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Independent control processes? Evidence for concurrent distractor inhibition and attentional usage of distractor information[☆]

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ABSTRACT

Interference evoked by a distractor presented prior to a target stimulus is reduced when the distractor-target SOA is increased, suggesting inhibition of distractor-related activation. Distractor processing is also assumed to be (strategically) adjusted to the proportions of congruent and incongruent target-distractor combinations, yielding a larger distractor interference effect when the proportion of congruent trials is higher (i.e., Proportion Congruent Effect, *PCE*). To explore the interplay of proportion congruent-based processing adjustment and the time course of distractor-related activation we varied the proportions of congruent and incongruent trials as well as the distractor-target SOA. To control for item-specific priming we kept distractor-related contingencies (i.e., frequency of individual distractor-target conjunctions) constant for a subset of the stimuli (and used a different subset to manipulate the proportions of congruent and incongruent trials). A PCE occurred, even for the subset of stimuli associated with constant distractor-related contingencies, thus ruling out item-specific contingency learning. Distractor interference was reduced when the SOA was increased, but this reduction did not differ between the proportion congruent conditions, as confirmed by a Bayesian analysis. Our results are consistent with independent processes pertaining to usage of distractor information for biasing response selection and distractor inhibition during the SOA. Alternative interpretations of the independent effects of the PC manipulation and the distractor-target SOA are discussed.

1. Introduction

Processes of cognitive (or executive) control are assumed to coordinate and regulate other cognitive process in the service of goal-directed behavior (e.g., Diamond, 2013; Miller & Cohen, 2001). Although sophisticated models concerning particular aspects of cognitive control, such as adjustment of attention to conflict conditions, have been developed based on robust experimental findings (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver, 2012; Melara & Algom, 2003), current theory is still far from offering a coherent account of various facets of cognitive control discussed in the literature. Overall, the situation appears to be characterized by a "divide-and-conquer" strategy (Logan, 2002) in which highly specific aspects are investigated in isolation. Given the current state of well-established theorizing regarding some individual executive functions or control processes, exploring the interplay of assumed mechanisms by combining manipulations which have yielded robust effects in different experimental protocols and led to the formulation of so far unconnected theoretical explanations seems a promising approach. In the current article, we focus on two prominent modulations of the impact of distractor stimuli on response performance in simple choice tasks, which have both been assumed to reflect the influence of executive control on distractor processing.

One of the most fundamental observations from selective attention tasks is that responding to a target stimulus can be influenced by the presence of additional stimuli (i.e., distractors). In many choice tasks, response performance is better (i.e., faster and/or more accurate) when the distractor is associated with the same response as the target (a condition referred to as *congruent*) than when the distractor is associated with a different response than the target (a condition referred to

[☆] All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. Ethical review and approval was not required for this study in accordance with the national and institutional requirements.

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as *incongruent*, e.g., Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979). The congruency effect (i.e., the performance difference between congruent and incongruent conditions) has been attributed to response activation elicited by the distractor. More precisely, it is assumed that (a) simultaneous activation of multiple responses (often referred to as response conflict) slows down response selection and increases the likelihood of selecting an incorrect (but activated) response and that (b) such response conflict is brought about, in incongruent conditions, by divergent response associations of the target and the distractor (e.g., Cohen, Dunbar, & McClelland, 1990; Eriksen & Eriksen, 1974; for physiological evidence concerning distractor-elicited response activation, see e.g., Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Jost, Wendt, Luna-Rodriguez, Löw, & Jacobsen, 2017).

Although incongruent distractors might impair performance in both RTs and response accuracy, the mere fact that participants usually succeed in responding correctly in the vast majority of trials demonstrates that response selection is dominated by target rather than distractor information. This dominance may be brought about by an attentional bias favoring target stimulus information over distractor stimulus information during early sensory stages of stimulus encoding (e.g., Hillyard & Anllo-Vento, 1998), as well as by inhibition of distractor processing during later stages (e.g., Machado, Guiney, & Struthers, 2013) or of down regulation of distractor-related response activation (e.g., Ridderinkhof, 2002).

The congruency effect has been shown to vary with two different factors. First, it tends to be reduced and possibly reversed (i.e., worse performance in congruent than in incongruent trials) when the distractor-target SOA is increased (e.g., Eriksen & Schultz, 1979; Jost et al., 2017; Machado, Wyatt, Devine, & Knight, 2007, Machado et al., 2013; Mattler, 2003; Wyatt & Machado, 2013a, 2013b). In this article, we refer to this finding as *Time-dependent Reduction of the Congruency Effect* (*TRCE*). The TRCE has been ascribed to inhibition of distractor-related representations (e.g., Machado et al., 2007; Machado et al., 2013; Machado, Devine, & Wyatt, 2009; Machado, Guiney, & Mitchell, 2011; Wyatt & Machado, 2013a, 2013b). Crucial for this interpretation, the congruency effect was found to be reversed in long SOA conditions. Wyatt and Machado (2013b) corroborated and extended this view, observing evidence for “reactive inhibition”, that is, stronger inhibition under conditions of stronger distractor interference. Specifically, the TRCE was more pronounced when the intensity of the distractor was higher or when distractors were presented more proximal to the target—manipulations associated with a larger congruency effect at short SOAs.

Second, the congruency effect varies with the proportions of congruent versus incongruent trials, being more pronounced when the Proportion Congruent (PC) is larger. This finding has been labelled the *PC Effect* (*PCE*, e.g., Abrahamse, Duthoo, Notebaert, & Risko, 2013; Gratton, Coles, & Donchin, 1992; Jost et al., 2017; Wendt & Luna-Rodriguez, 2009; Wendt, Luna-Rodriguez, & Jacobsen, 2014; see Bugg & Crump, 2012, for an overview) and has been attributed to differential biasing of attentional weights assigned to target and/or distractor information (e.g., Botvinick et al., 2001). It is thus assumed that attention is focused less strongly on target information if the PC is high, resulting in stronger activation of distractor-related responses than in low-PC conditions. This attentional adjustment hypothesis of the PCE has been criticized, however. A main point of criticism relates to a confound with item-specific contingencies (i.e., distractor-target or distractor-response conjunctions), inherent in many experiments that demonstrated a PCE, which allows for an alternative interpretation in terms of contingency learning (e.g., Miller, 1987; Schmidt, 2013; Schmidt, Crump, Cheesman, & Besner, 2007; Wendt & Luna-Rodriguez, 2009). For illustration, consider the case of a Stroop task, in which the two color-words RED and GREEN are presented in the two colors red and green. When the PC is high, 75%, say, each of the two words will occur together with the corresponding response (i.e., the response associated with the color named by the word) in 75% of the cases. By contrast, when the PC is low (e.g., 25%), each word will occur together with the response associated with the other color in 75% of the trials. These item-specific (i.e., distractor-related) contingencies might facilitate responding in congruent trials, when the PC is high, and in incongruent trials, when the PC is low in the absence of adjustment of attentional weights given to target and distractor information.

However, deconfounding of PC and item-specific contingencies has been achieved by dividing the set of stimuli into two distinct subsets, presented in the same blocks of trials, and manipulating PC for only one of them. We refer to the items of the manipulated subset as *induction stimuli*, and to the items of the unmanipulated subset as *test stimuli*. Observing transfer of the PCE from trials associated with induction stimuli to test stimuli could not be accounted for in terms of contingency learning because distractor-related contingencies are kept constant for the latter (e.g., Abrahamse et al., 2013; Crump & Milliken, 2009; Torres-Quesada, Funes, & Lupiáñez, 2013; Wendt, Luna-Rodriguez, Kiesel, & Jacobsen, 2013). Using this procedure, some past studies dismissed a contingency-learning account as an explanation for the PCE (e.g., Crump & Milliken, 2009; Torres-Quesada et al., 2013; Wendt et al., 2013).

Moreover, physiological evidence in support of an attentional adjustment account of the PCE was obtained by Wendt et al. (2014) (see also Jost et al., 2017; Jost, Wendt, Luna-Rodriguez, Löw, & Jacobsen, 2019). These authors investigated attentional adjustment of distractor processing by analyzing distractor-elicited event-related potentials in the EEG. Presenting the distractor and target of a four-choice task successively (in the same location, i.e., *Temporal Flanker Task*, Hazeltine, Lightman, Schwarb, & Schuhmacher, 2011), sensory potentials (i.e., posterior N1), observed during the distractor-target interval, were larger when the PC was high, suggesting increased sensory/perceptual processing of the distractor in this condition. In addition, the high PC condition was also associated with a larger distractor-related lateralized readiness potential (LRP), suggesting stronger distractor-evoked response activation. Lacking control of item-specific contingencies (i.e., all stimulus items were used to manipulate PC), however, it cannot be dismissed that the LRP findings of Wendt et al. (2014) and Jost et al. (2017, 2019), as well as the PCE found in the performance data, reflect contingency learning rather than attentional adjustment. Moreover, because Wendt et al. (2014) as well as Jost et al. (2017, 2019) used a four-choice task and varied the congruent/incongruent ratio between 75/25 (high PC) and 25/75 (low PC), the two conditions were not only associated with different PCs but also with different values of predictiveness of a given distractor for the required response. Specifically, whereas in the high PC condition, each distractor predicted the correct response with a probability of 75% (versus probabilities of 8.3% for each of the other three possible responses), in the low PC condition the probability was 25% for each of the four responses. Assuming that deployment of attention to a stimulus is modulated by the utility of the stimulus for the prediction of the response, the increase in distractor-evoked sensory potentials in the high PC condition may reflect attentional adjustment to distractor predictiveness rather than to the PC (cf. Schmidt, 2016; see Murray, Machado, & Knight, 2011, Experiment 4, for evidence that frequent identical distractor-target conjunctions may yield increased deployment of attention to the distractor).

In light of these shortcomings, the PCEs observed by Jost et al. (2017) and Wendt et al. (2014) deserve corroboration under conditions of controlled response contingencies of individual distractors as well as controlled overall distractor predictiveness. In the current study, we controlled distractor-response contingency in high and low PC conditions by using separate sets of induction stimuli and test stimuli. This was achieved by dividing the four-choice task used by Jost et al. (2017) and Wendt et al. (2014) into two two-choice tasks, involving separate stimulus sets. More specifically, we grouped the four letters A, B, C, and D into two sets, made up of different letter pairs (i.e., A/B and C/D). Target-distractor conjunctions could only involve elements from the same pair. One of the sets (i.e., induction stimuli) was used to manipulate PC (i.e., the congruent stimuli of this set were presented more frequently in the high PC condition and the incongruent stimuli of this set were presented more frequently in the low PC condition, likewise the incongruent stimuli of this set were presented less frequently in the high PC condition and the congruent stimuli of this set were presented less frequently in the low PC condition). By contrast, congruent and incongruent target-distractor conjunctions of the other set (i.e., test stimuli) were presented with equal probability, in both PC conditions. Table 1 displays the presentation rates of individual target-distractor conjunctions used to achieve overall PCs of 75% or 25% for participants who were administered the letters A and B as induction stimuli and the letters C and D as test stimuli.

As Table 1 depicts, in the subset of test stimuli each distractor occurred with equal frequency in congruent and incongruent trials in both PC conditions. Moreover, distractors from the subset of induction stimuli occurred together with one of the two possible responses with probabilities of 83.3% and 16.7%, respectively, in each of the PC conditions and distractors from the subset of test stimuli occurred together with each of the two possible responses with probabilities of 50%. Therefore, the distractors' predictiveness for the correct response did not differ between PC conditions.[1]

The main objective of the current study was, however, to investigate the interplay of the putative control processes that underlie the TRCE and the PCE. Although distractor inhibition during the SOA appears to be a useful means to counter unwanted interference, the degree of such inhibition may depend on contextual factors such as the PC. Specifically, assuming that the two control processes serve the optimization of behavior in a coordinated manner, one might expect that less (if any) inhibition is applied to the distractor during the SOA under conditions in which the distractor is thought to be used for response activation (or allowed to elicit such activation) more strongly, that is, when the PC is high. By consequence, the TRCE should be reduced in high PC conditions. On the other hand, it is conceivable that attentional adjustment to PC and distractor inhibition during the SOA constitute independent processes. For instance, if one conceives the PCE as a result of passive accumulation of previously adopted states of less strongly or more strongly focused attention (in high versus low PC conditions, respectively), rather than as resulting from strategic processing adjustment to bias response selection, such independence would not seem unexpected. In fact, in the original model of Botvinick et al. (2001), although frequently interpreted in terms of strategic adjustment, increased focusing of attention in high PC conditions is brought about by accumulation of previous conflict experience. Attentional adjustment to PC could thus be conceptualized as a “passive” consequence of the PC manipulation rather than as a strategic means to optimize performance in the current context conditions. Similarly, distractor inhibition during the SOA might be oblivious of contextual differences in the usefulness of the distractors. For such processes, there would seem no obvious reason for an interaction and thus for a reduction of the TRCE in high PC conditions.

To summarize, modulations of distractor-target congruency effects by the distractor-target SOA and by the PC have been related to distractor inhibition and attentional adjustment of distractor processing, respectively. The current study was conducted to investigate the interplay of these control processes by comparing the TRCE between conditions of high and low PC (controlled for item-specific contingency learning and overall distractor predictiveness). Assuming coordinated control processes of strategic PC-based adjustment of distractor processing and inhibition one might expect less inhibition and thus a reduced or absent TRCE when the PC is high.

[1] This resembles the frequently used situation in which only two different stimuli are used as target and distractor in a two-choice task and deconfounding of PC and distractor-response contingency is not possible. By consequence, PCEs obtained under such conditions have sometimes been attributed to distractor-response priming (e.g., Logan & Zbrodoff, 1979) or to attentional adjustment (e.g., Botvinick et al., 2001; Gratton et al., 1992).

Table 1
Percentages of presentation of Distractor/Target Combinations for induction stimuli A and B and test stimuli C and D.

Proportion congruent	Induction stimuli				Test stimuli			
	A/A	A/B	B/A	B/B	C/C	C/D	D/C	D/D
75%	31.25	6.25	6.25	31.25	6.25	6.25	6.25	6.25
25%	6.25	31.25	31.25	6.25	6.25	6.25	6.25	6.25

2. Method

2.1. Participants

Sixty-four students of the Medical School Hamburg participated in the experiment. All participants had normal or corrected-to-normal vision according to self-report. They gave informed consent and in exchange for participation in this study, they received partial course credit. The participants were assigned to two groups. The first group started with a high-PC condition (75%-PC-first-group), whereas the second group started with a low-PC condition (25%-PC-first-group). The 75%-PC-first-group comprised 26 female and 6 male participants, ranging in age from 19 to 38 years (mean age: 23.8 years). The 25%-PC-first-group comprised 22 female and 10 male participants, ranging in age from 18 to 30 years (mean age: 23.7 years). A power analysis showed that for a large effect of $\eta_p{}^2 = 0.4$, and a medium effect of $\eta_p{}^2 = 0.25$ (Cohen, 1988) of this interaction of PCE and TRCE, sample sizes of $N = 51$ and $N = 125$, respectively, would be required to achieve a power of $P = .8$ (G*Power, Faul, Erdfelder, Lang, & Buchner, 2007, Faul, Erdfelder, Buchner, & Lang, 2009

2.2. Apparatus and stimuli

The paradigm was presented on a Lenovo PC, Intel (R) Pentium(R) CPU G 3220 at 3.00 GHz, Ram: 4.0 GB; 22″-LCD-Display screen; Responses were detected by the Serial Response Box, Model 200a (Psychology Software Tools, Inc). Stimulus presentation and recording of response times were controlled by E-Prime 2.0 (Psychology Software Tools, Inc.) under Windows 7 Professional (64 Bit). Participants were seated approximately 60 cm in front of the screen. The background color was white. The letters *A*, *B*, *C*, and *D* presented in white color on a grey rectangle (1.6 cm × 1.6 cm) served as distractor/target stimuli. Letters were always presented in the center of the screen and extended from 1.4 cm vertically and 1.2 cm horizontally, subtending approximately 1.3° of visual angle vertically and 1.1° of visual angle horizontally.

2.3. Procedure

In each trial a distractor and target were randomly presented with a stimulus onset asynchrony (SOA) of either 300 ms or 900 ms, as displayed in Fig. 1. Each of these stimuli was presented for 100 ms. Participants were instructed to ignore the first letter and identify the second letter by responding with the respective key of the serial response box, using the index and middle finger of both hands. The letters were mapped to the response keys (arranged horizontally) in alphabetical order from left to right. Participants started with a practice block of 32 trials each, followed by the main experiment that consisted of 12 blocks à 64 trials. The practice block consisted of 32 trials, each distractor-target combination (A/A, A/B, B/A, B/B, C/C, C/D, D/C, D/D) was presented four times (two times with SOA of 300 ms and two times with SOA of 900 ms). Regarding the 12 experimental blocks, percentages of distractor-target combinations for high PC (i.e., 75%) and low

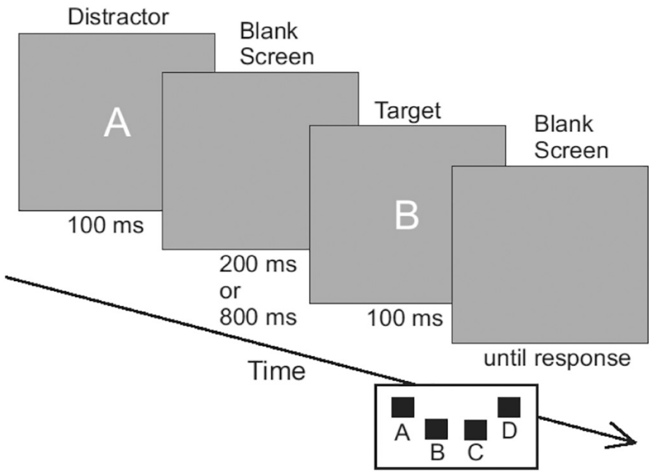

Fig. 1. Example of the structure of a trial.

PC (25%) blocks of trials for the two subsets of the stimuli are displayed in Table 1.The 75%-PC-first-group started with six blocks of the high PC condition, followed by six blocks of the low PC condition whereas 25%-PC-first-group were administered the two PC conditions in the reversed order. After each block, accuracy and mean RT were displayed on the screen. An erroneous response was indicated by presenting "falsch" ('wrong') on the screen for an interval of 500 ms. After a correct response the screen remained blank for an interval of 500 ms. The distractor of the following stimulus was presented 500 ms later in both cases. The assignment of specific letters (A and B vs. C and D) to induction and test stimuli was counterbalanced across all subjects.

3. Results

Data from the practice block were excluded from the analysis. Furthermore, data from the first three trials of each block (4.69%), and trials following error trials (0.51%) were not used for the analyses. For the RT analyses only data from trials associated with a correct response (error trials = 2.04%) that fell within the range of 200 ms to 2500 ms were considered for analysis (3.84% trials did not meet this criterion). A more conservative upper cutoff of 2000 ms did not substantively change the results. In particular, all significant main effects and interactions remained significant. Mean RTs for all experimental conditions are shown in Figs. 2 and 3. Mean error rates are shown in Tables 2 and 3. Fig. 4 displays the congruency effects in the various conditions.

Analyses of Variance (ANOVAs) with repeated measures on the factors Congruency (congruent, incongruent), Proportion Congruent (75%, 25%), Stimulus Type (induction, test), and SOA (short, long) and the between-subjects factor Order (75%-PC-first, 25%-PC-first) were conducted on RTs and error rates (Tables 4 and 5) using RStudio (v1.1.463; RStudio Team, 2015), the *ez* package (v4.0-0; Lawrence, 2011).

3.1. Overall analysis

Repeated measures ANOVA for RTs yielded significant main effects of Congruency, Stimulus Type, and SOA, demonstrating that responding was faster in congruent trials than in incongruent trials, faster in trials associated with induction stimuli than in trials associated with test stimuli, and faster when SOA was long than when SOA was short. Order and Proportion Congruent entered into a significant interaction, reflecting that responses in the 25%-PC blocks were overall slowed for participants who started with the 25%-PC condition compared to participants who started with the 75%-PC condition. More importantly, both the interactions of Congruency X Proportion Congruent, and of Congruency X SOA, were significant, reflecting a larger congruency effect for 75%-PC (i.e., a PCE), and that the congruency effect was reduced when the SOA was increased (i.e., a TRCE), respectively. The former two-way interaction was further modulated by Stimulus Type, indicating that the PCE was more pronounced for the induction stimuli than for the test stimuli. Also, the interaction of Congruency X SOA was further modulated by Stimulus Type, and by Order X Stimulus Type, reflecting that the TRCE tended to be more pronounced for the test stimuli than for the induction stimuli in the group of participants that started with the 25%-PC condition, whereas the TRCE for the two stimulus types was comparable in the group of participants that started with the 75%-PC condition.

Of importance regarding our research question, the TRCE was not less pronounced in the high PC condition (i.e., Congruency X Proportion Congruent X SOA, $F(1,62) < 1$), and this was not qualified by any other factor or combination of factors (all *ps* $> .28$).

The analysis of error rates (see Table 5) yielded significant main effects of Congruency, Stimulus Type, and SOA, mirroring RT results by demonstrating that responding was less error-prone in congruent trials than in incongruent trials, in trials with induction stimuli than in trials with test stimuli, and when the SOA was long than when the SOA was short. Furthermore, the analysis yielded a significant main effect of Order, showing that responses of the 75%-PC-first-group were less error-prone. This was qualified, however, by a significant two-way interaction of Order X Proportion Congruent, demonstrating that participants of the 75%-PC-first-group made less errors in the 75%-PC block than in the 25%-PC block, whereas participants initially exposed to the 25%-PC block made more errors in the 75%-PC block than in the 25%-PC block. Finally, the analysis yielded a significant two-way interaction of Order X SOA, reflecting a larger SOA effect (i.e., reduced error rate when the SOA was long) for participants of the 25%-PC-first-group. Mirroring the RT analysis, the interaction Congruency X Proportion Congruent X SOA was not significant, and this was not qualified by any other factor or combination of factors (all *ps* $> .18$).

3.2. Item-specific analysis

To disentangle effects of item-specific frequency from generalized PC effects, we conducted separate analyses for trials with induction stimuli and trials with test stimuli, respectively. To this end, we conducted separate ANOVAs on the factors Congruency (congruent, incongruent), Proportion Congruent (75%-PC, 25%-PC), and SOA (short, long) and the between-subjects factor Order (75%-PC-first, 25%-PC-first) on RTs and error rates.

3.2.1. Induction stimuli

The RT analysis yielded significant two-way interactions of Congruency X Proportion Congruent, $F(1,62) = 47.03, p < .001, \eta_p^2 = 0.431$, reflecting a PCE, and of Congruency X SOA, $F(1,62) = 30.31$, $p < .001$, $\eta_p^2 = 0.328$, reflecting a TRCE. In addition, the three-way interaction of Congruency X Proportion Congruent X Order was significant, $F(1,62) = 4.34$, $p = .04$, $\eta_p^2 = 0.07$, reflecting a larger PCE in the 75%-PC-first-group. The three-way interaction Congruency X Proportion Congruent X SOA was not significant, $F(1,62) = 0.84$, $p = .36$, $\eta_p^2 = 0.013$.

The corresponding ANOVA on the error rates yielded only significant main effects of Congruency, $F(1,62) = 9.94$, $p = .002$, $\eta_p^2 = 0.138$, and of SOA, $F(1,62) = 8.84$, $p = .004$, $\eta_p^2 = 0.125$, reflecting increased errors for incongruent compared to congruent trials, and less errors with increasing SOA, respectively.

3.2.2. Test stimuli

The RT analysis involving only trials with test stimuli yielded significant two-way interactions of Congruency X Proportion Congruent, $F(1,62) = 6.81$, $p = .011$, $\eta_p^2 = 0.1$, and of Congruency X SOA, $F(1,62) = 43.5$, $p < .001$, $\eta_p^2 = 0.41$, demonstrating the occurrence of a PCE and of a TRCE for the subset of stimuli where contingencies were not manipulated. Furthermore, the three-way interaction of

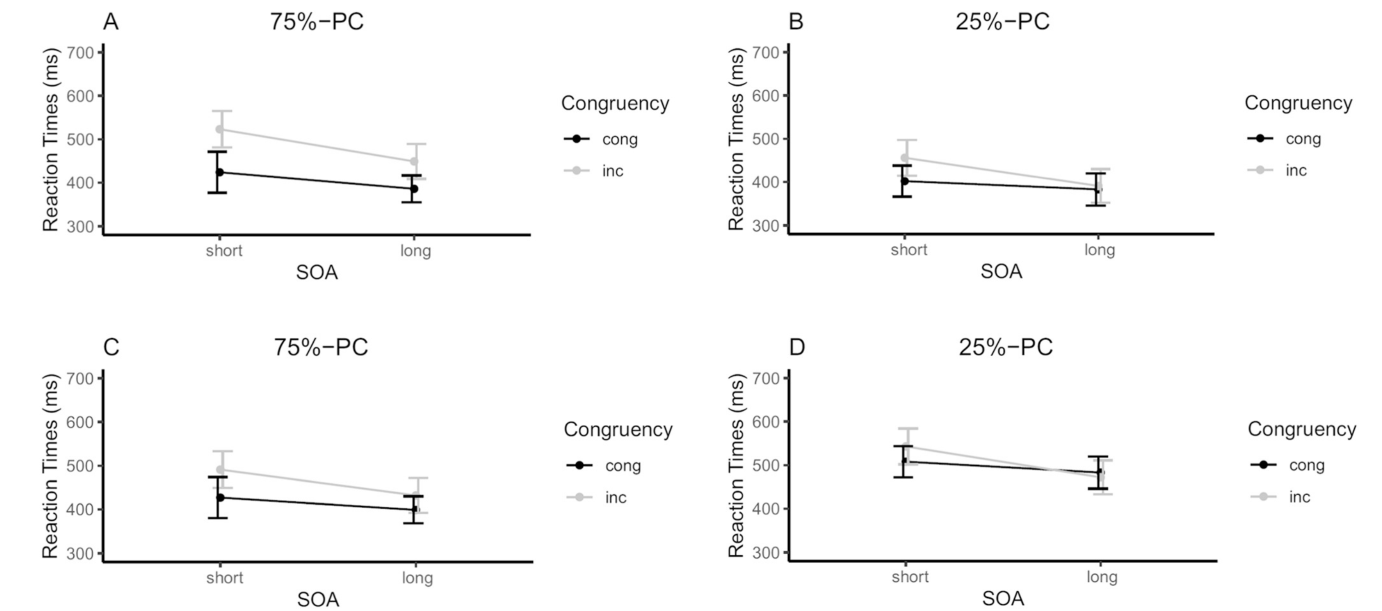

Fig. 2. Mean response times as a function of distractor Congruency (congruent [cong] vs. incongruent [inc]), Proportion Congruent during the block (A and C vs. B and D), and group of participants (A and B started with block of 75%-PC, C and D started with block of 25%-PC) for trials with induction stimuli. Error bars indicate 95%-confidence-intervals.

Congruency X SOA X Order was significant, $F(1,62) = 5.06, p = .03, \eta_p^2 = 0.06$, reflecting an increased TRCE for the 25%-PC-first-group. The three-way interaction Congruency X Proportion Congruent X SOA was once again, not significant, $F(1,62) = 0.09$, $p = .76$, $\eta_p^2 < 0.01$.

The analysis on the error rates yielded a main effect of Order, $F(1,62) = 5.49$, $p = .02$, $\eta_p^2 = 0.08$, showing that participants from the 25%-PC-first group were more error-prone, and of SOA, $F(1,62) = 18.65$, $p < .001$, $\eta_p^2 = 0.23$, showing that fewer errors were made when the SOA was long. Also, there were significant two-way interactions of Order X Proportion Congruent, $F(1,62) = 5.33$, $p = .02$, $\eta_p^2 = 0.08$, and of Order X SOA, $F(1,62) = 5.25$, $p = .02$, $\eta_p^2 = 0.08$, reflecting that participants tended to make less errors in the PC condition they were administered first, and that the reduction of errors when the SOA increased was larger in the 25%-PC-first-group, respectively.

In light of the theoretical importance of the null finding concerning the interaction of Congruency, PC, and SOA, we conducted a bayesian analysis in order to evaluate our null effects.

3.3. Bayesian analysis

Because our conclusions are based on null hypothesis significance testing (NHST), which only allows to reject the null but not the alternative hypothesis, we repeated our analysis with a Bayesian approach. The Bayes Factor was computed using the BayesFactor (v0.9.124.2, 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 full model including the three-way interaction of Congruency, Proportion Congruent, and

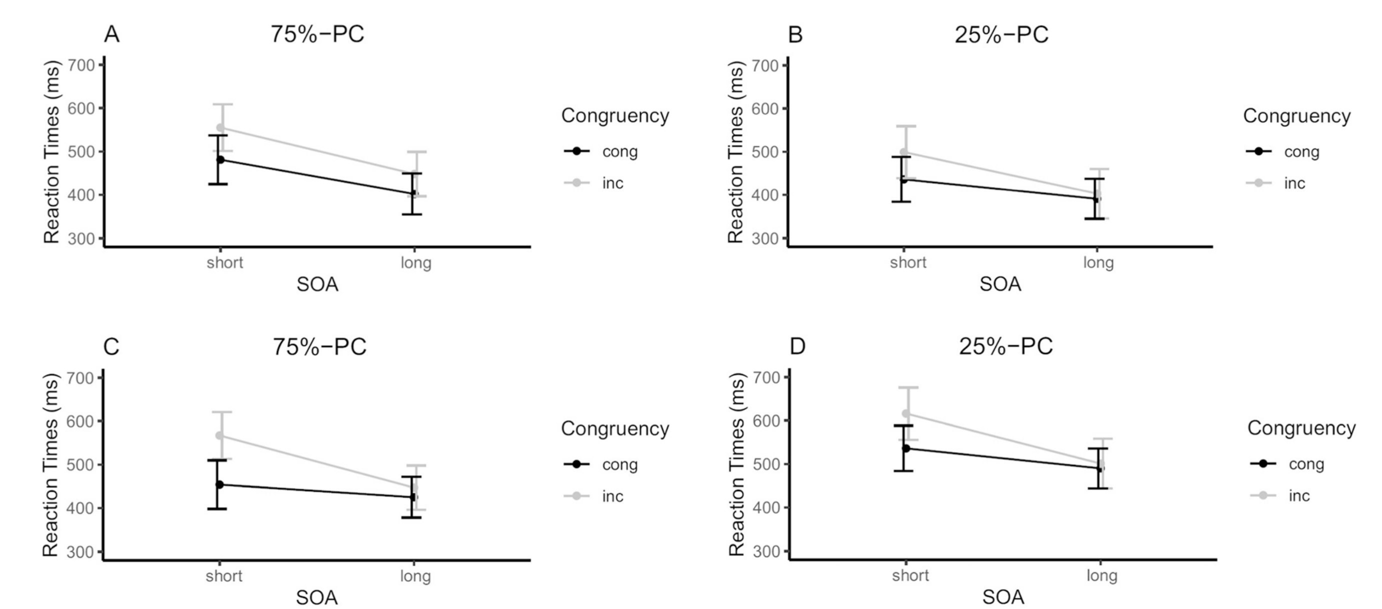

Fig. 3. Mean response times as a function of distractor Congruency (congruent [cong] vs. incongruent [inc]), Proportion Congruent during the block (A and C vs. B and D), and group of participants (A and B started with block of 75%-PC, C and D started with block of 25%-PC) for trials with test stimuli. Error bars indicate 95%-confidence-intervals.

Table 2
Mean Error Rates as a function of distractor Congruency (congruent [cong] vs. incongruent [inc]), Proportion Congruent during the block (left vs. right columns), and group of participants (first two rows vs. last two rows) for trials with induction stimuli.

	Distractor	75%-PC condition				25%-PC condition			
		SOA							
		200 ms		800 ms		200 ms		800 ms	
		M	SD	M	SD	M	SD	M	SD
75%-PC-first	cong	0.7	1	0.6	1	2.6	3.9	1.7	2.4
	inc	2.7	5.7	2.2	3.3	3	3.3	1.8	2.8
25%-PC-first	cong	2.4	4.5	2.2	3.7	6.1	7.2	3.7	5
	inc	4.5	4.3	2.3	3.3	6.6	6.9	3.5	6.4

Table 3
Mean Error Rates as a function of distractor Congruency (congruent [cong] vs. incongruent [inc]), Proportion Congruent during the block (left vs. right columns), and group of participants (first two rows vs. last two rows) for trials with test stimuli.

	Distractor	75%-PC condition				25%-PC condition			
		SOA							
		200 ms		800 ms		200 ms		800 ms	
		M	SD	M	SD	M	SD	M	SD
75%-PC-first	cong	2.6	3.9	1.7	2.4	2.6	4.1	1.4	2.2
	inc	3	3.3	1.8	2.8	3.1	4.3	3.3	5.2
25%-PC-first	cong	6.1	7.2	3.7	5	3.8	4.3	2	2.8
	inc	6.6	6.9	3.5	6.4	5.5	8.1	2.7	4.6

SOA: Congruency + Proportion Congruent + Congruency x Proportion Congruent + SOA + Congruency x SOA + Proportion Congruent x SOA + Congruency x Proportion Congruent x SOA + Stimulus Type + SOA x Stimulus Type + Order + Proportion Congruent x Order + Subject with the equivalent model excluding the three-way interaction and only including the two two-way interactions of Congruency with Proportion Congruent, and Congruency with SOA: Congruency + Proportion Congruent + Congruency x Proportion Congruent + SOA + Congruency x SOA + Stimulus Type + SOA x Stimulus Type + Order + Proportion Congruent x Group + Subject. We ran the same model comparison for the test stimuli, therefore only excluding the factor Stimulus Type from the model.

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).

Overall comparing the H0 (model including the three-way interaction (Congruency X Proportion Congruent X SOA)) with the H1 (model with the two two-way interactions (Congruency x Proportion Congruent + Congruency x SOA)) the Bayes Factor is found to be $BF_{01} = 0.021$, with an inverse of $1/BF_{01} = 48.77$. This suggests that the data actually provide more support for the alternative Hypothesis (the model not including the three-way interaction), being 48.77 more likely to occur under the alternative Hypothesis compared to the null hypothesis (model including the three-way interaction).

For the test stimuli, comparing the H0 (model including the three-way interaction (Congruency X Proportion Congruent X SOA)) with the H1 (model with the two two-way interactions (Congruency x Proportion Congruent + Congruency x SOA)) the Bayes Factor is found to be $BF_{01} = 0.026$, with an inverse of $1/BF_{01} = 38.91$. This suggests that the data actually also provide more support for the alternative hypothesis (the model not including the three-way interaction), being 38.91 more likely to occur under the alternative hypothesis compared to the null hypothesis (model including the three-way interaction).

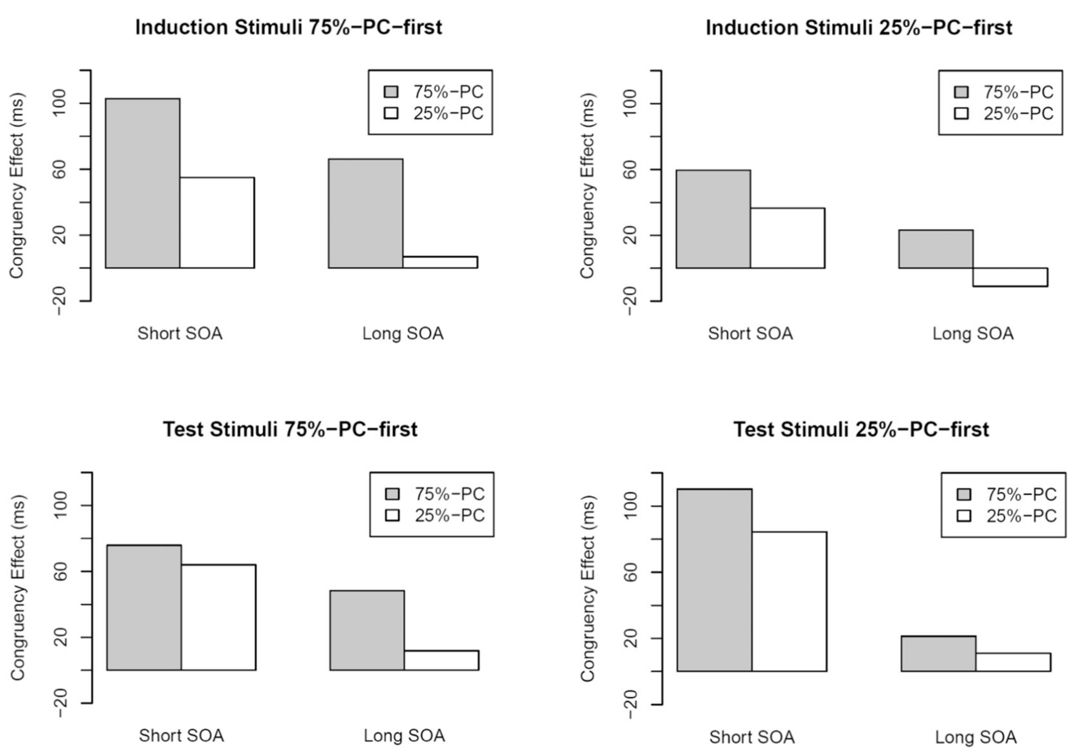

Fig. 4. Reaction time congruency effect (i.e., incongruent trials – congruent trials) in ms as a function of Stimulus Type (induction stimuli, test stimuli), Proportion Congruent (high, low), Order of Proportion Congruent conditions (1: high PC first/low PC second, 2: low PC first/high PC second), and SOA (short, long).

Table 4
Results for the repeated measures ANOVA for RTs on the factors Order, Congruency, Proportion Congruent, Stimulus Type and SOA.

Effect	DFn	DFd	F	p	p < .05	η_p^2
Order	1	62	3.95	.051	*	0.060
Congruency	1	62	116.24	< .001	*	0.652
Proportion Congruent	1	62	1.28	.261		0.020
Stimulus Type	1	62	18.92	< .001	*	0.234
SOA	1	62	159.15	< .001	*	0.720
Order x Congruency	1	62	1.82	.183		0.028
Order x Proportion Congruent	1	62	49.85	< .001	*	0.446
Order x Stimulus Type	1	62	0.79	.378		0.013
Order x SOA	1	62	0.14	.706		0.002
Congruency x Proportion Congruent	1	62	27.00	< .001	*	0.303
Congruency x Stimulus Type	1	62	2.87	.095		0.044
Proportion Congruent x Stimulus Type	1	62	0.12	.734		0.002
Congruency x SOA	1	62	50.69	< .001	*	0.450
Proportion Congruent x SOA	1	62	1.94	.169		0.030
Stimulus Type x SOA	1	62	14.92	< .001	*	0.194
Order x Congruency x Proportion Congruent	1	62	1.68	.199		0.026
Order x Congruency x Stimulus Type	1	62	8.33	.005	*	0.118
Order x Proportion Congruent x Stimulus Type	1	62	0.50	.483		0.008
Order x Congruency x SOA	1	62	2.01	.161		0.031
Order x Proportion Congruent x SOA	1	62	4.10	< .001	*	0.062
Order x Stimulus Type x SOA	1	62	0.24	.625		0.004
Congruency x Proportion Congruent x Stimulus Type	1	62	6.80	.011	*	0.099
Congruency x Proportion Congruent x SOA	1	62	0.70	.406		0.011
Congruency x Stimulus Type x SOA	1	62	4.33	.004	*	0.065
Proportion Congruent x Stimulus Type x SOA	1	62	0.21	.650		0.003
Order x Congruency x Proportion Congruent x Stimulus Type	1	62	1.51	.224		0.003
Order x Congruency x Proportion Congruent x SOA	1	62	1.16	.287		0.018
Order x Congruency x Stimulus Type x SOA	1	62	5.58	.021	*	0.083
Order x Proportion Congruent x Stimulus Type x SOA	1	62	1.31	.257		0.021
Congruency x Proportion Congruent x Stimulus Type x SOA	1	62	0.11	.747		0.002
Order x Congruency x Proportion Congruent x Stimulus Type x SOA	1	62	1.00	.322		0.016

Despite the quite low Power for a medium effect, Bayesian analysis indicates, that the model including the three-way interaction provides less support, than the model including only the two two-way interactions.

4. Discussion

In the current study, we analyzed the interplay of two assumed control processes, distractor inhibition during a pre-target interval and

Table 5
Results for the repeated measures ANOVA for error rates on the factors Order, Congruency, Proportion Congruent, Stimulus Type and SOA.

Effect	DFn	DFd	F	p	p < .05	η_p^2
Order	1	62	5.48	.023	*	0.081
Congruency	1	62	9.25	.003	*	0.013
Proportion Congruent	1	62	1.47	.230		0.023
Stimulus Type	1	62	12.98	< .001	*	0.173
SOA	1	62	27.72	< .001	*	0.309
Order x Congruency	1	62	< 0.01	.988		< 0.001
Order x Proportion Congruent	1	62	7.08	.010	*	0.103
Order x Stimulus Type	1	62	2.50	.119		0.039
Order x SOA	1	62	5.45	.022	*	0.081
Congruency x Proportion Congruent	1	62	0.13	.724		0.002
Congruency x Stimulus Type	1	62	0.66	.419		0.011
Proportion Congruent x Stimulus Type	1	62	1.31	.257		0.021
Congruency x SOA	1	62	0.766	.385		0.012
Proportion Congruent x SOA	1	62	0.16	.692		0.003
Stimulus Type x SOA	1	62	2.83	.097		0.044
Order x Congruency x Proportion Congruent	1	62	1.22	.274		0.019
Order x Congruency x Stimulus Type	1	62	0.05	.831		< 0.001
Order x Proportion Congruent x Stimulus Type	1	62	0.79	.377		0.013
Order x Congruency x SOA	1	62	1.13	.293		0.018
Order x Proportion Congruent x SOA	1	62	0.17	.680		0.003
Order x Stimulus Type x SOA	1	62	1.79	.186		0.028
Congruency x Proportion Congruent x Stimulus Type	1	62	3.70	.006		0.056
Congruency x Proportion Congruent x SOA	1	62	1.09	.300		0.017
Congruency x Stimulus Type x SOA	1	62	0.44	.509		0.007
Proportion Congruent x Stimulus Type x SOA	1	62	0.97	.329		0.015
Order x Congruency x Proportion Congruent x Stimulus Type	1	62	0.90	.347		0.014
Order x Congruency x Proportion Congruent x SOA	1	62	< 0.01	.981		< 0.001
Order x Congruency x Stimulus Type x SOA	1	62	0.34	.560		0.006
Order x Proportion Congruent x Stimulus Type x SOA	1	62	0.48	.493		0.008
Congruency x Proportion Congruent x Stimulus Type x SOA	1	62	0.01	.920		< 0.001
Order x Congruency x Proportion Congruent x Stimulus Type x SOA	1	62	1.76	.190		0.028

attentional usage of the distractor for response preparation, by comparing the TRCE in conditions of 75% and 25% PC. We extended previous work by using two different sets of stimuli, induction stimuli and test stimuli, to induce the PC manipulation and to assess the congruency effect uncontaminated by item-specific contingency learning, respectively. Our main results involved (a) the demonstration of a PCE for both induction and test stimuli and (b) a substantial TRCE in the high PC condition that was not lower than the TRCE in the low PC condition. In previous studies using a similar methodology (i.e., PC manipulation in the Temporal Flanker Task, Jost et al., 2017, 2019; Wendt et al., 2014) a single set of stimuli was used, preventing assessment of the PCE uncontaminated by contingency learning. The PCE found for the test stimuli in the current study precludes an interpretation in terms of contingency learning.

Our approach was similar to the one used by Abrahamse et al. (2013). These authors analyzed the PCE in a Stroop task, manipulating the PC between different blocks of trials. The PCE was larger when participants switched from the high PC condition to the low PC condition than vice versa. Dismissing reduction of the congruency effect as a result of mere practice, the authors explained this result by assuming that a change in PC is more likely to be detected, and thus attentional adjustment more likely to occur, if the distractors are processed more strongly (as should be the case when the PC is high). Noteworthy, the order of administration of PC conditions had an effect on trials with induction stimuli whereas trials with test stimuli did not display a PCE at all. The authors concluded that the adjustment of attention occurred in an item-specific manner (i.e., item-specific PCE, see Bugg & Crump, 2012, for an overview). The results of the current study resemble these findings in two aspects. First, we observed the effect of order of administration of PC conditions on the PCE for the induction stimuli but not for the test stimuli. (Lacking a control condition in which the PC was kept constant throughout the session, we cannot rule out mere practice as the origin of this modulation, however). Also, the PCE in RTs was more pronounced for the induction stimuli than for the test stimuli, consistent with the notion that item-specific attentional adjustment and/or contingency learning contributed to the PCE in these trials in addition to item-unspecific attentional adjustment which caused the PCE in trials with test stimuli.

Because in previous Temporal Flanker Task studies of Jost et al. (2017, 2019) and Wendt et al. (2014) distractors were generally more predictive regarding the upcoming response in the high PC condition than in the low PC condition, the enhancement of distractor-related sensory potentials observed in the high PC condition might reflect attentional adjustment to the frequency of distractor-target conflict (Botvinick et al., 2001).

To alleviate this shortcoming, predictiveness of the distractor was matched in the two PC conditions in the current study. More precisely, in the 75%-PC condition a distractor was followed by an identical target with a probability of 75% and by the other letter of the stimulus pair with a probability of 25%, whereas in the 25%-PC condition a distractor was followed by the other letter of the stimulus pair with a probability of 75% and by an identical target with a probability of 25%. Despite this formal matching, however, it might be argued that frequent repetitions of identical stimuli represent events of particular salience and thus the contingencies of the high PC conditions may be acquired more easily than the contingencies of the low PC condition. Attentional adjustment to "perceived" predictiveness of the distractors rather than to the frequency of distractor-target conflict, therefore, remains a plausible possibility.

By repeating our analysis with a Bayesian approach, we gathered strong evidence that the two processes of PCE and TRCE seem to work independently. The likelihood for an overall model containing two two-way interactions is 48.77 times more likely than the model containing the three-way interaction.

For the test stimuli, the likelihood for a model containing two two-way interactions is 38.91 times more likely than the model containing the three-way interaction. Our study thus failed to support the assumption that distractor inhibition during the SOA is adjusted to the degree of usage of the distractor for response preparation. Within the framework of this reasoning, it thus seems that the two assumed control processes are applied in an independent uncoordinated manner.

Several possibilities are conceivable to explain this independence. First, as laid out in the Introduction, assuming that the PCE and the TRCE do not reflect the operation of strategic attempts to optimize behavior to the current context condition, but automatic consequences of the history of previous attentional sets or distractor-based activation, respectively, no interaction between them would have to be expected. Second, as for many other null effects it is possible that two processes, working in opposite directions, prevent the detection of either of them in the observed variable. Based on previous findings of reactive inhibition (i.e., stronger inhibition of distractor based activation if this activation was higher in the first place, Wyatt & Machado, 2013b), a high PC condition might be characterized by a strategic tendency to apply less inhibition to the distractor as well an opposing tendency for increased inhibition to counter a higher degree of initial distractor-based activation.

It must be considered that the PCE and the TRCE do not reflect control processes at all, however. Although we made considerable efforts to rule out alternative explanations of the PCE, a final decision on this issue might still be premature. In general terms this is because the PCE can be conceived of as a congruency level repetition advantage (i.e., better performance in trials of a given congruency level if the frequency of the presentation of this level is higher). This pattern of results may, in principle, result from the facilitatory repetition of some yet unidentified feature associated with the congruency level. To control this fundamental confound, Wendt, Luna-Rodriguez, and Jacobsen (2012) introduced a probe task method which yielded evidence of attentional adjustment to the PC in an Eriksen Flanker Task. In another study of Tomat, Wendt, Luna-Rodriguez, Sprengel, and Jacobsen (in press), however, a modified probe task failed to yield evidence for attentional adjustment in the Temporal Flanker Task.

In addition to these principle concerns, Schmidt (2013) put forward a temporal learning account of the PCE which predicts the occurrence of a PCE even for test stimuli. In short, it is assumed that responding is affected by expectations concerning the point in time when the response decision will be completed. This expectation is thought to be derived from previous experience, that is, response selection is expected to take longer if most trials are associated with more time-consuming response selection processes. It is further assumed that responding is facilitated if the expectation is met more closely, predicting an advantage if the time to complete the response selection process corresponds with the majority of trials. This should be the case in congruent trials if the PC is high and in incongruent trials if the PC is low.

As concerns the TRCE, other processes than distractor inhibition must also be considered. This is particularly so because the crucial evidence for distractor inhibition, reversal of the congruency effect after a long SOA (ruling out passive decay to baseline activation), was not observed in our study. Although assuming that the TRCE in the current study was brought about by different processes than the TRCE in previous studies in which reversal of the congruency effect did occur does not appear to a parsimonious view, other processes than inhibition, such as passive decay or stronger preparedness for the resolution of response conflict after a long SOA must be considered as possible options. Concerning the latter possibility, it is interesting that Jost et al. (2019) who investigated distractor-evoked response activation observed in trials associated with a long distractor-target SOA of 1000 ms, a biphasic pattern of distractor-evoked LRPs. More precisely, although the LRP was characterized by a drop back to baseline after an initial activation, subsequent re-activation occurred, reaching a high level before target onset. This is clearly not the pattern one would expect if the TRCE was brought about by perpetual inhibition during the course of the SOA. Rather, a longer SOA might be used to prepare for the resolution of possible distractor-target conflict, which would then speed up responding in incongruent trials. In light of the fact that for the 25%-

PC condition of our experiment the congruency effect hardly differed from 0 when the SOA was long (see Figs. 2 and 3), replicating the experiment with an even longer SOA may yield reversal of the congruency effect, lending more support for an inhibition account.

In summary, the current study demonstrated a PCE in the Temporal Flanker Task under conditions of controlled distractor-related contingencies, as well as a TRCE which was unaffected by the PC. Assuming that these two effects reflect cognitive control processes of distractor usage and distractor inhibition suggests that these processes are applied in an independent, uncoordinated manner. Alternative accounts may be investigated in follow-up studies including, for instance, a probe task methodology, longer SOAs, and analyses of physiological measures such sensory or response-related potentials in the EEG.

Declaration of Competing Interest

None.

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