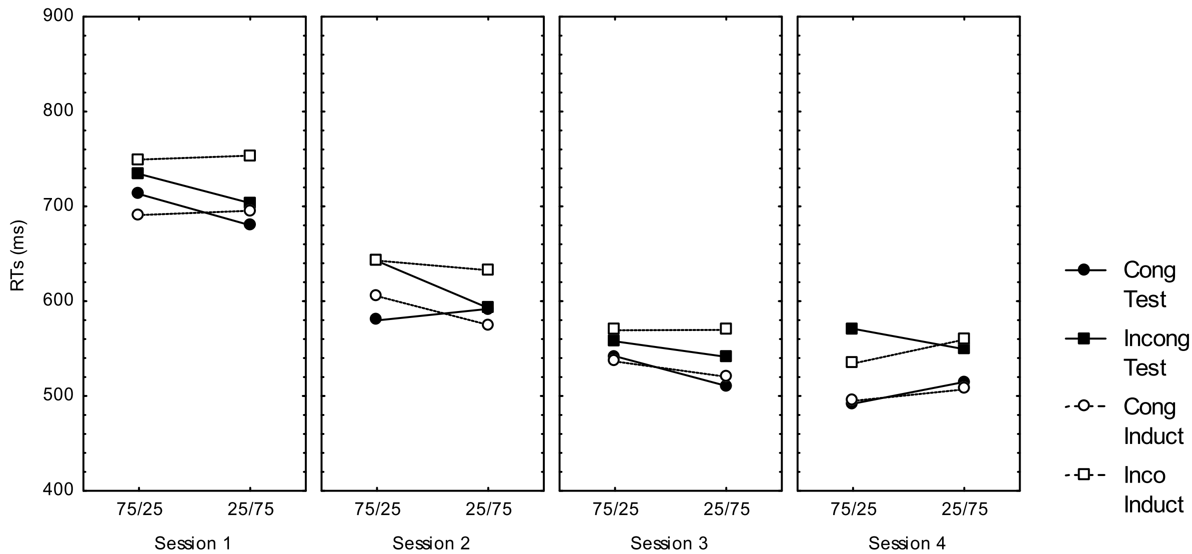

Fig. 5. Mean reaction times of the magnitude task as a function of Session (Session 1–4), Congruent/Incongruent Ratio (75/25 versus 25/75), Congruency (congruent versus incongruent), and Stimulus Type (induction versus test) in Experiment 2. Note that the Congruent/Incongruent Ratio relates to the parity task because the ratio in the magnitude task was held constant at 50/50. Cong = Congruent. Incong = Incongruent. Induct = Induction.

task trials, in task switch trials than in task repetition trials, and in trials involving an incongruent stimulus than in trials involving a congruent stimulus, respectively. Congruency entered into significant two-way interactions with Task Sequence, $F(1, 19) = 7.69, p < .05, \eta_p^2 = 0.29$, showed that the congruency effect was larger in task switch trials than in task repetition trials. Furthermore, Congruency interacted with Task, $F(1, 19) = 29.41, p < .001, \eta_p^2 = 0.61$, and with Congruent/Incongruent Ratio, $F(1, 19) = 16.52, p < .01, \eta_p^2 = 0.47$. These were further modulated by a significant three-way interaction involving all three factors, $F(1, 19) = 29.39, p < .001, \eta_p^2 = 0.61$. Mirroring the RT results and replicating the results of Wendt et al. (2013), these interactions reflect that the congruency did not vary significantly across the different Congruent/Incongruent Ratio conditions in the (non-manipulated) magnitude task, whereas in the (manipulated) parity task the

Table 2
Percentage of errors in Experiment 2 including the factors (Session (1 to 4), Congruent/Incongruent Ratio (75/25 s. 25/75), Task (Parity vs. Magnitude), Task Sequence (Repetition versus Switch), Stimulus Type (Induction vs. Test), and Congruency (Congruent versus Incongruent).

					Session			
Ratio	Task	Task sequence	Stimulus type	Congruency	1	2	3	4
75/25	Parity	Repetition	Induction	Congruent	1.4	0.3	1.0	1.8
				Incongruent	12.3	7.9	9.2	13.5
			Test	Congruent	1.5	1.5	1.5	1.1
				Incongruent	5.3	6.8	12.1	11.7
		Switch	Induction	Congruent	2.0	0.8	1.9	2.7
				Incongruent	13.1	11.0	11.3	17.5
			Test	Congruent	1.7	0.8	1.1	3.2
				Incongruent	11.5	7.9	12.3	10.5
	Magnitude	Repetition	Induction	Congruent	1.1	1.5	2.0	1.4
				Incongruent	2.4	2.4	3.0	3.5
			Test	Congruent	1.4	1.5	1.5	3.4
				Incongruent	2.7	4.1	4.0	5.1
		Switch	Induction	Congruent	1.4	1.5	2.1	1.7
				Incongruent	6.6	4.7	3.2	5.1
			Test	Congruent	0.8	1.1	1.8	2.4
				Incongruent	4.8	6.7	4.8	9.2
25/75	Parity	Repetition	Induction	Congruent	1.1	1.4	2.3	2.1
				Incongruent	6.6	6.7	7.3	8.7
			Test	Congruent	0.0	1.4	2.6	1.8
				Incongruent	5.3	4.7	4.4	5.4
		Switch	Induction	Congruent	2.0	2.3	1.0	1.6
				Incongruent	8.8	6.6	11.0	7.8
			Test	Congruent	1.0	1.0	0.0	1.9
				Incongruent	6.1	6.6	6.4	5.8
	Magnitude	Repetition	Induction	Congruent	1.3	1.9	1.9	0.7
				Incongruent	2.7	2.9	4.0	4.8
			Test	Congruent	1.8	1.8	0.9	2.0
				Incongruent	4.9	2.8	5.0	6.9
		Switch	Induction	Congruent	2.4	1.4	2.0	1.2
				Incongruent	5.4	4.0	4.0	3.9
			Test	Congruent	1.5	1.1	1.6	2.6
				Incongruent	5.9	5.7	5.5	4.9

congruency effect was larger when the Congruent/Incongruent Ratio was low. Inconsistent with the RT analysis, there was no further interaction with Stimulus Type, that is, the pattern of a task-specific PCE was not more pronounced for the induction stimuli than for the test stimuli, $F(1, 19) < 1$. Of importance for the present study, there was no interaction of Session and Congruency or of Session, Congruency, and Congruent/Incongruent Ratio, $Fs < 1.8$, $ps > .15$.

3.2.3. Bayesian analysis

As in Experiment 1, we added a Bayesian analysis, conducted on the data of the initial and the final session (using the same priors as for Experiment 1). The Bayes Factor was calculated by comparing the model for the test trials involving the manipulated task (parity task) including the three-way interaction of Congruency, Proportion Congruency, and Session (Congruency + Proportion Congruency + Congruency × Proportion Congruency + Session + Congruency × Session + Proportion Congruency × Session + Congruency × Proportion Congruency × Session + Subject) with the equivalent model excluding the three-way interaction and only including two-way interaction of Congruency with Proportion Congruency (Congruency + Proportion Congruency + Congruency × Proportion Congruency + Session + Subject).

Concerning RTs, an overall comparison of the H0 (model including the three-way interaction: Congruency × Proportion Congruency × Session) with the H1 (model only including the two two-way interaction: Congruency × Proportion Congruency) yielded a Bayes Factor of $BF_{01} = 0.040$, with an inverse of $BF_{10} = 1/0.04 = 25$. This suggests that the data actually provide more support for the alternative Hypothesis (the model not including the three-way interaction), being 25 times more likely to occur under the alternative Hypothesis compared to the null hypothesis (model including the three-way interaction). Concerning error rates, an overall comparison of the H0 (model including the three-way interaction: Congruency × Proportion Congruency × Session) with the H1 (model only including the two two-way interaction: Congruency × Proportion Congruency) yielded a Bayes Factor of $BF_{01} = 0.035$, with an inverse of $BF_{10} = 1/0.035 = 28.57$. This suggests that the data provide more support for the alternative Hypothesis (the model not including the three-way interaction), being > 28 times more likely to occur under the alternative hypothesis compared to the null hypothesis (model including the three-way interaction).

3.3. Discussion

The present findings replicated the task-specific PCE previously found in non-practice studies, suggesting that control of conflict frequency is confined to the context of the task in which it is varied (Wendt et al., 2013). Mirroring the results of Experiment 1, task switching costs were reduced during the course of practice (i.e., from the first to the second session and from the second to the third session; see also Berryhill & Hughes, 2009; Strobach et al., 2012), whereas the congruency effect remained unaffected. Consistent with the results of our re-analysis concerning trial-to-trial effects of attentional adjustment, the PCE remained substantial over the course of four practice sessions. Again, task-specificity was preserved, that is, the PCE did not transfer to the non-manipulated task. These findings accord with the conclusion of the CSE analysis of Experiment 1, namely the lacking evidence for practice-related modulation of attentional adjustments in a task switching context which is characterized by frequent re-activation of interfering processes.

4. General discussion

The CSE (Botvinick et al., 2001; Gratton et al., 1992; Kerns et al., 2004; Mayr & Awh, 2009) and the PCE (Gratton et al., 1992; Wendt & Luna-Rodriguez, 2009) are widely considered hallmarks of attentional control and adjustment during conflict processing. Although various problems of confounds have been discussed, experimental control thereof can be exerted. For instance, confounds of stimulus repetition were overcome in previous studies by excluding trials with such repetitions (Wendt & Luna-Rodriguez, 2009). Although the CSE and PCE, observed in tasks involving perceptually distinct target and distractor stimuli, such as the Stroop task, the Eriksen flanker task, or the Simon task, do not allow to locate attentional adjustment to non-perceptual processing stages, some previous studies observed the attentional adjustment when participants switched between semantic classification tasks in the absence of perceptually distinct target and distractor stimulus features (Kiesel et al., 2006; Schneider, 2015; Wendt et al., 2013). This adjustment was confined, however, to task repetition trials and did not occur in task switching conditions, supporting the assumption of task-specific adjustment; that is the assumption that this adjustment is specific for the task in which it takes place and does not transfer to alternative tasks. In a similar vein, Wendt et al. (2013) observed a task-specific PCE when they manipulated the proportion of congruent and incongruent trials in only one of two tasks of a task switching protocol.

The present experiments replicated and extended these findings. Specifically, Experiment 1 and Experiment 2 not only demonstrated task-specific CSEs and PCEs, respectively, but also their robustness across substantive practice during six (Experiment 1) and four (Experiment 2) sessions. That is, the present study extended previous investigations of practice effects on conflict adjustment (Mayr & Awh, 2009) from within-session to between-sessions designs and from single-task situations to task switching. The lack of a reduction of the CSE across practice sessions fits nicely with the idea that in task switching conditions, in which the interfering processes cannot be suppressed in a sustained fashion, a strategy of dynamic attentional adjustment is maintained despite extensive practice. Considering that the congruency effect as such did not decrease with practice, this maintenance may be mediated by a constantly high degree of conflict exerted by the interfering processes. A positive relation of conflict strength and attentional adjustment is consistent with theoretical assumptions (Botvinick et al., 2001) and empirical evidence (Forster, Carter, Cohen, & Cho, 2011; Wendt, Kiesel, Geringswald, Purmann, & Fischer, 2014). Unlike in single-task situations, in which participants might learn to re-distribute attentional weights to the processing of task-relevant features exclusively (i.e., ink color) away from processing task-irrelevant features (i.e., word meaning), frequent task switching might thus prevent conflict strength from being reduced to a level at which the dynamic adjustment strategy is abandoned.

This assumption of an impact of conflict strength on practice-related changes of attentional adjustment would also predict that there is not only no effect of practice over sessions, but there is also no effect of practice on attentional adjustment within Session 1 of the current Experiment 1. The later practice effect was demonstrated in Mayr and Awh (2009) when they analyzed the first two experimental blocks in comparison to the remaining blocks and found a CSE in the former, but not in the latter blocks; this change was interpreted as a practice-related effect on attentional adjustment in this Stroop situation without constant conflict strength. When we re-analyzed the data of Session 1 of the current Experiment 1, we separated this session into two phases equivalent to Mayr and Awh. Phase 1 included the first two blocks while Phase 2 included the remaining eight blocks. To investigate the effect of practice on the CSE within Session 1, we would predict an interaction of Phase, Congruency Current Trial and Congruency Previous Trial. However, the RT analysis as well as the analysis of error rates showed no such interactions, $Fs(1,18) < 1.164$, $ps > .295$, $Fs(1,18) < 1.176$, $ps > .294$. Thus, under the current condition of constant conflict strength, there is no evidence for practice effects on attentional adjustments within the first session, while there is such an effect in situations without constant conflict strength (Mayr & Awh, 2009). Hence, we interpret these findings as evidence consistent with the constant conflict strength explaining the lacking attentional adjustment in the current study.

Concerning the reduction of task switch costs after practice found in our study, it is noteworthy that our experiment confounded the sequence of tasks and cues, thus preventing us from drawing firm conclusions whether the reduction reflects a relative speed-up of task switching proper or reduced cue encoding repetition priming (for an overview, see Jost, De Baene, Koch, & Brass, 2013) after practice. As the focus of our study was on conflict adjustment processes, irrespective of the task sequence, however, this limitation does not compromise our interpretation of the data. Nevertheless, observing a CSE selectively on task/cue repetition trials (Experiment 1) clearly warrants the question of what precise components of a task-set need to be repeated to yield a CSE. Future research is needed to address this issue.

Another aspect that deserves consideration pertains to the precise origin of the conflict investigated in the current study.[2] Given that task switching protocols are characterized by frequent application of both tasks to a limited set of stimuli implies that a stimulus presented in one of the tasks will also be processed in the context of the other task. Assuming that responding to a stimulus in a particular task context leads to the formation of a memory episode involving that stimulus and the response executed, it appears likely that the congruency effect is, at least in part, brought about by the retrieval of such episodes when the stimulus occurs in the other task, rather than by application of the abstract stimulus-response translation rules of the other task. A possible means to prevent such episodic effects is to administer as many different stimuli as there are trials in the course of the experiment (e.g., Schneider, 2015). Although it seems difficult to apply this method to multi-session experiments comparable in total trial number to the experiments reported in the current study, presenting a unique subset of "single occurrence stimuli" in each session (or at least in the first and the final session) would seem feasible, potentially allowing dissociating effects of practice on adjustment to conflict elicited by the application of abstract stimulus-response translation rules versus by mismatching response information in retrieved memory episodes.

In general, the current studies are consistent with the findings of previous studies on task switching practice. Consistent with these studies, we demonstrated a reduction of task switching costs over sessions in Experiment 1 and 2. This reduction in the current context of bivalent stimuli (i.e., each stimulus has two different meanings and can signal two different tasks under the two S-R mapping rule sets such as magnitude and parity mapping) is consistent with previous studies also using bivalent stimuli (Berryhill & Hughes, 2009; Karbach & Kray, 2009; Soveri, Waris, & Laine, 2013; Wendt et al., 2017; Zinke, Einert, Pfennig, & Kliegel, 2012) and studies using univalent stimuli (i.e., each stimulus is mapped onto no more than one response; Strobach et al., 2012). It might be of interest whether re-analyzing the former type of studies (studies with bivalent stimuli) could replicate the current findings of task-specific attentional adjustments and lacking practice thereof within and over sessions. Furthermore, the lacking practice effects on attentional adjustments in the present Experiment 1 and 2 as explained with the constant conflict strength is different from the general finding of effects of practice, experience, and training in other domains of cognitive control and beyond (for an overview see Strobach & Karbach, 2016). Thus, the current situation might be one of the few situations in which extensive practice was not effective.

In sum, we investigated the impact of task switching practice on the congruency effect and the modulation thereof by (a) re-analyzing the data of a task switching experiment involving six consecutive sessions (CSE, Experiment 1) and (b) conducting a novel four-session experiment in which the proportions of congruent and incongruent trials were manipulated (PCE, Experiment 2). Although practice reduced overall RTs and task switch costs to an asymptotic level, the CSE and the PCE remained remarkably constant. These findings thus do not provide evidence that conflict effects between tasks and attentional adjustment are affected by task switching practice.

[2] We are grateful to an anonymous reviewer for drawing our attention to this point.

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