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The Role of Temporal Order of Relevant and Irrelevant Dimensions Within Conflict Tasks

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Conflict tasks are commonly used to investigate control processes under situations of relevant and irrelevant sources of information. In addition to compatibility effects at a mean behavioral level, delta plot analyses of reaction time distributions reveal that the compatibility effect generally increases with time (i.e., positive delta plot slopes) across most conflict-like tasks. Critically, the underlying causes of the increasing delta plot slopes with different types of distractors are still poorly understood. The present study tested whether the relative onset of target-to-distractor processing affects the delta plot slope. Specifically, we manipulated the temporal order of relevant and irrelevant dimensions within an Eriksen flanker task (Experiment [Exp.] 1), an Arrow-Simon task (Exp. 2), and a manual Stroop task (Exp. 3a/3b). The results of the Eriksen flanker task and Arrow-Simon task revealed that the delta plots slopes were less increasing (and instead rather decreasing) when the irrelevant dimension appears first (IR condition) compared to the reversed order (RI condition)—consistent with the idea that the underlying mechanism driving the slope of the delta plot is the temporal overlap of activation between the relevant and irrelevant dimensions. In contrast, for the Stroop task, the delta plots in the RI condition were not more increasing than the ones for the IR condition. Overall, these results suggest that the temporal properties strongly influence delta plot shape, but that the temporal dynamics operating in the flanker task and the Arrow-Simon task differs from the Stroop task, at least under conditions where relevant and irrelevant information is presented sequentially.

Public Significance Statement

In many real-world situations, people are required to select and process goal-relevant information in environments overloaded with distracting—and potentially conflicting—sources of information. It is important to uncover the mental control mechanisms that prevent interference allowing successful goal-directed behavior for both practical and theoretical reasons. In the present study, we systematically investigated the temporal processing dynamics with different sources of distracting information. The results indicate that some types of distracting information are similarly processed across time whereas others are not, suggesting the existence of distractor-general and distractor-specific control mechanisms.

Keywords: Eriksen flanker task, Simon task, Stroop task, conflict, delta plots

We are constantly required to select and process task-relevant information in environments overloaded with distracting information. Thus, to execute a relevant action goal, control processes are required that shield information processing from potentially conflicting sources of information. A much-debated question in the field of cognitive psychology is whether similar or different processing mechanisms are involved when dealing with different types of irrelevant sources of information (e.g., Hübner & Többel, 2019; Treccani et al., 2009; Verbruggen et al., 2004). Recent studies emphasize the importance of considering the temporal dynamics of conflict processing (e.g., Hübner & Többel, 2019; Luo & Proctor, 2020b; Miller & Schwarz, 2021; Mittelstädt et al., 2022; Ulrich et al., 2015). One useful approach to identify the underlying dynamics is to combine experimental manipulations with distributional analyses to clarify the underlying causes of the observed mean reaction time (RT) and error-rate (ER) pattern (Hübner & Többel, 2019; Mittelstädt & Miller, 2020; Pratte, 2021).

The purpose of the present study was (a) to shed further light on potential distinct versus shared processing mechanisms across three different conflict tasks (i.e., Eriksen Flanker task, Arrow-Simon task, Stroop task) by manipulating the order of the onset of

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relevant-to-irrelevant information and (b) to investigate whether this temporal manipulation produces similar effects on the size of the compatibility effect (i.e., RT and ER) at a mean, and in particular, at a distributional RT level (i.e., the slope of RT delta plots). Recent theoretical accounts and empirical findings suggest that the slope of delta plots may reflect, at least partially, the temporal overlap of relevant and irrelevant activation (Hübner & Többel, 2019; Miller & Schwarz, 2021; Ulrich et al., 2015). Thus, to the extent that this temporal overlap contributes to the slope of delta plots, the conflict task-specific delta plots should be similarly affected by an order manipulation. Alternatively, the effects may differ across conflict tasks, reflecting that, at least partially, task-specific processes also play a role in dealing with different types of distracting information (i.e., flanker identity, spatial arrow direction, word meaning).

Delta Plots in Conflict Tasks

Within a lab setting, the most frequently used tasks to investigate conflict resolution processes are probably the Eriksen flanker task, the Stroop task, and the Simon task (see Eriksen & Eriksen, 1974; MacLeod, 1991; Simon, 1990, respectively). In versions of the Eriksen Flanker task, participants are required to respond to a central target (e.g., H = left, S = right) that is surrounded by task-irrelevant items or flankers (e.g., HHHHH vs SSHSS). When the target and the flankers indicate the same (a different) response, the stimulus is said to be compatible (incompatible; e.g., Servant & Logan, 2019; White et al., 2011). In a standard version of the visual Simon task, participants are required to respond (left vs. right) to a feature (e.g., color) of a laterally (left vs. right) presented stimulus (e.g., D'Ascenzo et al., 2021; Mittelstädt & Miller, 2020; Wühr & Heuer, 2018). When the required response matches (mismatches) the task-irrelevant stimulus location, the trial is said to be compatible (incompatible). Alternative versions of the Simon task where location information is task-irrelevant include the Word- and Arrow-Simon effects. Here, the stimulus contains irrelevant location information (e.g., LEFT, <), while the task requires responses according to another feature (e.g., color; e.g., Luo & Proctor, 2019, 2020a, 2021; Marble & Proctor, 2000). In the Stroop task, participants are required to verbally or manually respond to the font color of color words. For example, the word *BLUE* is presented either in blue font (compatible) or an alternative color (incompatible; e.g., Fennell & Ratcliff, 2019; Hedge et al., 2019; Steinhauser & Hübner, 2009).

While such conflict tasks differ with regard to the nature of the irrelevant information (i.e., Flanker task: the identity of the flankers; standard and Arrow-Simon task: the spatial and directional information; Stroop task: word meaning), task performance at the mean behavioral level is consistent. Specifically, RTs are slower, and the ER is usually higher when the trial is incompatible compared to compatible. However, differences in task performance between conflict tasks can become evident when the compatibility effect is calculated across different portions of the RT distribution, as reflected in so-called delta plots (e.g., Burle et al., 2014; De Jong et al., 1994; Schwarz & Miller, 2012). Here, RTs within compatible and incompatible conditions are sorted separately for each participant, then split into a number of bins with equal size (e.g., deciles). The compatibility effect (incompatible–compatible) is calculated for each bin, as is the mean RT across both conditions at each bin. Finally, the compatibility effect (*y*-axis) is plotted as a function of bin RT (*x*-axis). The most striking difference is the observation of positive-going versus negative-going delta plots: Typically, the compatibility effect in RT increases with increasing RT (increasing delta plot) within all of the above-mentioned conflict tasks (e.g., Luo & Proctor, 2020b; Pratte et al., 2010; Ulrich et al., 2015)—except for the location-based visual Simon task with horizontal stimuli, which usually shows decreasing delta plots (e.g., Gade et al., 2020; Hazeltine et al., 2011; Ridderinkhof, 2002), but see also Xiong and Proctor (2016) for decreasing delta plots in an auditory version of the Simon task.

In general, the underlying causes of different delta plot slopes and the factors that influence slope shape are still under debate (for some discussion, see Schwarz & Miller, 2012). A prominent account assumes that a less-positive going slope may reflect more efficient inhibitory processes (e.g., for an example specific to the Eriksen flanker & Simon tasks, see Ridderinkhof et al., 2005, 2002, respectively). Critically, such accounts require additional assumptions regarding why the slope differs in the Simon (decreasing) compared to the other (increasing) conflict tasks. First, it seems possible that differences in the shape of the delta plots might imply that somewhat different control mechanisms are (at least partially) also at play (e.g., Pratte et al., 2010; Vallesi et al., 2005). For example, the decreasing delta plot shape observed within the visual horizontal Simon task, but not in other conflict tasks could indicate that specific inhibitory processes are involved in suppressing irrelevant activation in this task (e.g., Ridderinkhof, 2002) and/or a specific involvement of motor processes (e.g., Leuthold & Schröter, 2006; Mittelstädt & Miller, 2018; Servant et al., 2016).

Second, and not mutually exclusive, the slope of delta plots may also reflect the temporal overlap between relevant and irrelevant activation (e.g., Burle et al., 2014; Miller & Schwarz, 2021, Pratte, 2021; Ulrich et al., 2015), with slope differences arising when the relative speed of distractor versus target processing changes. Specifically, it is conceivable that location-based information in the standard Simon task is processed faster than distractors in the other conflict tasks, and as a result, the irrelevant activation is already fading out when superimposed with relevant activation, resulting in decreasing delta plots (e.g., Finkbeiner & Heathcote, 2016; Hommel, 1993). Note that the fade-out may result from passive decay (e.g., Hommel, 1993, 1994) and/or active inhibition (Ridderinkhof, 2002) of location-based activation.

The theoretical idea of conflict task-specific time-based distractor processing receives support from recent modeling studies. For example, the Diffusion Model for Conflict (DMC) tasks suggest that a single—initially increasing and then decreasing—irrelevant activation function underlies all these conflict effects and that differences at a distributional level can be modeled by varying the time course of overlap from irrelevant to relevant activation (Ulrich et al., 2015). Similarly, the activation suppression (ASR) model by Miller and Schwarz (2021) assumes a race between suppression of irrelevant activation and recognition of relevant information before decision-making and motor processes take place. Fitting results suggest that the average time needed for suppressing distractor-based activation is less in the Eriksen than in the Simon task, leading to increased versus decreased delta plots (Mittelstädt et al., 2022). Thus, the modeling work suggests that the speed of processing different types of distractors (relative to targets) may be sufficient to affect the shape of delta plots. Following this, one may argue that increasing delta plots result from a relatively large temporal overlap from irrelevant to relevant activation and that the slope of delta plots should be less steep—potentially even negative—when this overlap is reduced.

To assess whether the increasing slope of delta plots can be solely explained by the relative speed of distractor-to-target processing, we manipulated the overlap of the relevant-to-irrelevant activation across three common visual-manual conflict tasks. Specifically, we chose the Eriksen flanker, the Arrow-Simon, and the Stroop task for the following reasons. These tasks use fundamentally different types of distracting information (i.e., flanker identity, arrow direction, word meaning), but they can be comparable regarding a target feature (e.g., color). Thus, using the same temporal manipulation (and experimental procedure) allows (potential) effects on delta-plot slope to be attributed to the speed and/or characteristics of distractor as opposed to target processing. Relatedly, if the temporal manipulation differentially affects task-specific delta plot slope, it is more straightforward to isolate conflict task-specific control mechanisms.

However, although the chosen tasks share the basic idea that overlap of distractor- and target-based activation produces conflict, one has to consider that they also partially differ in their type of conflict. Specifically, according to the dimensional overlap account (Kornblum et al., 1990; see also, Hommel, 2011), the distracting dimension that overlaps with a target dimension can also produce conflict at an early perceptual stage (i.e., S-S compatibility effects; e.g., identity of the central target and of the surrounding flankers, color of font of written word meaning). Conversely, distracting dimensions that overlap with the response can only produce conflict at stages when the response is selected or initiated (i.e., S-R compatibility effects; e.g., left/right direction of arrows and left/right response indicated by color). Thus, even though response-related conflict resolution processes may also be involved in the manual Stroop and Eriksen flanker task, conflict resolution in these tasks likely involves perceptual processes (e.g., Schmidt & Cheesman, 2005). In sum, the chosen tasks seem appropriate to test the temporal overlap account in an experimentally tight manner, while considering conceptual and experimental breadth. As reviewed next, this approach seems particularly important in light of previous studies that do not provide decisive evidence regarding whether increasing delta plots in these three tasks simply reflect the time course of relevant-to-irrelevant information.

Influence of Temporal Manipulations on Delta Plots

Although the present study focuses on temporal-based processing mechanisms in conflict tasks in which the delta plots are typically increasing, findings from the most prominent conflict task with decreasing delta plots—the horizontal visual Simon task—offer some hints for the temporal overlap account. First, in some Simon task studies, the delta plots were initially increasing and then decreasing, suggesting that distractor-based activation follows a reversed U-shaped time course (e.g., Ellinghaus & Miller, 2018; Ulrich et al., 2015; Wiegand & Wascher, 2005). Second, a study by Burle et al. (2005) separated irrelevant and relevant dimensions in the horizontal Simon task using a range of intervals from −400 to 300 ms (step size 50 ms). The corresponding delta plots were primarily increasing when the relevant dimension appeared before the irrelevant dimensions, but primarily decreasing for the reversed temporal order of dimensions. Based on this slope pattern, one may speculate that the decreasing delta plot slope in the horizontal Simon task may also primarily reflect the relative speed of irrelevant-to-relevant processing. However, some caution is required when interpreting this pattern because the slopes were not directly compared across SOA (stimulus-onset asynchrony) conditions, and the Simon effects were generally quite small (i.e., ranging between −7 ms and 10 ms across SOAs), with the mean compatibility effect not being significant.[1] Still, there seems good reason to assume that the temporal overlap of activation in tasks with only response-related conflict may drive the shape of delta plots. Hence, the typically increasing Arrow-Simon delta plots should be less increasing when the relevant dimension (e.g., color) is presented after the irrelevant spatial dimension of the arrow.

Interestingly, the same could be true for the Eriksen flanker tasks in which the irrelevant flankers produce incorrect motor activation (e.g., Mattler, 2003; Servant et al., 2015), but presumably already interfere during perceptual processing, for example, due to perceptual grouping (see Luo & Proctor, 2016; Moore et al., 2021), and/or limits in focusing spatial attention (see Servant et al., 2015). Specifically, using a flanker task with a vertical stimulus arrangement, Mattler (2003) investigated the influence of presenting the irrelevant flankers with different target delays (0, 100, 400 ms) on delta plot slopes. Visual inspection of delta plots showed positive-going delta plots for the 0 ms SOA and negative-going delta plots for the 100 and 400 ms SOA conditions in line with the idea that the speed of distractor-to-target processing influences the slope of delta plots. Similarly, Hübner and Töbel (2019) directly tested the idea that decreasing delta plots can also be observed in the Eriksen flanker task when postponing target onset relative to flanker onset. Visual inspection from the delta plots obtained in this study (Experiment 1, $N = 16$) indicated that at least partially decreasing delta plots were observed in the Flanker task when the relevant central target stimulus appeared 400 ms after the irrelevant flanker stimuli, whereas increasing delta plots were observed in the condition with less delay (target delays of 17 ms and 100 ms).

Unfortunately, the statistical analyses in both of these previous studies did not necessarily provide conclusive evidence for slope difference between delay conditions. Specifically, in the study by Hübner and Töbel (2019) the slopes numerically differed across conditions (slopes of .55, .13, .04, in the 17, 100 and 400 ms target-delay conditions, respectively), but the authors did not report

[1] We also applied a similar approach to that of Burle et al. (2005) within the horizontal Simon task using two SOAs (±150 ms). However, in our experiment ($N = 50$), the mean Simon effect was absent indicating the lack of an influence of the irrelevant location-based information. This finding suggests that it is difficult to observe a substantial impact of location-based activation within the horizontal Simon when the irrelevant and relevant dimension are separated temporally. As a consequence, this specific task appears unsuitable/less suited to investigate whether whether the temporal overlap manipulation influences the shape of the delta plot as the Simon effect fluctuated around zero across the full RT distribution within both SOA conditions. Future studies are clearly warranted to directly investigate the reason for this issue.

whether these differences were significant. Moreover, the three-way ANOVA with the factors of bin, SOA, compatibility did not provide evidence for differences in slopes as indicated by a non-significant three-way interaction (p = .364). Mattler (2003) did not report any delta plot slopes or distributional analyses so the interpretation is even more problematic. Thus, there still exists some uncertainty that the temporal distance of relevant-to-irrelevant information can indeed affect the slope of delta functions in the presence of perceptual conflict in the Eriksen flanker task.

Whereas all the previous studies generally favor a distractor-general temporal overlap account, there is one study which suggests that this account requires some elaboration.[2] Specifically, using a hybrid Simon-Stroop-like set-up, Kornblum et al. (1999) temporally separated the irrelevant dimensions (i.e., position and word meaning) that either overlapped with the relevant color stimulus dimension (perceptual-related/S-S conflict) or the required response (response-related/S-R conflict). Consistent with the temporal overlap account, the delta plots capturing S-R conflict generally decreased when the relevant dimension followed the irrelevant dimension (i.e., SOAs of > 100 ms). Interestingly, the delta plots capturing S-S conflict generally increased or remained rather stable even with delays up to 800 ms —even when combined with S-R compatibility. Thus, even though the delta plots were not analyzed, visual inspection suggests that the same temporal manipulation had qualitatively different effects on the conflict-type specific delta plots. Based on these findings, Kornblum et al. (1999) emphasized a distinction between perceptual and response-related conflict resolution processes. It is not clear how the potentially opposing effects of a temporal manipulation on manual Flanker- and Stroop-delta plots could be reconciled since both of these tasks involve perceptual and response-related conflict according to Kornblum et al.'s (1990) taxonomy. Before further elaborating on potential additional differences and mechanisms between these tasks, an important first step is to firmly establish whether the temporal overlap account requires elaboration when controlling for methodological aspects (e.g., target dimensions) and statistically comparing the corresponding slopes.[3] Although the size of the mean Stroop effect was modulated by the specific SOA manipulations, it is not clear whether this also affected the distributional pattern because no delta plots were reported. Thus, these prior Stroop studies do not allow clear conclusions because changes in mean RT could arise due to different delta plot patterns (e.g., Mittelstädt & Miller, 2020).

Taken together, it is still unclear whether influencing the overlap of relevant-to-irrelevant information via an SOA manipulation can affect the typically increasing slopes of delta plots in the Eriksen flanker task, the arrow-Simon task and the manual Stroop task. On the one hand, previous studies provide some hints that relatively slow distractor processing (e.g., flankers in the Eriksen task) versus fast distractor processing (e.g., horizontal locations in the Simon task) may produce increasing versus decreasing delta plots due to differences in the relative timing of distractor-to-target-based activations. In other words, increasing delta plots are usually observed when the distractor-based activation develops rather slowly before being superimposed with target-based activation. However, the slope of delta plots may not be simply influenced by the relative speed of distractor and target in a distractor-general manner, because there are also hints that the slope of delta plots partially reflects distractor-specific control mechanisms concerned with the resolution of perceptual-versus response-related conflict. In order to more directly infer similarities and/or differences across different conflict tasks, we tested the temporal overlap account using the same experimental design.

Goal of the Present Study

The goal of the present study is to investigate whether the relative timing of distractor-and-target processing can influence the slope of delta plots in the Eriksen flanker (Exp. 1), Arrow-Simon (Exp. 2) and Stroop tasks (Exp. 3a and 3b) as predicted by the temporal overlap account (see Burle et al., 2005; Hübner & Töbel, 2019; Ulrich et al., 2015). The basic experimental manipulation was inspired by previous experiments that manipulated the interval between relevant and irrelevant stimulus dimensions (see, Burle et al., 2005; Dyer, 1971; Glaser & Glaser, 1982; Hübner & Töbel, 2019; Mattler, 2003). Specifically, similar to Glaser and Glaser (1982) and Burle et al. (2005), either the relevant or the irrelevant information appeared delayed relative to the other (i.e., RI condition: relevant information is first presented followed by irrelevant information; IR condition: irrelevant information is first presented followed by relevant information). If the shape (or slope) of the delta plots are simply the result of the relative overlap from a single superimposed relevant-to-irrelevant activation function, we would expect that the slope of delta plots is more strongly positive going when the target appears before the irrelevant stimulus feature (i.e., RI condition) as opposed to delta plots when the irrelevant stimulus feature appears before the target stimuli (i.e., IR condition). Statistically, this should result in a significantly smaller delta plot slope in the IR compared to RI delay condition. Observing this pattern in a specific conflict task (i.e., Flanker, Arrow-Simon, Stroop) would provide further support for the basic assumption that the overlap of relevant-to-irrelevant activation is a crucial aspect in impacting the shape of delta plots in this task (e.g., Burle et al., 2014; Hübner & Töbel, 2019; Ulrich et al., 2015). Naturally, observing this pattern across some or all conflict tasks would suggest that these tasks share some distractor-general conflict resolution mechanisms. Conversely, distinct patterns across tasks would imply that the temporal overlap account would require some elaboration; for example, by assuming conflict task-specific processing loci and/or the consideration of alternative accounts that can produce different delta plot shapes (e.g., Schwarz & Miller, 2012; Zhang & Kornblum, 1997).

Experiment 1: Flanker Task

In the first experiment, either the central target or the surrounding flanker stimuli appeared delayed relative to the other (i.e., RI condition: relevant information is first presented followed by irrelevant information; IR condition: irrelevant information is first presented followed by relevant information).

[2] We would like to point out that we became aware of this study during the revision process. Thus, the present study was developed independently of Kornblum et al. (1999).

[3] Note that two previous studies have also investigated the time-course of Stroop interference by temporally separating the relevant and irrelevant dimensions in the vocal color naming Stroop task (Dyer, 1971; Glaser & Glaser, 1982).

Method

Participants

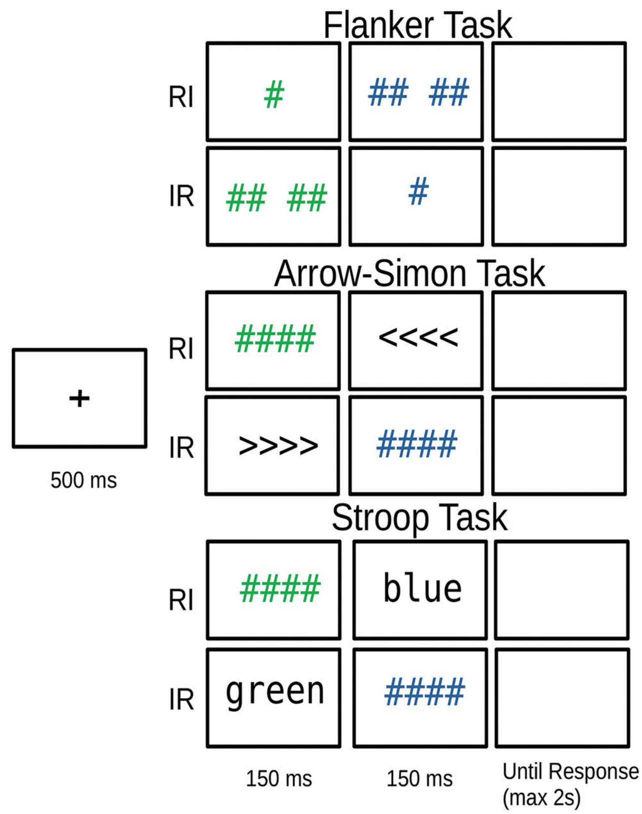
Data were collected from 50 participants (M = 22.64, range = 18–54, 40 female, 46 right-handed). Note that the sample size of 50 participants was somewhat arbitrarily yet conservatively set. Lacking any effect size estimates for the slope comparison based on previous studies using similar manipulations, we proceeded from a somewhat arbitrary effect size estimate of $d_z = .50$. Specifically, a power analysis using G*power to detect a medium-sized effect with a sample size of 50 for a less positive slope in the IR compared to RI condition would have suggested we have over 95% power to detect a significant effect (one-sided paired t test). Note that the actual effect observed in Experiment 1 was considerably larger (i.e., $d_z = 1.19$). Nevertheless, we decided to stick to a planned sample size of 50 participants for the following experiments to (a) allow for the possibility that the effect may be smaller with other conflict tasks and (b) to directly compare the pattern across experiments (i.e., see Appendix A). Three participants were removed from subsequent analyses due to poor task performance (i.e., overall ER greater than 30%).[4] All participants (plus those within the experiments reported subsequently) were recruited from the pool of psychology students at the University of Tübingen via internal departmental email lists. In this and in the following experiments, all participants provided informed consent before testing. Furthermore, all experiments adhered to the standards set by the local ethics committee and were performed in accordance with the ethical standards described in the 1964 Declaration of Helsinki. Participants could receive course credit as reward. Participants who did not require course credits were offered the option to be entered into a random draw to win vouchers for a local book shop.

Apparatus and Stimuli

The experiment was conducted online using the JavaScript library jsPsych (De Leeuw, 2015). The experiment was hosted on a local server, with the appropriate link being provided to participants. Participants completed the experiment using their personal computer within their preferred browser.[5] Participants were requested to use a standard desktop computer or laptop and to complete the experiment in a quiet environment. An initial screen-size check at the start of the experiment ensured that each participant had a minimum screen resolution of approximately 1280 × 720 pixels. Stimulus size was controlled by a calibration routine performed at the start of the experiment. The calibration routine involved adjusting the size of a rectangular shape using the mouse until the size matched that of a regular bank card. All visual stimuli were presented on a gray background. A centrally positioned black plus sign served as the fixation point. The stimuli were colored number/hashtag signs (i.e., #, see Figure 1). For half of the participants, the colors green and blue were assigned to left- and right-hand responses, respectively, whereas this order was reversed for the other half of the participants. The colored target #-sign always appeared in the center of the screen with the two colored flanker #-signs appearing on each side of the target stimulus (i.e., #####). RTs were measured from the onset of the target stimulus. Responses were key presses with the left and right index fingers using the Q and P keys of a QWERTZ computer keyboard.

Figure 1

Example Trial Sequences in the Flanker, Simon-Arrow and Stroop Tasks for Relevant-Irrelevant (RI) and Irrelevant-Relevant (IR) Presentation Order



Note. The task across all three experiments was to respond to the color (blue vs. green) of the relevant stimulus feature with left and right key presses. In the Flanker task, the relevant stimulus feature is the centrally presented hashtag symbol, while in the Arrow-Simon and Stroop tasks, the relevant stimulus feature was the color of the hashtag array. Note that in German, the words *blue* and *green* have the same number of letters. See the online article for the color version of this figure.

Procedure

All participants were instructed to respond as quickly and as accurately as possible. They first performed one practice block consisting of 32 trials, followed by 13 experimental blocks consisting of 72 trials per block. Each experimental block consisted of nine presentations of each of the eight possible stimulus displays (i.e., 2 possible target colors × 2 possible flanker colors × 2 possible target/flanker order) in a random order. Each trial began with the presentation of a fixation cross for 500 ms. In relevant-irrelevant (RI) trials, the target stimulus was presented first for 150 ms, followed directly by the

[4] Including the data of those participants excluded due to a high error rate did not change the overall result pattern in this or the subsequently reported experiments.

[5] Pilot testing was performed using popular modern browsers (e.g., Chrome/Chromium, Firefox and Safari). Participants were requested not to use Internet Explorer.

presentation of the flankers for 150 ms. In irrelevant-relevant (IR) trials, the flanker stimuli were first presented for 150 ms followed by the presentation of the target stimulus for 150 ms. Thus, in this (and all other experiments) the irrelevant and relevant dimensions were never presented simultaneously and only for the time of the SOA (i.e., 150 ms in Exp. 2 and 3a and 400 ms in Exp. 3b).[6] Both RI and IR stimulus presentation sequences were followed by a blank response interval (max duration: 2,000 ms from the onset of the target stimulus). In compatible (incompatible) trials, target and flanker stimuli had the same (different) color. After each response, feedback indicated whether the response was (1) *Richtig* (*Correct*), (2) *Falsch* (*Error*), (3) *Zu langsam* (*Too slow*), if RT $>$ 2,000 ms, or (4) *Zu schnell* (*Too fast*), if RT $<$ 100 ms. Feedback was displayed for 500 ms if the response was correct and for 1,000 ms if the response was incorrect. The fixation cross of the new trial appeared immediately after feedback (i.e., after 500 ms when the response was correct and after 1,000 ms if the response was incorrect). Thus, the response-to-stimulus interval (as measured from response onset to distractor/target onset) was constant.

Design

The dependent variables were RT and ER. The independent variables were compatibility (compatible vs. incompatible) and order (RI vs. IR). Initial analyses involved repeated measures ANOVA on RT and ER. Additional analyses involved distributional analyses (see De Jong et al., 1994) of the RT compatibility effect as a function of order (RI vs. IR). For RT, data points were calculated at nine percentile intervals (10, 20, … 80, 90%) separately for each participant.[7] For ER, conditional accuracy functions (CAFs) were calculated for five bins (0–20%, 20–40%, 40–60%, 60–80%, 80–100%). Distributional analyses were performed using the R-Package DMCfun (Mackenzie & Dudschig, 2021). Specifically, analyses assessed whether the slope of the delta function is different depending on order (i.e., RI vs. IR). To do so, we fitted a linear regression model to the delta plot for each participant and condition (see Ellinghaus & Miller, 2018; Mittelstädt et al., 2022, for example). Pratte et al. (2010) have shown via computer simulations that estimating the slope via linear regression is more appropriate than other methods.

Results

RT outliers ($<$100 ms or $>$2,000 ms; .26%) were removed from both the RT and ER analysis, whereas choice errors (10.95%) were removed from the RT analysis. Figure 2 displays the condition means for RT and ER (1st column, 1st and 3rd rows), and the respective means for the distributional analyses (1st column, 2nd and 4th rows). For RT, there was a main effect of compatibility, $F(1, 46) = 285.30$, $p < .001$, $\eta_p^2 = .86$, with faster responses to compatible trials (481 ms) than incompatible trials (536 ms). There was a main effect of order, $F(1, 46) = 247.85$, $p < .001$, $\eta_p^2 = .84$, with faster responses for IR (467 ms) than RI (550 ms) conditions. The interaction between compatibility and order was significant, $F(1, 46) = 146.39$, $p < .001$, $\eta_p^2 = .76$. Follow-up analyses showed that the compatibility effect was significant for both the RI (22 ms) condition ($t(46) = 5.52$, $p < .001$, d_z = .81, 95% CI [14, 30 ms]), and the IR (87 ms) condition ($t(46)$ = 19.81, $p < .001$, d_z = 2.89, 95% CI [78, 96 ms]), but was significantly larger for the IR condition ($t(46) = 12.10$, $p < .001$, d_z = 1.76, 95% CI [54, 76 ms]).

Visual inspection of the delta plots showed an increasing compatibility effect with slower RTs for the RI condition, whereas for the IR condition, the compatibility effect decreased with slower RTs. A linear regression was fitted to the individual participant data points, separately for order condition. A paired *t* test on the slope (RI vs. IR) was significant ($t(46) = -8.17$, $p < .001$, d_z = 1.19, 95% CI [−.39, −.23]), with a positive slope for the RI condition (.18) and a negative slope for the IR condition (−.13). Both slopes were significantly different from zero (RI: $t(46) = 7.33$, $p <$ .001, d_z = 1.07, 95% CI [.13, .24], IR: $t(46) = -3.95$, $p < .001$, d_z = −.58, 95% CI [−.19, −.06].

For ER, there was a main effect of compatibility, $F(1, 46)$ = 72.66, $p < .001$, $\eta_p^2 = .61$, with fewer error responses to compatible trials (6.10%) than incompatible trials (15.81%), and a main effect of order, $F(1, 46) = 87.78$, $p < .001$, $\eta_p^2 = .66$, with more error responses for IR (16.58%) than RI (5.33%) conditions. The interaction between compatibility and order was significant, $F(1, 46) = 67.98$, $p < .001$, $\eta_p^2 = .60$. Follow-up analyses showed that the compatibility effect was significant for the IR (18.39%) condition ($t(46) = 8.87$, $p < .001$, d_z = 1.29, 95% CI [14.21, 22.56%]), but not the RI (1.05%) condition ($t(46) = 1.46$, $p = .151$, d_z = .21, 95% CI [−.39, 2.49%]), with the difference between the RI and IR conditions being significant, ($t(46) = 8.24$, $p < .001$, d_z = 1.2, 95% CI [13.11, 21.57%]). For completeness, we also plotted the size of the compatibility effects in error rates across time. Specifically, we constructed so called conditional-accuracy function (CAF) by computing the error rates within each RT bin. As can be seen in Figure 2 (1st column, 4th row), the larger compatibility effect on error rates were mainly restricted to the faster responses.

Discussion

The results revealed that the flanker effect on mean RT was larger when the irrelevant information was presented before the relevant information (IR condition) as opposed to the reverse order (RI condition). More importantly, the order manipulation significantly affected the slopes of delta plots, with a more positive-going slope in the RI compared to the IR condition. This finding is in line with the account that the relative speed of distractor-to-target processing seems to be a driving factor in influencing the slopes of delta plots within the Eriksen flanker task.

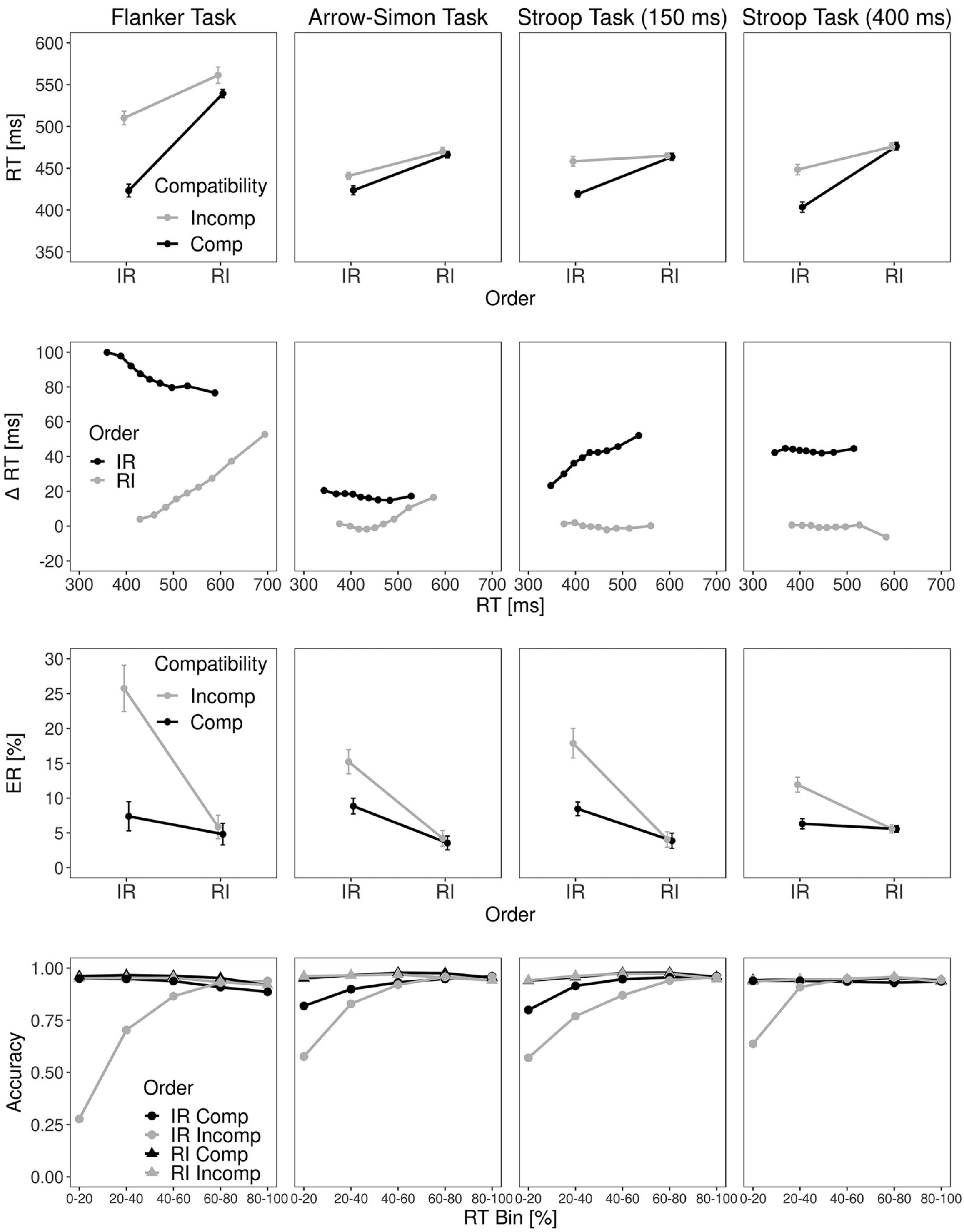
These findings nicely extend the findings of Hübner and Többel (2019; Exp. 1). As mentioned in the introduction, they also observed numerically less positive-going slopes when the target appeared sufficiently delayed (albeit they did not report a statistical significant effect for these differences). Interestingly, in our experiment, the delta plot was even negative with a delay of 150 ms, whereas the slopes were numerically still positive when the central target appeared following a delay of 100 ms or 400 ms in the study by Hübner and Többel (2019). Of course, the lack of a negative slope in this previous study may be just due to differences in between-subjects variability since Hübner

[6] We opted for a short SOA to ensure that the irrelevant dimension still affects task processing to a sufficient degree in the RI condition. The specific short SOA was chosen based on pilot-testing.

[7] It should be emphasized that the overall pattern of results remained stable when using different number of RT bins (i.e., 5, 19 bins). Hence, the choice of bins does not affect the conclusions.

Figure 2

Mean Reaction Time (Top Row) and Error Rate (Third Row) in the Flanker (1st Column), Arrow-Simon (2nd Column), and Stroop Tasks (3rd and 4th Columns) for Relevant-Irrelevant (RI) and Irrelevant-Relevant (IR) Presentation Order as a Function of Compatibility



Note. The error-bars represent the 95% CI of the within-subject standard error (Morey, 2008). The second row shows the delta plots of the four experiments with incompatible minus compatible differences in mean RT within each of nine RT bins, plotted against the bin average RTs separately for each presentation order (Relevant-Irrelevant [RI] vs. Irrelevant-Relevant [IR]). The bottom row shows the conditional accuracy function (CAFs) of the four experiments showing that a larger number of errors were produced in the IR condition, especially for the fastest RT bin.

and Töbel (2019) analyzed data of 16 participants (here: 47 participants). Furthermore, the differences may also be due to procedural differences. For example, in the study by Hübner and Töbel (2019) only the target appeared delayed—that is, only an IR condition was implemented—whereas we systematically manipulated the order of stimuli. Albeit speculative, we reason that with an unpredictable order of target to distractor onset, the effect of the temporal manipulation might be more effective in influencing delta plot shape in the current study, whereas participants somehow adapt their processing strategies to the predictable onset of target-delay order in the study by Hübner and Töbel (2019). In any case, the findings of the present experiment suggest that systematically manipulating the temporal order of irrelevant and relevant activation is a useful approach to investigate the impact of the relative speed of target-distractor processing on conflict processing.

Experiment 2: Arrow-Simon Task

The goal of the second experiment was to see whether a similar influence on delta plot slopes would emerge when conflict arises from mismatching information between response location and arrow-pointing location. Specifically, we now tested the influence of temporal order of information in an Arrow-Simon task. As in the first experiment, the relevant target dimension color appeared either before (RI condition) or after presentation of the irrelevant arrow (IR condition).

Method

Participants

Data were collected from 51 participants[8] (M = 23.53, range = 19–59, 41 female, 43 right-handed). One participant was removed from subsequent analyses due to poor task performance (i.e., overall ER greater than 30%).

Apparatus and Stimuli, Procedure, Design

The apparatus, stimuli, procedure, and design were the same as in Experiment 1, except as otherwise described. The target stimuli were four colored number/hashtag signs (i.e., #, see Figure 1), presented centrally. The task-irrelevant stimulus consisted of an arrow array, with all arrows within a single array either pointing leftward or rightward. In RI order trials, the target #-stimuli were first presented for 150 ms, followed by the presentation of the task-irrelevant arrow-stimuli for 150 ms, with this order being reversed for IR order trials (see Figure 1). Like in Experiment 1, the participants task was to respond to the colored target stimulus according to an assigned color-to-key mapping.

Results

RT outliers (<100 ms or >2,000 ms; .57%) were removed from both the RT and ER analysis, whereas choice errors (7.95%) were removed from the RT analysis. Figure 2 displays the condition means for RT and ER (2nd column, 1st and 3rd rows), and the respective means for the distributional analyses (2nd column, 2nd and 4th rows). For RT, there was a main effect of compatibility, $F(1, 49) = 34.44$, $p < .001$, $\eta_p^2 = .41$, with faster responses to compatible trials (445 ms) than incompatible trials (456 ms). There was a main effect of order, $F(1, 49) = 120.08$, $p < .001$, $\eta_p^2 = .71$, with faster responses for IR (432 ms) than RI (468 ms) conditions. The interaction between compatibility and order was significant, $F(1, 49) = 23.36$, $p < .001$, $\eta_p^2 = .32$. Follow-up analyses showed that the compatibility effect was significant for both the RI (4 ms) condition ($t(49) = 2.19$, $p = .033$, $d_z = .31$, 95% CI [.3, 7.6 ms]), and the IR (17 ms) condition ($t(49) = 6.50$, $p < .001$, $d_z = .92$, 95% CI [12, 23 ms]), but was significantly larger for the IR condition ($t(49) = 4.83$, $p < .001$, $d_z = .68$, 95% CI [8, 19 ms]).

Visual inspection of the delta plots (see Figure 2, 2nd column, 2nd row), showed a slightly increasing compatibility effect with slower RTs for the RI condition. In contrast, for the IR condition, the compatibility effect slightly decreased with slower RTs. A linear regression was fitted to the individual participant data points separately for order condition. A paired t test on the slope (RI vs. IR) was significant ($t(49) = -3.17$, $p = .003$, $d_z = .45$, 95% CI [−.13, −.03]), with a positive slope for the RI condition (.06) and a negative slope for the IR condition (−.02). Only the RI slope was significantly different from zero (RI: $t(49) = 2.81$, $p = .007$, $d_z = .4$, 95% CI [.02, .10], IR: $t(49) = -1.35$, $p = .184$, $d_z = -.19$, 95% CI [−.06, .01]).[9]

For ER, there was a main effect of compatibility, $F(1, 49) = 50.72$, $p < .001$, $\eta_p^2 = .51$, with fewer error responses to compatible trials (6.19%) than incompatible trials (9.71%). There was a main effect of order, $F(1, 49) = 90.16$, $p < .001$, $\eta_p^2 = .65$, with more error responses for IR (12.03%) than RI (3.87%) conditions. The interaction between compatibility and order was significant, $F(1, 49) = 33.32$, $p < .001$, $\eta_p^2 = .40$. Follow-up analyses showed that the compatibility effect was significant for the IR (6.38%) condition ($t(49) = 6.83$, $p < .001$, $d_z = .97$, 95% CI [4.50, 8.25%]), and the RI (.66%) condition ($t(49) = 2.02$, $p = .049$, $d_z = .29$, 95% CI [.003, 1.313%]). There was a significant difference between the compatibility effect for RI and IR conditions ($t(49) = 5.77$, $p < .001$, $d_z = .82$, 95% CI [3.73, 7.71%]).

Discussion

The results of this experiment replicate Experiment 1's major finding. In the present Arrow-Simon task, the mean RT compatibility effect was again increased in the IR compared to the RI condition and more importantly, the RI delta plot was again more positive than the IR delta plot. Thus, these findings generalize the idea that the relative speed of distractor-to-target processing influences delta plot slopes to the Arrow-Simon task (and hence to different types of distracting information). It should be noted that—contrary to Experiment 1—the slope in the IR condition was only numerically, but not reliably, different from zero. However, this may be simply due to the overall smaller compatibility effect.

[8] We intended to collect data from only 50 participants. However, the experiment link remained active for longer than intended, resulting in one extra participant being recruited. The data pattern did not change when analyzing only the data from the first 50 participants.

[9] Because the overall compatibility effects were rather small in this experiment, we also checked whether the delta plot RT pattern was generally similar when looking separately at the data of the half of participants showing larger mean compatibility effects versus small compatibility effects. This was the case in this as well as in all other experiments.

Crucially, the difference between slopes clearly replicates the pattern of Experiment 1.

Experiment 3a: Stroop Task (150 ms Interval)

In this experiment, we aimed to explore whether the finding obtained from the previous two experiments can be generalized to the manual Stroop-task. Thus, as in Experiment 2, the relevant target dimension color appeared either before (RI condition) or after the presentation of the irrelevant dimension (IR condition), but the arrows were replaced by the name of words.

Method

Participants

Data were collected from 51 participants[8] (M = 23.55, range = 18–59, 41 female, 47 right-handed).

Apparatus and Stimuli, Procedure, Design

The apparatus, stimuli, and procedure were the same as in Experiment 1 except as otherwise described. The target stimulus was a row of four colored (blue vs. green) # signs (i.e., ####, see Figure 1). Irrelevant German word stimuli (*blau* vs. *grün*; blue vs. green) were presented in black. In RI order trials, the target # stimuli was first presented for 150 ms, followed by the presentation of the irrelevant word stimuli for 150 ms, with this order being reversed for IR order trials.

Results

RT outliers (<100 ms or >2,000 ms; .46%) were removed from both the RT and ER analysis, whereas choice errors (8.57%) were removed from the RT analysis. Figure 2 displays the condition means for RT and ER (3rd column, 1st and 3rd rows), and the respective means for the distributional analyses (3rd column, 2nd and 4th rows). For RT, there was a main effect of compatibility, $F(1, 50) = 113.50$, $p < .001$, $\eta_p^2 = .69$, with faster responses to compatible trials (441 ms) than incompatible trials (462 ms). There was a main effect of order, $F(1, 50) = 76.19$, $p < .001$, $\eta_p^2 = .60$, with faster responses for IR (439 ms) than RI (464 ms) conditions. The interaction between compatibility and order was significant, $F(1, 50) = 167.51$, $p < .001$, $\eta_p^2 = .77$. Follow-up analyses showed that the compatibility effect was significant for the IR (39 ms) condition ($t(50) = 12.72$, $p < .001$, $d_z = 1.78$, 95% CI [33, 45 ms]), but not the RI (1 ms) condition ($t(50) = .88$, $p = .384$, $d_z = .12$, 95% CI [−2, 4 ms]), and that the difference between the RI and IR conditions was significant ($t(50) = 12.94$, $p < .001$, $d_z = 1.81$, 95% CI [32, 44 ms]).

Visual inspection of the delta plots (see Figure 2, 3rd column, 2nd row) showed a slightly increasing compatibility effect with slower RTs for the IR condition, whereas for the RI condition, the compatibility effect was small across all portions of the RT distribution. Thus, in contrast to the two previous experiments, the delta plot was more strongly increasing in the IR than in the RI condition. A linear regression was fitted to the individual participant data points separately for order condition. A paired t test on the slope (RI vs. IR) was significant ($t(50) = 5.89$, $p < .001$, $d_z = -.83$, 95% CI [.10, .20]), with a positive slope for the IR condition (.14) and a negative slope for the RI condition (−.01). Only the IR slope was significantly different from zero (IR: $t(50) = 6.97$, $p < .001$, $d_z = 0.98$, 95% CI [.10, .18], RI: $t(50) = -.62$, $p = .537$, $d_z = -.09$, 95% CI [−.04, .02]).

For ER, there was a main effect of compatibility, $F(1, 50) = 69.14$, $p < .001$, $\eta_p^2 = .58$, with fewer error responses to compatible trials (6.16%) than incompatible trials (10.97%). There was a main effect of order, $F(1, 50) = 101.21$, $p < .001$, $\eta_p^2 = .67$, with more error responses for IR (13.17%) than RI (3.96%) conditions. The interaction between compatibility and order was significant, $F(1, 50) = 71.22$, $p < .001$, $\eta_p^2 = .59$. Follow-up analyses showed that the compatibility effect was significant for the IR (9.43%) condition ($t(50) = 8.58$, $p < .001$, $d_z = 1.2$, 95% CI [7.22, 11.63%]), but not the RI (.18%) condition ($t(50) = .74$, $p = .462$, $d_z = .1$, 95% CI [−.32, .68%]). There was a significant difference between the compatibility effect for RI and IR conditions ($t(50) = 8.44$, $p < .001$, $d_z = 1.18$, 95% CI [7.04, 11.44%]).

Discussion

The mean results of the Stroop experiment replicate the ones obtained in the previous two experiments. Specifically, compatibility effects on mean RTs (and error rates) were again larger in the IR compared to the RI condition. Critically, however, the slopes differed significantly but in the opposite direction compared to the previous experiments. Specifically, the IR delta plot was more strongly increasing than the one of the RI condition. One possibility may be that processing of the irrelevant word is considerably slower than the processing of the previous types of irrelevant information (i.e., flankers and arrows). According to this line of reasoning, the SOA in the present experiment was too small to sufficiently separate irrelevant and relevant activation in time. Thus, we decided to conduct another experiment using a substantially longer SOA (400 ms) to see whether a pattern in line with the temporal overlap account (as found in Experiments 1 and 2) will emerge. If not, the temporal overlap account would require some more elaboration to account for conflict resolution in the Stroop task.

Experiment 3b: Stroop Task (400 ms Interval)

Method

Participants

Data were collected from 50 participants (M = 20.64, range = 18–26, 46 female, 43 right-handed).

Apparatus and Stimuli, Procedure, Design

The apparatus, stimuli, procedure, and design were the same as in Experiment 3, with the exception that the interval between the relevant and irrelevant dimensions was extended to 400 ms.

Results

RT outliers (<100 ms or >2,000 ms; .91%) were removed from both the RT and ER analysis, whereas choice errors (7.34%) were removed from the RT analysis. Figure 2 displays the condition means for RT and ER (4th column, 1st and 3rd rows), and the respective means for the distributional analyses (4th column, 2nd and 4th rows). For RT, there was a main effect of compatibility, $F(1, 49) = 141.33$, $p < .001$, $\eta_p^2 = .74$, with faster responses to compatible trials (440 ms) than incompatible trials (462 ms). There was a main effect of order, $F(1, 49) = 167.27$, $p < .001$, $\eta_p^2 = .77$, with faster responses for IR (426 ms) than RI (476 ms) conditions. The interaction between compatibility and order was significant, $F(1, 49) = 129.56$, $p < .001$, $\eta_p^2 = .73$. Follow-up analyses showed that the compatibility effect was significant for the IR (45 ms) condition ($t(49) = 12.29$, $p < .001$, $d_z = 1.74$, 95% CI: 38 to 52 ms), but not the RI (0 ms) condition ($t(49) = -.51$, $p = .609$, $d_z = -.07$, 95% CI [−3, 2 ms]), and that the difference between the RI and IR conditions was significant ($t(49) = 11.38$, $p < .001$, $d_z = 1.61$, 95% CI [38, 54 ms]).

Visual inspection of the delta plots (see Figure 2, 4th column, 2nd row) showed a relatively flat delta plot for both the RI and IR conditions. A paired t test on the slope difference (RI vs. IR) was not significant ($t(49) = .19$, $p = .849$, $d_z = -.03$, 95% CI [−.05, .06]). In addition, both the RI and the IR condition were not significantly different from zero (RI: $t(49) = -1.11$, $p = .272$, $d_z = -.16$, 95% CI [−.05, .02]; IR: $t(49) = -.65$, $p = .522$, $d_z = -.09$, 95% CI [−.06, .03]).

For ER, there was a main effect of compatibility, $F(1, 49) = 59.28$, $p < .001$, $\eta_p^2 = .55$, with fewer error responses to compatible trials (5.93%) than incompatible trials (8.75%). There was a main effect of order, $F(1, 49) = 87.10$, $p < .001$, $\eta_p^2 = .64$, with more error responses for IR (9.12%) than RI (5.56%) conditions. The interaction between compatibility and order was significant, $F(1, 49) = 57.86$, $p < .001$, $\eta_p^2 = .54$. Follow-up analyses showed that the compatibility effect was significant for the IR (5.63%) condition ($t(49) = 8.13$, $p < .001$, $d_z = 1.15$, 95% CI [4.24, 7.02%]), but not the RI (0%) condition ($t < 1$). There was a significant difference between the compatibility effect for RI and IR conditions ($t(49) = 7.61$, $p < .001$, $d_z = 1.08$, 95% CI [4.14, 7.12%]).

Discussion

Again, the mean pattern of larger compatibility effects in the IR compared to the RI condition was similar to those obtained in the previous experiments. However, even with a longer SOA, the delta plot in the IR condition was not less increasing than the delta plot of the RI condition. In fact, in this experiment the temporal overlap manipulation appeared not to affect the delta plot slopes at all. Whereas the flat delta plot in the RI condition presumably is a result of complete target processing before distractor onset, it is difficult to explain why the Stroop effect with an SOA of 400 ms did not decrease for very slow responses if the slope of delta plots only reflects the relative speed of distractor-based to target processing.

General Discussion

The present study investigated the temporal dynamics of processing mechanisms within three different conflict tasks (Eriksen Flanker task, Arrow-Simon task, Stroop task) by investigating whether and how the shape of delta plots is influenced when manipulating the temporal order of relevant and irrelevant stimulus dimensions. Based on the idea that the slope of delta plots reflects the relative speed of processing irrelevant versus relevant information, we systematically varied the onset of irrelevant and relevant stimulus dimensions. We reasoned that when the irrelevant dimension appears before the relevant dimension (IR condition), earlier irrelevant activation in the system has more time to fade out before being combined with relevant activation (e.g., due to passive decay or active suppression). Conversely, with the reversed order (RI condition), later irrelevant activation in the system is probably still developing with the fade out of this activation having taken place to a smaller degree before being combined with relevant activation. If the slope is indeed primarily affected by the relevant-to-irrelevant activation overlap, the net result of these two counteracting influences on the temporal overlap of activations should be that the delta plot slopes in the IR conditions is less positive than the ones in the RI conditions—in the most extreme case, the delta plots would become even negative in the IR condition.

Overview of Findings

Overall, the combination of findings indicate that the temporal overlap account might be sufficient to explain the delta plots slopes in the Eriksen and Arrow-Simon task, but the delta plot slopes in the Stroop task seem to reflect additional and/or different control processes. Specifically, for the Eriksen task (Experiment 1), there was an increasing delta plot slope in the RI condition and a decreasing delta plot slope in the IR condition. Similarly, the temporal manipulation yielded a similar, yet somewhat less pronounced, difference in the slope of the delta plots for the Arrow-Simon task (Experiment 2). In contrast, using the same SOA of 150 ms as in Experiments 1 and 2, for the manual Stroop task (Experiment 3a), an opposite effect on the delta plots slopes emerged—that is, the delta plots in the IR were more strongly increasing than in the RI condition. In other words, the temporal dynamics of conflict processing in the Stroop tasks were differentially affected by the temporal order manipulation because in Experiments 1 and 2, there was a positive slope in the RI condition (see Appendix A for the delta plot slope comparisons across experiments). In contrast, there was only a positive slope in the IR condition of Experiment 3a. Interestingly, the Stroop experiment using a substantially longer SOA (Experiment 3b) still did not produce less steep positive slopes in the RI compared to the IR condition. Specifically, the delta plots observed in the IR condition was now relatively stable across the whole RT distribution, resulting in a flat delta plot as in the RI condition. Next, we consider our findings in the context of temporal overlap accounts of conflict processing, followed by a discussion of possible additional assumptions that may explain why the effects of delta plots differ between the conflict tasks.

Implications for Temporal Overlap Accounts

The findings from the Eriksen flanker and Arrow-Simon task are generally in line with recent suggestions that the delta plots reflect similar time-varying processes when dealing with the distracting flankers and left-right pointing arrows (Burle et al., 2014; Hübner & Töbel, 2019; Luo & Proctor, 2020b; Ulrich et al., 2015). Specifically, the delta plot pattern suggests that when irrelevant information has a temporal processing advantage by presenting this information before the relevant information in the Eriksen and Arrow-Simon task, irrelevant activation seems to already fading out in these two tasks. In general, this fade-out can be conceptualized by passive decay and/or active suppression of irrelevant activation (Hommel, 1993; Ridderinkhof, 2002) after this activation had initially built up. The critical point, however, here is that whenever distractor-based processing is sufficiently speeded up relative to target processing in these two tasks decreasing delta plots, as in the standard location-based Simon task, can be observed. Notably, the temporal overlap of activation can also be influenced by other factors. For example, Pratte (2021) showed that the delta plots in the Eriksen flanker task can critically depend on the specific target and flanker characteristics (e.g., arrows, colored squares) even with simultaneous onset of stimuli.

Interestingly, the increasing versus flat Stroop delta plot in the IR condition in Experiment 3a (SOA = 150) versus 3b (SOA = 400) suggests that the overlap of activation also partially plays a role in the Stroop tasks, but it seems quite difficult to explain why with such a long SOA, the IR delta plot shows no sign of decrease as compared to the RI delta plot. Considering also that we have tried to minimize differences between experiments as much as possible, the qualitative different effects of our manipulation across conflict tasks are not readily explained by potential experimental particularities between tasks. Thus, differences in the temporal overlap of irrelevant and relevant activation are not sufficient to explain the temporal processing dynamics within the Stroop task, which in turn suggests that at least some conflict task-specific processing adjustments operate in the Stroop compared to the other tasks (e.g., Kornblum et al., 1999; Rey-Mermet et al., 2019).

Implications for Task-Specific Conflict Resolution

As reviewed in the introduction, conflict effects might arise during different processing stages such as perceptual or response selection stages (e.g., Kornblum, 1994; Scerrati et al., 2017). Assuming that conflict during response selection arises at least partially in all of the present conflict tasks (e.g., Kornblum, 1994; Parris et al., 2022; Scerrati et al., 2017; Treccani et al., 2009), one might speculate that the semantic irrelevant word features require somewhat different control mechanisms to shield target processing than the nonsemantic irrelevant features in the other conflict tasks. For example, perceptual conflict might arise (e.g., Parris et al., 2022; Scerrati et al., 2017) and/or higher-level task conflict due to interference between color-naming and word-reading tasks (e.g., Goldfarb & Henik, 2007).

In this context, the present Stroop findings nicely extend an earlier manual Stroop task study for which increasing/stable delta plots were observed even when presenting the irrelevant word considerably later than the relevant dimension (Kornblum et al., 1999). Note that this pattern cannot be simply attributed to S-S dimensional overlap as suggested by Kornblum et al. (1999), because in that case we would expect the same pattern for the Eriksen and Stroop task as both of these tasks share SS conflict. While the present study does not allow a clear conclusion regarding what are the driving special characteristics of the Stroop tasks, it might be illuminating to shed further light on this issue by extending the current approach to the word-based Simon task for which typically increasing delta plots are also observed (Luo & Proctor, 2020b). In any case, our results clearly demonstrate that it is important to consider differences in the speed of processing irrelevant information before inferring more elaborated and potentially distinct cognitive mechanisms. Thus, it is also possible that the delta plots in other tasks involve specific processing adjustments. In the Eriksen flanker task, for example, spatial attentional processes might reduce the impact of flanker processing due to the spatial reconfiguration of relevant and irrelevant information, whereas a spatial processing bias cannot deal with a centrally presented distracting arrow in the Arrow-Simon task.

Finally, even though we have conceptualized the present study (and hence, discussed the results) against the prediction of a temporal overlap account regarding delta plot slope, it should be emphasized that there are alternative accounts that can produce different delta plot shapes (e.g., Schwarz & Miller, 2012; for a recent discussion, see Mittelstädt & Miller, 2020). While the temporal overlap account may be extended by additional (task-specific) assumptions to explain the pattern across all conflict tasks, it may be worth investigating whether and how the observed effects may help to constrain theorizing within other accounts.

Further Methodological and Theoretical Considerations

Although the temporal order manipulation seems a straightforward way to manipulate the relative speed of irrelevant-to-relevant processing, this manipulation might have also affected additional processes. For example, presenting the irrelevant information earlier could affect task-relevant processing because participants can use the temporal interval to prepare for the task (for foreperiod effects, see Bausenhart et al., 2008; Steinborn & Langner, 2011). The present results indeed show some support for the additional impact of such preparatory processes because mean RT was shorter in the IR compared to RI condition. Note however that the overall RT advantage in the IR condition may at least partially reflect responses within some trials erroneously triggered by the irrelevant dimension. This idea seems plausible given the unpredictability of the target-to distractor onset and also receives some empirical support.[10] Specifically, mean error rates were lower in the RI compared to the IR condition in all experiments, and this effect was particularly pronounced for the fastest responses (additional analyses including the factor bin confirmed this visual inspection). However, it should be emphasized that there was no sign of speed–accuracy trade-offs regarding the vulnerability to distractor-based information since the mean compatibility effects were larger in the IR than in the RI condition for both RTs and error rates.

Nevertheless, it is certainly possible that the order manipulation influences additional processes (e.g., temporal preparation, readiness, strength of suppression), which in turn affect the slope of delta plots in the present study. In other words, it may not necessarily be true that the temporal overlap manipulation simply shifts all processes in time—in particular because of possible (additional) influences on other processes. Note, however, similar

[10] Note that a similar mean RT and mean error pattern was also observed in the horizontal-Simon task study with both RI and IR conditions by Burle et al. (2005).

arguments could also be applied to previous studies reviewed in the introduction (e.g., Burle et al., 2005; Hübner & Töbel, 2019) and potential more elaborated accounts need to consider why the present Stroop task produced such a qualitatively different delta plot pattern than the other tasks since we have tried to minimize any experimental particularities in the three experiments as much as possible (e.g., always using color as task-relevant stimulus dimensions). However, it seems still useful to apply different ways to manipulate the temporal overlap in future studies (e.g., selectively manipulating processing speed of target vs. distractor dimensions) and to investigate the effects on a distributional level. In this regard, it should be highlighted that a more methodological implication of the present findings is the usefulness of going beyond mean RT when examining the effects of experimental manipulation (e.g., Balota et al., 2008; Mittelstädt & Miller, 2020; Rousselet et al., 2017; Van Zandt, 2002). Specifically, the mean RT (and error rate) pattern was fairly consistent across experiments, but it is important to bear in mind that these similar mean patterns could arise due to different distributional patterns—as was the case in the present study.

Sequential Modulation Effects and Their Implications

Finally, we explored the order-specific delta plots pattern while taking into account the previous trial condition (i.e., previous trial compatibility and previous trial order). As can be seen in Figure B2 in Appendix B, the delta plot slopes observed in the main analyses appeared relatively independent of the specific previous trial condition which in turn indicates that the effects of the temporal manipulation on processing are independent of the ones triggered by sequential modulations. For example, the size of conflict effects decreased following incompatible trials compared to compatible trials and this conflict sequence effect (CSE) can be seen as a marker that distractor-based activation is more strongly and/or faster suppressed when it was just harmful. Considering that the CSE in the present study appeared to be exclusively reflected in a shift of delta plots along the *y*-axis without further modulating the slopes, one theoretical implication could be that sequential modulation only affects the strength of suppressing distractor-based activation but not its speed within all these conflict tasks (for a similar pattern and suggestion in the context of the horizontal Simon task, see Finkbeiner & Heathcote, 2016; Mittelstädt & Miller, 2018, 2020). On a broader level, the carry-over of conflict- and condition-specific temporal characteristics from trial-to-trial may also be relevant for research investigating sequential modulations (e.g., Freitas & Clark, 2015; Wendt et al., 2006) and conflict effect correlations across conflict tasks (e.g., Rey-Mermet et al., 2018). It is possible that control processes appear highly task specific because control acts on when (instead of where) conflict emerges (see also, Rey-Mermet et al., 2019; Schlaghecken & Maylor, 2020).

Conclusion

In summary, based on the present data, the theoretical implications are that (a) the overlap of relevant-to-irrelevant activation influences the shape of delta plots in all conflict tasks and (b) the specific effects on delta plots are different in the Stroop compared to the other tasks—presumably due to specific conflict-resolution processes at a perceptual and/or task level. Thus, these results provide further support and constraints for models of conflict tasks with time-based processing mechanisms (e.g., Ulrich et al., 2015).

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(*Appendices follow*)

Appendix A

Additional Between-Experiment Delta Plot Comparisons

In order to compare the delta plot slopes across experiments, we first conducted a mixed 2 $\times$ 4 ANOVA with the within-subject factor of order (RI, IR) and the between-subjects factor of experiment (Exp. 1, Exp. 2, Exp. 3a, Exp. 3b). This ANOVA revealed a significant main effect of order with a negative slope for IR (−.004) presentation order and a positive slope for RI presentation order (.051), $F(1, 194) = 13.76$, $p < .001$, $\eta_p^2 = .07$, that was further modulated by experiment, $F(3, 194) = 40.80$, $p < .001$, $\eta_p^2 = .39$. To investigate this interaction in more detail, separate mixed 2 $\times$ 2 ANOVAs with the factors of order and experiment were carried out for the different experiment-specific combinations. In the ANOVAs comparing Exp. 1 and Exp. 2, there was a significant interaction between experiment and order, $F(1, 95) = 25.74$, $p < .001$, $\eta_p^2 = .21$, reflecting a larger RI/IR difference within the flanker task (.310) than in the Arrow-Simon task (.081). In the ANOVAs comparing Exp. 3a and Exp. 3b, there was also a significant interaction between experiment and order, $F(1, 99) = 12.22$, $p = .001$, $\eta_p^2 = .11$. Here, follow-up t-tests indicated that the difference between the IR slopes was significantly different, $t(98.48) = 4.88$, $p < .001$, being negative (−.010) in the 400 ms SOA interval and positive (.132) in the 150 ms SOA experiment, whereas the difference between the slopes within the RI conditions was not significant, $t(98.89) = .34$, $p = .732$.

(*Appendices continue*)

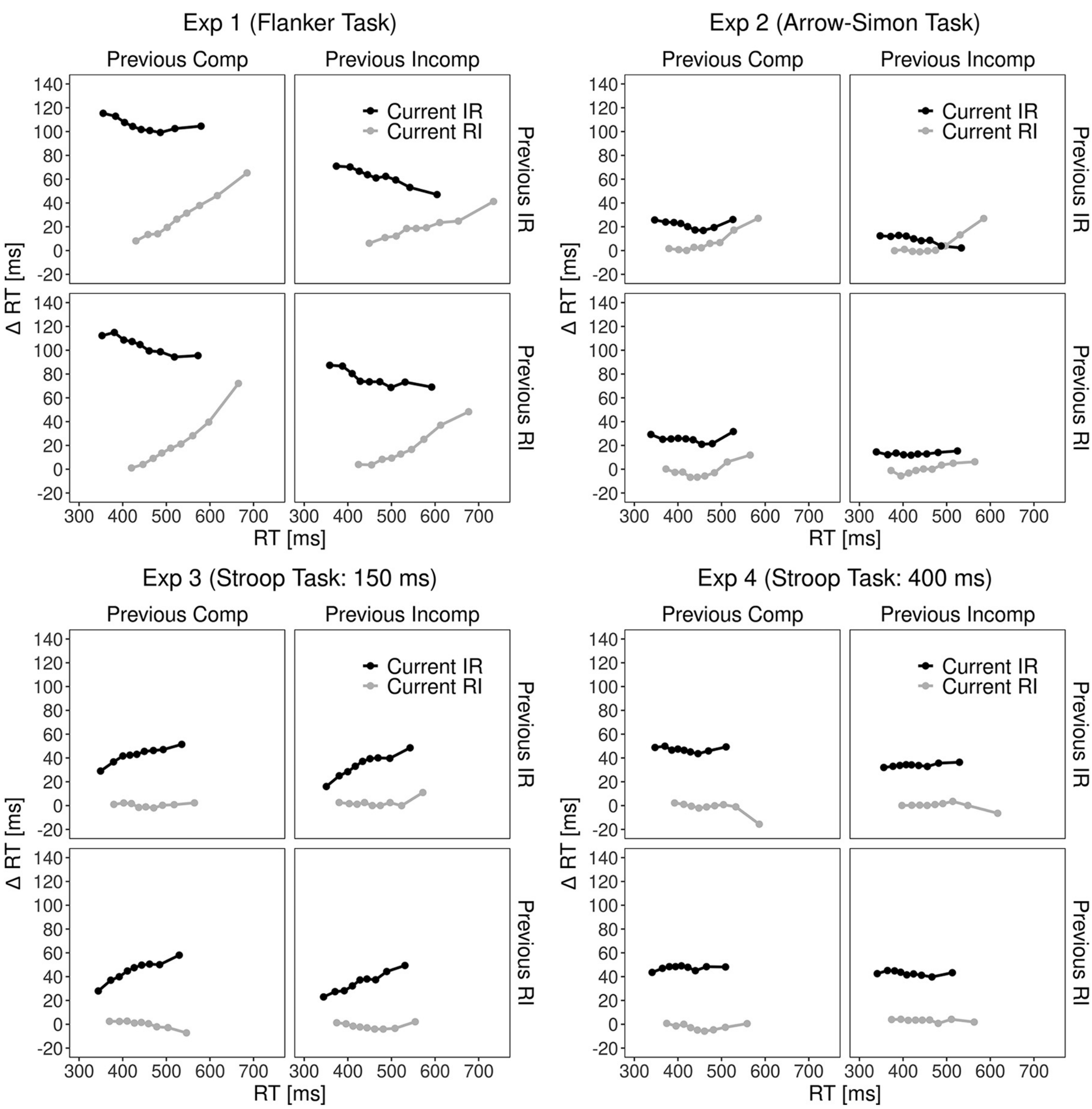
Appendix B

Sequential Delta Plots and CAFs of Experiments 1–3b

In this appendix, we show the distributional data pattern as a function of trial sequence, specifically visualizing delta plots and CAF for the RI and IR conditions in the current trial as a function of the compatibility status (previous compatible, previous incompatible) and order condition (previous RI, previous IR) of the previous trial. As can be seen in Figure B1, the delta plot slopes across all conditions were generally quite similar to the ones from the main analyses without taking into

Figure B1

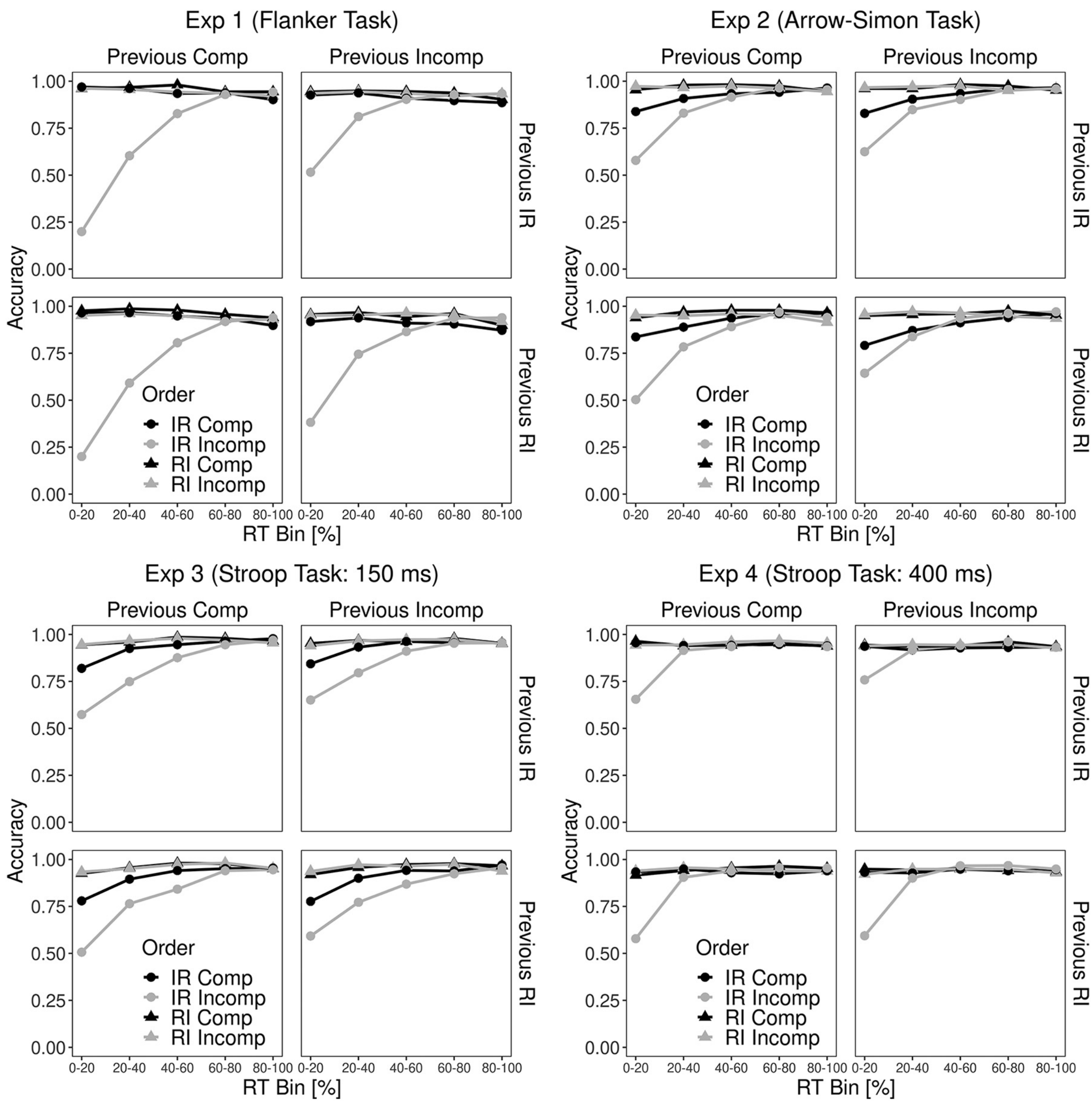
Delta Plots in Each Experiment Showing Incompatible Minus Compatible Mean RT Within Each of Nine RT Bins, Plotted Against the Bin Average RTs Separately for Each Presentation Order (Relevant-Irrelevant [RI] vs. Irrelevant-Relevant [IR]) as a function of Previous Trial Compatibility (Previous Comp vs. Previous Incomp) and Order Condition (Previous RI vs. Previous IR)



(*Appendices continue*)

Figure B2

Conditional Accuracy Function (CAF) in Each Experiment Showing Mean Accuracy in Compatible and Incompatible Conditions Within Each of Five RT Bins Separately for Each Presentation Order (Relevant-Irrelevant [RI] vs. Irrelevant-Relevant [IR]) as a function of Previous Trial Compatibility (Previous Comp vs. Previous Incomp) and Order Condition (Previous RI vs. Previous IR)



account previous trial history. Indeed, similar to the main analyses, paired *t*-tests between the RI and IR delta plot slopes separately for each specific previous trial combination revealed significant differences in Exp. 1, Exp. 2 and Exp. 3a but not in experiment 3b. Furthermore, the experiment-specific slopeswere not further modulated by previous compatibility and previous order condition.[11]

[11] Note also that in each experiment, significant mean compatibility sequence RT and ER effects (CSEs) were found (i.e., a significant interaction between current and previous trial compatibility).

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