Journal of Experimental Psychology:
Human Perception and Performance
2009, Vol. 35, No. 5, 1398–1412

0096-1523/09/$12.00 DOI: 10.1037/a0016467

Distinguishing Response Conflict and Task Conflict in the Stroop Task: Evidence From Ex-Gaussian Distribution Analysis

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It has been suggested that performance in the Stroop task is influenced by response conflict as well as task conflict. The present study investigated the idea that both conflict types can be isolated by applying ex-Gaussian distribution analysis which decomposes response time into a Gaussian and an exponential component. Two experiments were conducted in which manual versions of a standard Stroop task (Experiment 1) and a separated Stroop task (Experiment 2) were performed under task-switching conditions. Effects of response congruency and stimulus bivalency were used to measure response conflict and task conflict, respectively. Ex-Gaussian analysis revealed that response conflict was mainly observed in the Gaussian component, whereas task conflict was stronger in the exponential component. Moreover, task conflict in the exponential component was selectively enhanced under task-switching conditions. The results suggest that ex-Gaussian analysis can be used as a tool to isolate different conflict types in the Stroop task.

Keywords: Stroop task, task switching, response time distribution, cognitive conflict

The Stroop task (Stroop, 1935) is one of the most frequently applied paradigms in cognitive psychology (MacLeod, 1991). It requires that participants name a word's color but ignore its meaning, which refers to a different color. The Stroop effect denotes the finding that the latency and accuracy of color naming is strongly affected by the word's meaning. For instance, naming the font color of a word shown in blue takes longer and is more prone to error when the meaning of the word is "red" than when the meaning is "blue." The Stroop task often serves as a tool for investigating cognitive processes such as selective attention (e.g., Spieler, Balota, & Faust, 2000), automaticity (e.g., Cohen, Dunbar, & McClelland, 1990), and reading (e.g., Masson, Bub, Woodward, & Chan, 2003).

In recent years, the Stroop task was also used to examine mechanisms involved in cognitive control and conflict resolution (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). These studies typically assumed that the Stroop effect results from a conflict between relevant and irrelevant representations. However, despite the huge body of research on this issue, relatively little work has been conducted to reveal the level(s) on which these conflicts occur. The goal of the present study was to determine the contribution of different conflict types to Stroop performance. Using ex-Gaussian distribution analysis (Heathcote, Popiel, & Mewhort, 1991), we provide evidence that task conflicts and response conflicts are reflected in different features of the response time (RT) distribution.

Response Conflict and Task Conflict

The Stroop effect is frequently explained in terms of a response conflict (e.g., Cohen et al., 1990; Hunt & Lansman, 1986; Roelofs, 2003). In this view, the word automatically activates the phonological code of its meaning. If this code does not correspond to the phonological code of the color, a response conflict emerges that delays responding. In addition, Monsell, Taylor, and Murphy (2001) proposed that performance in the Stroop task is also influenced by a task conflict. They assumed that a Stroop stimulus activates not only two competing responses but also two competing tasks: color naming and word naming. To corroborate this idea, Monsell et al. (2001) showed that the interfering influence of neutral words on color naming is independent of word frequency, which suggests that the effect is mediated by stimulus–task associations. However, this result provides only indirect evidence for the idea of a task conflict. Moreover, it has been contradicted by recent evidence showing that word frequency can influence color naming under some conditions (Burt, 2002).

For a closer examination of the effects of different conflict types in the Stroop paradigm, it would be helpful to have a direct indicator not only of the strength of response conflict but also of the strength of task conflict. In recent years, such indicators have been examined in the task-switching paradigm, in which participants alternate between different tasks (Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). Task-switching studies often focus on the *switch costs*, that is, the performance decrement on task-switching trials relative to task-repetition trials. However, the paradigm can also be used to examine the influence of stimulus-induced conflicts.

For instance, Rogers and Monsell (1995) as well as Steinhauser and Hübner (2007) used stimuli that contained a target associated

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This research was supported by a grant to Ronald Hübner from the Deutsche Forschungsgemeinschaft (DFG: Hu 432/8). We thank Andrew Heathcote, Michael Masson, and an anonymous reviewer for helpful comments.

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with the relevant task and a distractor associated either with none of the tasks (univalent stimulus) or with the irrelevant task (bivalent stimuli). In bivalent stimuli, the distractor could be linked to the same response as the target (congruent stimulus) or to a different response (incongruent stimulus). The result pattern found in these studies is illustrated in Figure 1A. Performance for incongruent stimuli was impaired relative to that for congruent stimuli. This congruency effect was assumed to indicate the amount of response conflict. Most important, however, mean performance for both bivalent stimuli was impaired relative to that for univalent stimuli. This *bivalency cost* was considered to reflect the amount of task conflict (Steinhauser & Hübner, 2007).

Basically, the same method should be applicable in determining the contribution of task conflicts and response conflicts in the Stroop task. Unfortunately, Stroop studies that used univalent stimuli (e.g., with meaningless words or letter strings) reported a result pattern that differed from that in task-switching studies. As illustrated in Figure 1B, it was often found that performance for univalent Stroop stimuli was between that for congruent and that for incongruent Stroop stimuli, although it was typically closer to that for congruent stimuli (MacLeod, 1991).

From the task conflict perspective, this pattern could be interpreted as reflecting a small bivalency cost and, therefore, a small task conflict (see Figure 1B). In the Stroop literature, however, this pattern was typically explained without referring to task conflict. Rather, univalent stimuli were interpreted as a baseline against which facilitation by a congruent word and interference by an incongruent word was computed (e.g., Cohen et al., 1990). From this perspective, the pattern in Figure 1B simply indicates that interference is stronger than facilitation.

These considerations demonstrate the difficulty of dealing with bivalency effects. Because bivalent stimuli are either congruent or incongruent, one has to average across both to calculate the bivalency cost. Unfortunately, this estimates the bivalency cost correctly only if it is assumed that facilitation by a congruent stimulus and interference by an incongruent stimulus is rather similar. However, if facilitation is selectively increased, then the average performance for bivalent stimuli is reduced and, therefore, the bivalency cost is underestimated. Indeed, as discussed in the upcoming text, there are good reasons to believe that the difference between the patterns observed in the task-switching paradigm (Figure 1A) and the Stroop paradigm (Figure 1B) is attributable to two phenomena: an increased facilitation effect and a smaller task conflict in the Stroop paradigm.

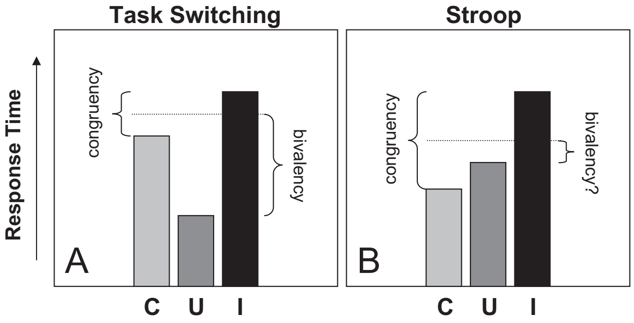

Figure 1. Typical result pattern for congruent stimuli (C), univalent stimuli (U), and incongruent stimuli (I) for (A) task-switching studies and (B) Stroop studies.

First, facilitation by congruent stimuli is probably stronger in the Stroop paradigm than in the task-switching paradigm because color and meaning of the word in congruent Stroop stimuli not only are associated with the same responses (i.e., the phonological codes “red”) but also refer to the same stimulus categories (i.e., the color “red”). It has been suggested that this produces facilitation already on the level of stimulus encoding (De Houwer, 2003; Zhang & Kornblum, 1998) or on a semantic level (Klopfer, 1996). This additional facilitation could have resulted in an underestimation of the bivalency cost in Stroop studies.

Second, several studies on task switching found that task conflicts are partially item specific; that is, performance for stimuli was impaired when these stimuli were performed with both tasks, compared with when they were performed with only one task (Waszak, Hommel, & Allport, 2003, 2004, 2005). Moreover, these bivalency costs were even more increased when participants performed the tasks in random order compared with when the tasks were performed in different blocks (Koch, Prinz, & Allport, 2005; Steinhauser & Hübner, 2007). Steinhauser and Hübner (2007) attributed this to the fact that, under constant task conditions, selective attention is more efficient in suppressing the stimulus dimension associated with the irrelevant task. In typical Stroop studies, however, either the color naming task is performed only, or color naming and word naming tasks are performed in separate blocks. This could have resulted in a reduced task conflict in Stroop studies relative to task-switching studies. Unfortunately, the few task-switching studies using color naming and word naming (Allport & Wylie, 1999; Wylie & Allport, 2000) did not include univalent stimuli and thus did not report bivalency effects.

Although these two factors could be responsible for the differences observed in the two paradigms, the main problem remains: When task conflict is small and response conflict (or its facilitation component) is strong, it is difficult to determine the bivalency cost and, therefore, the amount of task conflict. It would be desirable to have a method by which response conflict and task conflict can be measured relatively independently of each other. In this article, we show that such a method is provided by the analysis of RT distributions. We argue that response conflict and task conflict influence different features of the RT distribution. In this way, it should be possible to measure both conflict types independently of their relative size.

Ex-Gaussian Distribution Analysis

A viable method for analyzing RT distributions is fitting a theoretical distribution to the data. A theoretical distribution is any mathematical function that describes the cumulative probability or density of the range of possible RTs as a function of a set of parameters. Fitting the theoretical distribution to the empirical RT distribution implies that those parameters are identified for which the theoretical distribution best resembles the empirical distribution. These parameters can be analyzed in the same way as mean RT. In this way, one can reveal how experimental variables affect the specific feature of the RT distribution represented by each of the parameters.

A theoretical distribution that provides a good fit to empirical RT distributions is the ex-Gaussian distribution (e.g., Heathcote et al., 1991; Hohle, 1965; Ratcliff, 1979). It assumes that RT is the sum of a Gaussian (i.e., normally distributed) variable and an exponentially distributed variable. The resulting theoretical distribution is a convolution of the Gaussian and the exponential distribution. The three parameters of the ex-Gaussian are those of the two component distributions: Whereas μ and σ correspond to the mean and the standard deviation of the Gaussian component, respectively, the parameter τ represents mean and standard deviation of the exponential component. Moreover, the mean of the ex-Gaussian equals $\mu + \tau$, and its variance equals $\sigma^2 + \tau^2$ (Ratcliff, 1979).

Although the ex-Gaussian distribution provides a good fit to the empirical RT distribution, the reason for this is under debate. Initially, it has been suggested that the Gaussian component reflects perceptual and motor processes, whereas the exponential component reflects decisional stages (Hohle, 1965). Unfortunately, there is little evidence supporting this notion (e.g., Luce, 1986). Therefore, it has been argued that ex-Gaussian distribution analysis is helpful simply because of its ability to capture typical regularities in RT distributions, such as their skewness (e.g., Spieler et al., 2000).

Applied to the Stroop paradigm, ex-Gaussian analysis has revealed a characteristic and replicable pattern (Heathcote et al., 1991; Spieler, Balota, & Faust, 1996; Spieler et al., 2000): For the Gaussian parameters μ and σ, the univalent condition showed values that were between those for the congruent and the incongruent conditions. For the exponential parameter τ, however, the univalent condition showed a value that was smaller than those for the congruent and incongruent conditions. In other words, whereas the Gaussian parameters showed a pronounced congruency effect, the exponential parameter revealed a strong bivalency cost.

If we assume that bivalency costs reflect task conflict, then this finding supports the idea that Stroop stimuli induce task conflict even under conditions in which the second task (word naming) is never performed and exists only implicitly (see Monsell et al., 2001). Moreover, it suggests that ex-Gaussian analysis could be used to distinguish between response conflict and task conflict. One could hypothesize that, whereas response conflict is evident mainly in the Gaussian component, task conflict affects the exponential component more strongly. Several explanations could account for such a relation. On the one hand, the conflict types could affect different stages of processing. On the other hand, the conflict types could affect different properties of RT distribution that are more linked to the exponential component or the Gaussian component, respectively. We discuss possible reasons for this in an upcoming section.

Until now, such an interpretation of the results of ex-Gaussian analysis has never been considered. Moreover, there are even results that seem to contradict our idea: If our hypothesis is valid, one would expect bivalency costs in the exponential component to be generally observable for paradigms in which task conflict can occur. Unfortunately, Spieler et al. (2000) demonstrated that this pattern is only characteristic for the classic Stroop paradigm. For three other paradigms (the Eriksen flanker task, the global–local paradigm, and a separated Stroop paradigm), the exponential component was not affected at all by the experimental conditions. To explain their results, Spieler et al. argued that each of these paradigms requires a variant of spatial selection. In contrast, the classical Stroop paradigm requires attribute selection. Accordingly, they concluded that the observed pattern indicates the involved selection mechanism.

However, if bivalency costs in the exponential RT component reflect task conflict, then another explanation could account for the data of Spieler et al. (2000). Possibly, the amount of task conflict must be sufficiently large to produce a bivalency cost in the exponential RT component. The paradigms that Spieler et al. identified as spatial selection paradigms might produce only weak or moderate levels of task conflict. For instance, spatial separation of target and distractor, as in the separated Stroop task, could imply a more effective distractor inhibition. On the basis of this consideration, one could derive a simple prediction: If task conflict is reflected in the exponential RT component, then inducing an increased task conflict should also increase bivalency cost in this component. In this way, it might even be possible to produce a bivalency cost in a spatial selection paradigm.

Rationale of the Present Study

The present study investigated the contribution of task conflict and response conflict to Stroop performance. We hypothesized that task conflict is reflected mainly in the exponential RT component, whereas response conflict is reflected mainly in the Gaussian RT component. Accordingly, we predict a strong bivalency cost in the exponential parameter τ but a strong congruency effect in the Gaussian parameters μ and σ. Our main goal was to validate the idea that bivalency costs in the exponential component reflect a task conflict. To this end, we manipulated the amount of task conflict and examined whether this specifically affects the bivalency cost in the exponential component. On the basis of recent findings (Koch et al., 2005; Steinhauser & Hübner, 2007), we expected task conflict to increase under task mixing (i.e., when the color task and the word task are performed in random order). Accordingly, we predict that task mixing should enhance the bivalency cost in the exponential parameter. Finally, if the task conflict induced by task mixing is sufficiently strong, we should obtain a bivalency cost in the exponential parameter even for a spatial selection paradigm.

To test these predictions, we conducted two experiments. Experiment 1 used the standard Stroop paradigm, in which colored words were presented. Experiment 2 used a separated Stroop paradigm, in which word and color were spatially separated. In each experiment, the participants worked through blocks in which either the same task was performed repeatedly (constant-task blocks) or the two tasks were performed in random order (mixed-task blocks). In this way, we could examine the effect of task mixing on our conflict types. In addition, we compared task-repetition trials and task-switching trials to examine whether a task switch affects conflict, although we recently showed that this comparison is less suited to reveal differences in task conflict in a randomized task paradigm (Steinhauser & Hübner, 2007).

To increase the probability of observing task conflicts, we used manual instead of vocal responses, and we mapped two colors on each response. Following De Houwer's (2003) study, this allows for distinguishing between stimuli for which color and word are identical (*identical* stimuli; e.g., the word "RED" in red font), stimuli for which color and word require only the same response while referring to a different color (*congruent* stimuli; e.g., the word "GREEN" in red font with both colors requiring the same response), and stimuli for which color and word require different responses (*incongruent* stimuli; e.g., the word "BLUE" in red font with both colors requiring different responses). In this way, the comparison between congruent and incongruent stimuli should reflect a more appropriate measure of response conflict and should not be confounded with facilitation due to stimulus encoding (DeHouwer, 2003). Because it has been shown that, with manual responses, the reversed Stroop effect (the effect of font color on the word task) is equally strong as the Stroop effect (the effect of word meaning on the color task; Blais & Besner, 2006), we not only considered the color task but applied our analyses to both tasks.

Experiment 1

Method

Participants

Twenty-four participants (18 female, 6 male) between 19 and 33 years of age (mean 22.9) with normal or corrected-to-normal vision participated in the study. Participants were recruited at the Universität Konstanz and were paid €5/hr.

Apparatus

The stimuli were presented on a 21-in. (53.34-cm) color monitor. An IBM-congruent PC controlled stimulus presentation and response registration.

Stimuli

Stimuli were colored words comprising a width of 5.5° to 6.2° visual angle and a height of 1.9° visual angle at a viewing distance of 127 cm. We used the German words that correspond to "red," "green," "yellow," and "blue" and the letter string XXXXX. These were depicted in the colors corresponding to the color words or the color white. By combining each of the four color words with each color, 20 stimuli for the word task were realized. By combining each of the four nonwhite colors with each word (and the letter string), 20 stimuli for the color task were realized. A circle and a square, both 1.43° in diameter and presented in white, were used as cues. Cues and stimuli were presented on a black background.

Design and Procedure

On each trial, participants had to categorize either the color represented by the word or the color represented by the color. Responses were given by pressing a response button with the index finger ("green" and "red") or the middle finger ("yellow" and "blue") of the right hand. Each trial started with the presentation of the cue for 300 ms, followed by a blank screen for 900 ms. A circle indicated the color task, and a square indicated the word task. The stimulus was presented for 150 ms, followed by a blank screen. A new trial started 1,000 ms after the response. In case of an error, a feedback tone was provided.

The stimulus set consisted of four stimulus types: For univalent stimuli, the irrelevant stimulus dimension was the letter string (for the color task) or the color white (for the word task). Both are not part of the response set and, therefore, are neutral with respect to the required response. Note that the univalent stimuli of the color task were similar to those used by Heathcote et al. (1991) and Spieler et al. (2000). For identical stimuli, the irrelevant stimulus dimension contained the same color as the relevant one. For congruent stimuli, the irrelevant stimulus dimension contained a different color as the relevant one, which, however, was linked to the same response. For incongruent stimuli, the irrelevant stimulus dimension contained a color that was linked to a different response than that for the relevant one.

Participants worked through 12 test blocks of 80 trials, resulting in a total amount of 960 trials. Each block contained 32 incongruent stimuli and 16 stimuli of each of the remaining stimulus types. In eight test blocks, the order of judgments was randomized (mixed-task blocks). Trials with task switches and task repetitions were equally distributed. In four test blocks, the same judgment was relevant throughout the block (constant-task block). The test blocks were equally distributed on two experimental sessions (one constant-task block per task in each session), and the order of block types was randomized. In the first session, four practice blocks with 40 trials each preceded the test blocks (two constant task blocks, two mixed-task blocks).

Data Analysis

The first trial in each block was removed because it cannot be classified as a task repetition or task switch. Then, after calculating error rates for each condition, we also removed trials with errors. For the remaining trials with correct responses, outliers were controlled with a procedure reported in Schmiedek, Oberauer, Wilhelm, Süβ, and Wittmann (2007). Participant's condition means were calculated, and trials with response times below 200 ms and above 4 standard deviations of the mean were excluded. This procedure was repeated until no further outliers were detected. In this way, 5.5 trials (< 1%) on average were discarded for each participant. Ex-Gaussian distribution analysis was conducted with QMPE v2.18 software (Heathcote, Brown, & Cousineau, 2004; Heathcote, Brown, & Mewhort, 2002). Specifically, we applied the QMP method on trials with correct responses using 10 quantiles. The mean number of trials used for fitting each condition of each participant was 55.9 for conditions involving incongruent stimuli and 30.1 for all other conditions. Inspection of Q-Q plots (see Appendix) revealed an acceptable goodness of fit. As a result, one set of parameters (μ, σ, and τ) was obtained for each condition and each participant.

Results

Ex-Gaussian distributions were fit to each combination of the variables task (word task, color task), stimulus type (identical, congruent, univalent, incongruent), and task mode (constant, mixed/repetition, mixed/switch). Figure 2 depicts mean RTs of correct responses as well as error rates. Figure 3 depicts estimates of ex-Gaussian parameters. Note that the identical stimulus condition is presented for comparison only and is not further analyzed.

For mean RTs, error rates and parameter estimates, we constructed two dependent variables that represent our conflict effects (see Table 1): The congruency effect represents the values for incongruent conditions minus the value for congruent conditions. The bivalency cost represents the mean of the values for congruent conditions and incongruent conditions minus the value for univa-

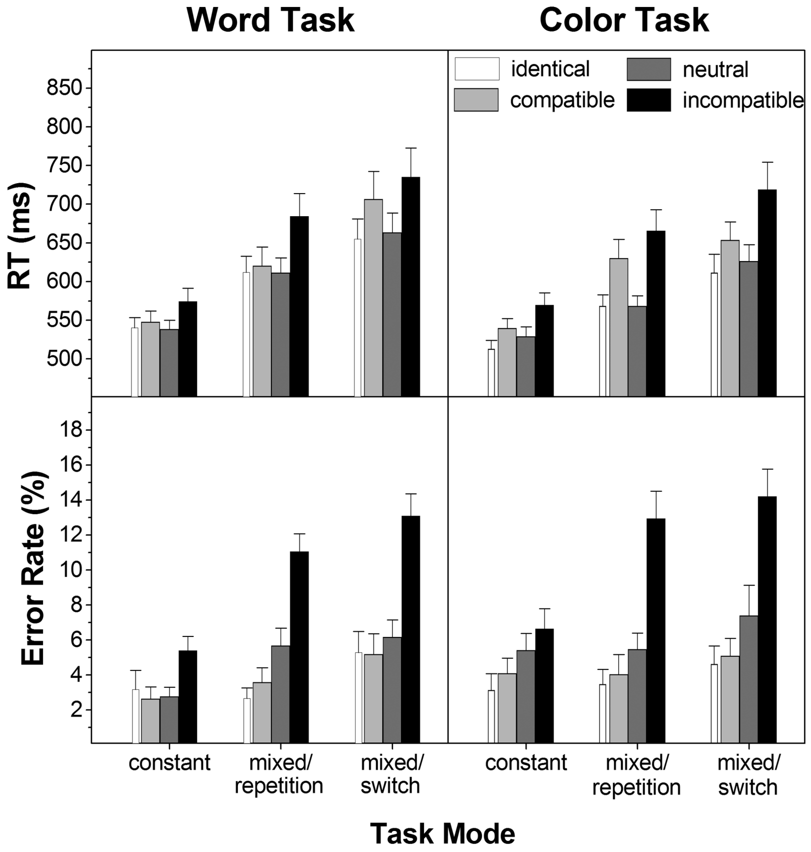

Figure 2. Response times (RT) and error rates as a function of task mode, stimulus type, and task in Experiment 1. Error bars represent standard errors of the mean.

lent conditions. Here we report separate analyses of each dependent variable considering (a) the effect of task mixing on the conflict effects, (b) the effect of a task switch on the conflict effects, and (c) mixing costs and switch costs.

Effects of Task Mixing on Conflict Effects

We examined the effects of task mixing on the conflict effects by comparing trials from constant-task blocks with task-repetition trials from mixed-task blocks. In this way, the effect of task mixing is not confounded with the effect of task-switching trials. Each dependent variable was analyzed in a two-way analysis of variance (ANOVA) with repeated measurement on the variables task (word task, color task) and task mode (constant, mixed/repetition).

Congruency effect. A significant congruency effect was obtained in the mean RT, $F(1, 23) = 33.8$, $p < .001$; and this effect was significantly larger in mixed-task blocks (50 ms) than in constant-task blocks (28 ms), $F(1, 23) = 4.86$, $p < .05$. Similarly, a significant effect was obtained in the error rates, $F(1, 23) = 77.2$, $p < .001$; which was also increased in mixed-task blocks (8.2%), compared with constant-task blocks (2.6%), $F(1, 23) = 31.5$, $p < .001$. Regarding the parameters of the distribution analysis, we obtained significant congruency effects for the μ parameter (14 ms), $F(1, 23) = 8.77$, $p < .01$; the σ parameter (10 ms), $F(1, 23) = 4.64$, $p < .05$; and the τ parameter (23 ms), $F(1, 23) = 12.5$, $p < .01$; but none of these effects were modulated by an independent variable. Taken together, congruency affected the Gaussian parameters as expected. Surprisingly, however, this was also the case for the exponential parameter.

Bivalency cost. A significant bivalency cost of 42 ms was obtained in the mean RT, $F(1, 23) = 20.5$, $p < .001$. Moreover, a significant effect of Task Mode, $F(1, 23) = 9.38$, $p < .01$; and a significant Task × Task Mode interaction, $F(1, 23) = 4.44$, $p < .05$; indicated that this cost was larger in mixed-task blocks (60 ms) than in constant-task blocks (24 ms) and that this difference was stronger for the color task (54 ms) than for the word task (18 ms). Furthermore, a significant bivalency cost was obtained in the error rates, $F(1, 23) = 12.6$, $p < .01$, and a significant effect of task mode, $F(1, 23) = 4.82$, $p < .05$, indicated that this cost was higher in mixed-task blocks (2.3%) than in constant-task blocks (0.6%). Distributional analysis indicated that the bivalency cost was not significant for the μ (-6 ms, $F < 1.5$) and σ parameters (-3 ms, $F < 1$). However, it was significant for the τ parameter (48 ms), $F(1, 23) = 22.2$, $p < .001$. Moreover, there was a significant effect of task mode, $F(1, 23) = 13.2$, $p < .01$; as well as a marginally significant Task × Task Mode interaction, $F(1, 23) = 4.11$, $p < .10$. The bivalency cost was increased in mixed-task blocks (79 ms), compared with constant-task blocks (17 ms), and this difference was higher for the color task (93 ms) than for the word task (30 ms). Taken together, these results suggest that a bivalency cost is observed mainly in the exponential component of response time and that this cost is enhanced by task mixing.

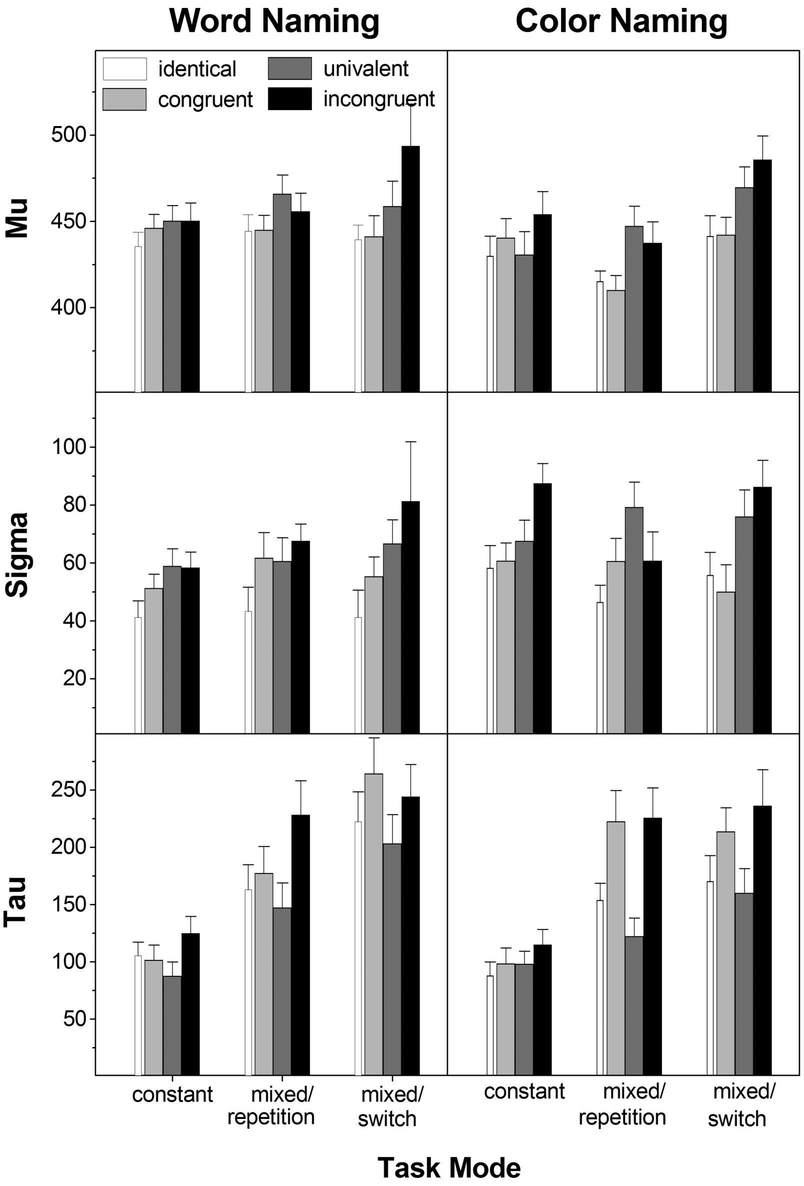

Figure 3. Estimated parameters as a function of task mode, stimulus type, and task in Experiment 1. Error bars represent standard errors of the mean.

Effects of a Task Switch on Conflict Effects

We examined the effects of a task switch on the conflict effects by comparing task-repetition trials from mixed-task blocks with task-switching trials from mixed-task blocks. Accordingly, each dependent variable was analyzed in a two-way ANOVA, with repeated measurement on the variables task (word task, color task) and task mode (mixed/repetition, mixed/switch). This analysis revealed only one significant effect involving the variable task mode. In the mean RT, the congruency effect was influenced by a significant Task × Task Mode interaction, $F(1, 23) = 5.52$, $p < .05$; indicating that this effect was larger on task-switching trials (65 ms) than on task-repetition trials (36 ms) for the color task, whereas it was larger on task-repetition trials (64 ms) than on task-switching trials (28 ms) for the word task. For all other dependent variables, neither the congruency effect nor the bivalency cost differed significantly between task-switching trials and task-repetition trials. It is interesting that, in contrast to the preceding analysis, the congruency effect in the τ parameter (14 ms) did not reach significance anymore ($F < 1.8$). Obviously, this was due to the fact that the congruency effect was strongly reduced on task-switching trials (1 ms), although this decrease did not result in a significant effect of task mode.

Switch Costs and Mixing Costs

For completeness, we also analyzed the switch costs, which refer to the impaired performance on task-switching trials relative

Table 1
Values of Congruency Effects and Bivalency Costs for Each Condition and Each Dependent Variable From Experiment 1

	Congruency effect					Bivalency cost				
Type of task	RT	ER	μ	σ	τ	RT	ER	μ	σ	τ
Word task										
Constant task	27 (7)	2.7 (0.8)	4 (8)	7 (7)	23 (12)	23 (6)	1.3 (0.8)	−2 (7)	−4 (5)	25 (10)
Mixed/repetition	64 (14)	7.5 (1.1)	11 (12)	6 (9)	51 (17)	41 (18)	1.6 (0.7)	−15 (11)	4 (10)	55 (22)
Mixed/switch	28 (19)	7.9 (1.4)	53 (24)	26 (19)	−20 (25)	57 (20)	3.0 (0.8)	8 (16)	2 (14)	51 (21)
Color task										
Constant task	30 (8)	2.5 (1.0)	14 (12)	27 (8)	16 (15)	26 (7)	0.0 (0.9)	16 (15)	7 (7)	9 (14)
Mixed/repetition	36 (14)	8.9 (1.3)	27 (12)	0 (14)	3 (24)	80 (16)	3.0 (1.0)	−23 (12)	−19 (10)	102 (19)
Mixed/switch	65 (20)	9.1 (1.2)	44 (8)	36 (11)	23 (23)	60 (18)	2.2 (1.5)	−6 (10)	−8 (10)	65 (24)
Both tasks										
Constant task	28 (5)	2.6 (0.6)	9 (7)	17 (5)	20 (9)	24 (5)	0.6 (0.6)	7 (8)	1 (4)	17 (9)
Mixed/repetition	50 (10)	8.2 (0.8)	19 (8)	3 (8)	27 (15)	60 (12)	2.3 (0.6)	−19 (8)	−7 (7)	79 (15)
Mixed/switch	47 (14)	8.5 (0.9)	48 (13)	31 (11)	1 (17)	59 (13)	2.6 (0.9)	1 (9)	−3 (9)	58 (16)

Note. A congruency effect is calculated by subtracting values of congruent stimuli from those of incongruent stimuli. A bivalency cost is calculated by subtracting values of univalent stimuli from the mean value of congruent and incongruent stimuli. All values are given in milliseconds. Parenthetical values are standard errors of the mean. RT = response time; ER = error rate; μ, σ, and τ are parameters of the distribution analysis; Mixed/repetition = mixed-task block/task-repetition trial; Mixed/switch = mixed-task block/task-switching trial.

to task-repetition trials, as well as the mixing costs, which refer to the impaired performance on task-repetition trials in mixed-task blocks relative to trials in constant-task blocks. To examine these effects independently of congruency effects and bivalency costs, we only considered univalent stimuli. Switch costs and mixing costs were computed for mean RTs, error rates, and ex-Gaussian parameters and were entered into one-way ANOVAs, with repeated measurement on the variable task (word task, color task). A significant switch cost was obtained for the mean RT (55 ms), $F(1, 23) = 23.1$, $p < .001$; and for the τ parameter (46 ms), $F(1, 23) = 8.29$, $p < .01$. A significant mixing cost was revealed for the mean RT, $F(1, 23) = 25.2$, $p < .001$; which was higher for the word task (73 ms) than for the color task (39 ms), $F(1, 23) = 8.99$, $p < .01$; as well as for the τ parameter (42 ms), $F(1, 23) = 7.56$, $p < .05$.

Discussion

In Experiment 1, we had two goals. First, we wanted to replicate the finding that the Gaussian RT component shows mainly a congruency effect, whereas only the exponential RT component shows a bivalency cost (Heathcote et al., 1991; Spieler et al., 1996, 2000). Second, we wanted to test the prediction that bivalency costs in the exponential component are enhanced by task mixing. These predictions were largely confirmed. We found a significant congruency effect but no bivalency cost in the Gaussian parameters. In contrast, the exponential parameter showed a significant bivalency cost, which was enhanced in mixed-task blocks. These results support the idea that bivalency costs in the exponential component reflect task conflict. When the tasks are mixed in a block, the distractor dimension can activate the irrelevant task more efficiently, which implies a stronger task conflict.

In contrast to our prediction, we also obtained a congruency effect in the exponential parameter. However, this effect was obtained only in the analysis of task-mixing effects. Moreover, closer inspection of Figure 3 reveals that it is mainly due to task-repetition trials of the word task in mixed-task blocks. The fact that the exponential parameter showed no congruency effect in the remaining conditions suggests that this result should be interpreted with caution. Experiment 2 will show whether this observation is replicable.

Some of our results differ from those of other studies. First, no bivalency costs were found in constant-task blocks. This is surprising because this was the condition under which earlier studies using very similar stimuli found this effect (Heathcote et al., 1991; Spieler et al., 2000). Second, our effects were rather similar for the color task and the word task. In other words, we did not obtain the typical strong asymmetry between the effect of word on the color task (the Stroop effect) and the effect of color on the word task (the reversed Stroop effect). As discussed earlier, both findings are presumably a consequence of the fact that we used a manual version of the Stroop task. This seems to reduce task conflicts and response conflicts in general, and it diminishes the relative dominance of the word task over the color task (Blais & Besner, 2006).

Experiment 2

Spieler et al. (2000) found that bivalency costs in the exponential component are restricted to the classical Stroop paradigm. No such effect was observed in a separated Stroop task, a flanker task, or a global–local task. They explained this by assuming that the bivalency cost is an indicator of attribute selection. In contrast, we hypothesized that task conflicts are reduced in spatial selection tasks because these tasks allow a strong suppression of distractor influence by means of spatial selective attention. As a consequence, bivalency costs should be observable even in spatial selection tasks when task conflicts are increased, for instance, by task mixing. Therefore, we conducted a second experiment in which a separated Stroop task was performed in constant-task blocks and mixed-task blocks. We predicted that bivalency costs should be observable at least in the mixed-task blocks.

Method

Twenty-four participants (15 female, 9 male) between 19 and 43 years of age (mean 23.8) with normal or corrected-to-normal vision participated in the study. Participants were recruited at the Universität Konstanz and were paid €5/hr. The experiment differed from Experiment 1 in a single aspect: The word was always presented in white font. In addition, a filled rectangle, 6.3° wide × 1.9° high, was displayed in one of the four colors. The two stimuli were located above and below the screen center; the stimulus located above the center was randomized across trials. The same analyses were computed as in Experiment 1. Visual inspection of Q-Q plots initially revealed a strong deviation of predicted and observed values for mixed-task blocks of the word naming task. To improve the fit, we applied a stronger criterion for outlier exclusion for this condition (3.5 standard deviations for task-repetition trials and 3 standard deviations for task-switching trials, respectively). The resulting Q-Q plots are provided in the Appendix. On average, 13.8 trials (1.4 %) per participant were discarded as outliers. The mean number of trials for each condition and participant that was used for fitting was 55.8 for conditions involving incongruent stimuli and 29.3 for all other conditions.

Results

The data were analyzed in the same way as in Experiment 1. Mean RTs of correct responses and error rates are shown in Figure 4. Estimates of ex-Gaussian parameters are provided in Figure 5. Again, congruency effects and bivalency costs were calculated for mean RT and each parameter (see Table 2), and the effects of task mixing and task switches on these measures were examined separately.

Effects of Task Mixing on Conflict Effects

We compared trials from constant-task blocks with task-repetition trials from mixed-task blocks to examine the effect of task mixing on the two conflict effects. Each dependent variable was analyzed in a two-way ANOVA, with repeated measurement on the variables task (word task, color task) and task mode (constant, mixed/repetition).

Congruency effect. For the mean RT, a significant congruency effect of 10 ms was obtained, $F(1, 23) = 5.79$, $p < .05$. Furthermore, a significant effect was obtained in the error rates, $F(1, 23) = 42.4$, $p < .001$; which was qualified by a significant Task × Task Mode interaction, $F(1, 23) = 6.86$, $p < .05$; indicating that the word task led to a larger congruency effect for mixed-task blocks (5.3%) than for constant-task blocks (2.8%), whereas the color task led to very small congruency effect for mixed-task blocks (0.8%) but a large effect for constant-task blocks (2.7%).

With respect to the results of the distributional analysis, a significant congruency effect of 15 ms was obtained for the μ parameter, $F(1, 23) = 4.36$, $p < 0.05$; which was qualified by a Task × Task Mode interaction, $F(1, 23) = 4.85$, $p < .05$; indicating that the word task led to a larger congruency effect for mixed-task blocks (30 ms) than for constant-task blocks (9 ms),

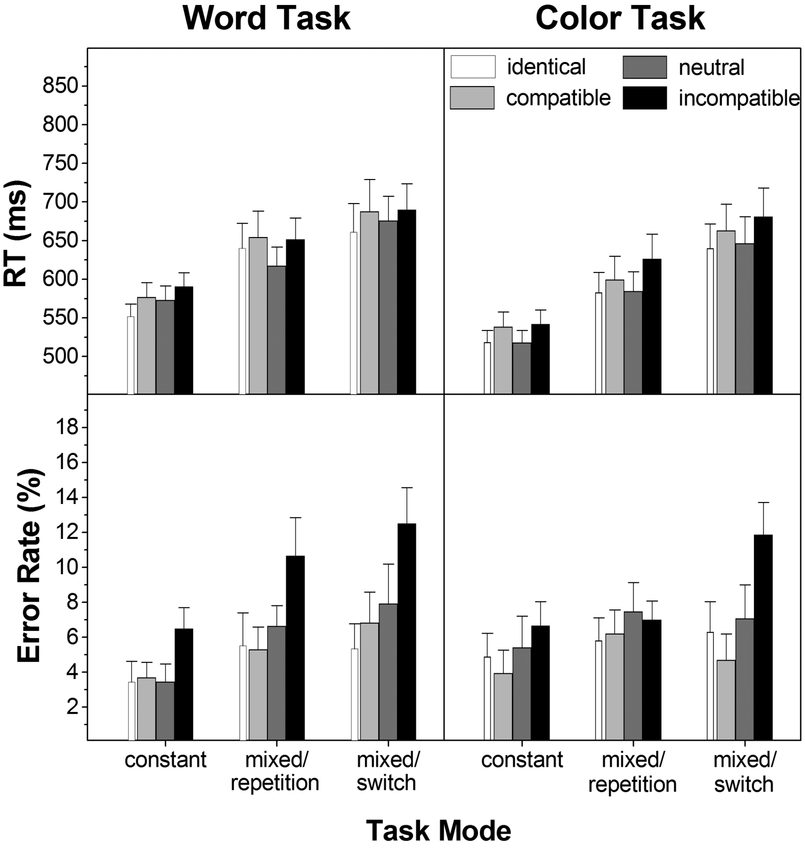

Figure 4. Response times (RT) and error rates as a function of task mode, stimulus type, and task in Experiment 2. Error bars represent standard errors of the mean.

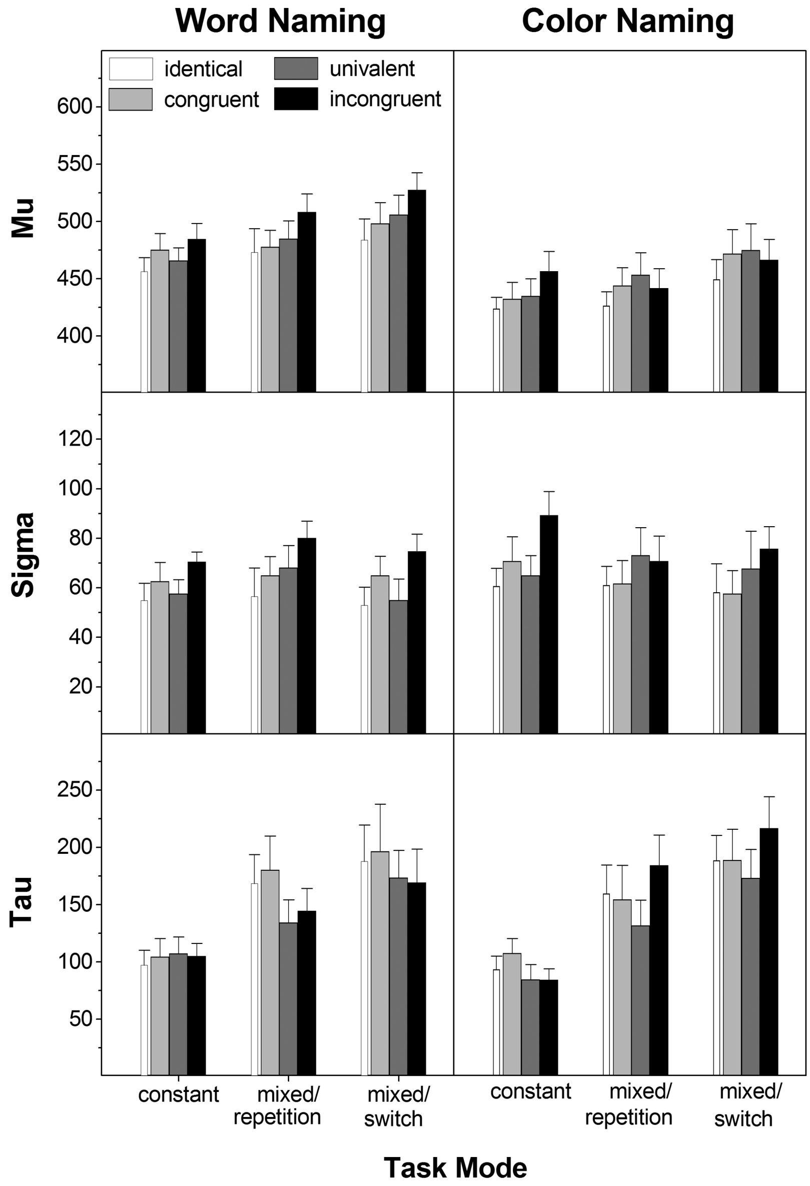

Figure 5. Estimated parameters as a function of task mode, stimulus type, and task in Experiment 2. Error bars represent standard errors of the mean.

whereas the color task led to a negative congruency effect for mixed-task blocks (−2 ms) but a positive effect for constant-task blocks (24 ms). A significant effect of 13 ms was also observed for the σ parameter, $F(1, 23) = 10.2$, $p < .01$. For the τ parameter, the Task Mode × Task interaction reached significance, $F(1, 23) = 4.58$, $p < .05$; this, however, reflects the fact that a congruency effect of 30 ms was obtained only for color-task trials in mixed-task blocks, whereas all other conditions in this analysis showed small or negative congruency effects (see Table 2). Taken together, our analyses revealed a congruency effect mainly for the Gaussian RT components.

Bivalency cost. A significant bivalency cost of 24 ms was obtained for the mean RT, $F(1, 23) = 23.8$, $p < .001$. However, a marginally significant Task × Task Mode interaction, $F(1, 23) = 3.52$, $p < .05$, indicated that this effect was increased in mixed-task blocks (32 ms), compared with constant-task blocks (16 ms) and that this increase was larger for the word task (25 ms) than for the color task (6 ms). No significant bivalency costs were obtained for the error rates (0.5%, $F < 1$) as well as for the μ and σ parameters (5 ms, $F < 1$; and 5 ms, $F < 1.3$, respectively). With respect to the τ parameter, however, we observed a significant bivalency cost of 19 ms, $F(1, 23) = 4.77$, $p < .05$. Although there was no significant effect of task mode, there was again a clear trend toward an increased bivalency cost for mixed-task blocks (33 ms) than for single-task blocks (5 ms) in the τ parameter, $F(1, 23) = 2.17$, $p < .16$. Taken together, we found again that the bivalency cost was mainly obtained in the exponential RT component.

Table 2
Values of Congruency Effects and Bivalency Costs for Each Condition and Each Dependent Variable From Experiment 2

	Congruency effect					Bivalency cost				
Type of task	RT	ER	μ	σ	τ	RT	ER	μ	σ	τ
Word task										
Constant task	13 (7)	2.8 (0.8)	9 (11)	8 (7)	1 (14)	11 (5)	1.6 (0.8)	14 (8)	9 (7)	−2 (11)
Mixed/repetition	−3 (15)	5.3 (1.3)	30 (13)	15 (9)	−36 (25)	36 (12)	1.4 (1.0)	8 (11)	4 (9)	28 (21)
Mixed/switch	2 (22)	5.7 (1.2)	29 (11)	10 (9)	−27 (29)	13 (13)	1.7 (0.9)	7 (9)	15 (8)	9 (18)
Color task										
Constant task	4 (6)	2.7 (1.1)	24 (12)	19 (6)	−23 (15)	22 (6)	−0.1 (1.0)	9 (11)	15 (8)	11 (12)
Mixed/repetition	27 (10)	0.8 (1.1)	−2 (15)	9 (11)	30 (20)	28 (9)	−0.9 (1.3)	−11 (14)	−7 (8)	38 (18)
Mixed/switch	18 (13)	7.2 (1.4)	−5 (12)	18 (6)	28 (19)	26 (14)	1.2 (1.6)	−6 (21)	−1 (14)	30 (23)
Both tasks										
Constant task	9 (5)	2.7 (0.7)	17 (8)	13 (5)	−11 (11)	16 (4)	0.8 (0.7)	12 (7)	12 (5)	5 (8)
Mixed/repetition	12 (9)	3.1 (0.9)	14 (10)	12 (7)	−3 (17)	32 (7)	0.2 (0.8)	−1 (9)	−1 (6)	33 (14)
Mixed/switch	10 (12)	6.4 (0.9)	12 (8)	14 (6)	0 (18)	19 (10)	1.5 (0.9)	1 (11)	7 (8)	19 (15)

Note. A congruency effect is calculated by subtracting values of congruent stimuli from those of incongruent stimuli. A bivalency cost is calculated by subtracting values of univalent stimuli from the mean value of congruent and incongruent stimuli. All values are given in milliseconds. Parenthetical values are standard errors of the mean. RT = response time; ER = error rate; μ, σ, and τ are parameters of the distribution analysis; Mixed/repetition = mixed-task block/task-repetition trial; Mixed/switch = mixed-task block/task-switching trial.

Effects of a Task Switch on Conflict Effects

Again, we examined the effects of a task switch on the conflict effects by comparing task-switching trials with task-repetition trials from mixed-task blocks. Our dependent variables were analyzed in a two-way ANOVA, with repeated measurement on the variables task (word task, color task) and task mode (mixed/repetition, mixed/switch). There was only one significant effect involving the variable task mode. The analysis of the congruency effect in the error rates revealed a significant interaction between task mode and task, $F(1, 23) = 9.56$, $p < .01$. The congruency effect was comparable on task-switching trials (5.7%) and on task-repetition trials (5.3%) for the word task, but it was larger on task-switching trials (7.1%) than on task-repetition trials (0.8%) for the color task.

Switch Costs and Mixing Costs

Again, we analyzed switch costs and mixing costs using data from univalent stimuli only. To this end, we conducted one-way ANOVAs with repeated measurement on the variable task (word task, color task). A significant switch cost was revealed in the mean RT (60 ms), $F(1, 23) = 25.9$, $p < .001$; as well as in the τ parameter (40 ms), $F(1, 23) = 4.93$, $p < .05$. Similarly, a significant mixing cost was obtained in the mean RT (56 ms), $F(1, 23) = 20.7$, $p < .001$; in the error rates (2.6%), $F(1, 23) = 12.8$, $p < .01$; and in the τ parameter (37 ms), $F(1, 23) = 9.31$, $p < .01$. In none of these analyses was a significant effect of task observed.

Discussion

Experiment 2 tested whether bivalency costs can be observed even in a separated Stroop paradigm when the tasks are mixed. Although the effects were much weaker and noisier than in Experiment 1, they were qualitatively similar. We obtained a clear bivalency cost in the exponential component. Moreover, as in Experiment 1, we found a tendency that this effect was enhanced in mixed-task blocks. In contrast, the Gaussian component showed only a congruency effect. As in the previous experiment, our data revealed also a congruency effect in the exponential component for some conditions. However, whereas Experiment 1 produced such an effect only in task-repetition trials of mixed-task blocks for the word task, Experiment 2 produced such an effect in mixed-task trials for the color task. Given this inconsistency, it is questionable whether these effects have a systematic source. Rather, it seems that, whereas bivalency effects are rather consistent across conditions, congruency effects are generally more instable. The following section summarizes our findings and discusses their implications.

General Discussion

The goal of the present study was to examine the contribution of task conflict to performance in the Stroop paradigm. More specifically, we investigated the idea that task conflict and response conflict affect different properties of the RT distribution: Whereas response conflicts mainly affect the Gaussian component, task conflicts are more pronounced in the exponential component. Evidence for this notion can be derived from studies showing that a congruency effect is found in the Gaussian component, whereas a bivalency cost is found in the exponential component (Heathcote et al., 1991; Spieler et al., 1996, 2000).

In the present study, we aimed at replicating this result and wanted to show that this finding can be interpreted in terms of response conflict and task conflict. We conducted two experiments using standard Stroop stimuli (Experiment 1) and separated Stroop stimuli (Experiment 2). Participants performed the color task and the word task in constant-task blocks and mixed-task blocks. In this way, we tested the predictions that task mixing enhances the bivalency cost in the exponential RT component and that this can lead to a bivalency cost even in a separated Stroop paradigm.

Our findings can be summarized as follows. We not only replicated the mentioned results but also confirmed our predictions. Task mixing enhanced specifically the bivalency cost in the exponential RT component. This supports the idea that the bivalency cost is an indicator of task conflict. When the tasks are mixed in a block, the irrelevant stimulus dimension should be more effective in activating the irrelevant task (Steinhauser & Hübner, 2007). Moreover, with mixed tasks, we observed a bivalency cost even in a separated Stroop paradigm. This contradicts the assumption of Spieler et al. (2000) that this pattern is indicative of an attribute selection process. Rather, our result suggests that the bivalency cost is a general phenomenon that, however, requires a minimum amount of task conflict to be observable. When the task is constant and the distractor dimension can be suppressed by means of spatial attention, then task conflict is probably too weak to produce a bivalency cost.

In contrast to what is typically observed, we obtained a bivalency cost already in the mean RTs of Experiment 1. This may be due to the specific paradigm we used. With a manual response and a 2:1 mapping, we could eliminate the influence of facilitation on the level of stimulus encoding. Furthermore, response conflict for the color task was generally diminished, which is typical for manual responses (Blais & Besner, 2006). These two reasons could be why we obtained only a small congruency effect, which was not sufficient to mask the bivalency cost.

Although our hypotheses focused mainly on effects in RT distributions, we also examined congruency effects and bivalency costs in the error rates. These effects were rather similar to what we obtained in the RTs with one exception. Error rates seem to be more sensitive to congruency effects than to bivalency costs. This might be due to the fact that task conflict cannot lead to errors for congruent stimuli. When the response is triggered by the wrong task in case of a task conflict, this leads to an error only when both tasks are associated with different responses (Meiran & Daichman, 2005; Steinhauser & Hübner, 2006, 2008). Accordingly, the frequency of errors due to task conflicts is underestimated for congruent stimuli, which increases congruency effects but reduces bivalency effects in the error rates. From this, one can conclude that error rates are less appropriate for examining these effects than RTs.

In addition, we analyzed further effects typically reported in task-switching studies: switch costs, which refer to the impaired performance on task-switching trials relative to task-repetition trials, and mixing costs, which refer to the impaired performance on task-repetition trials from mixed-task blocks relative to trials from constant-task blocks. To obtain a measure of these effects that is independent of conflict, we used only trials with univalent stimuli for these analyses. We found that both cost types were mainly observable in the exponential component of RT.

This finding also supports our hypothesis that task conflict is related to the exponential RT component. On the one hand, switch costs partially reflect a task conflict that is caused by a proactive effect of recent task performance. It is assumed that, after a task switch, responses are more strongly associated with the previously relevant task (Schuch & Koch, 2003; Steinhauser & Hübner, 2006). This causes a conflict that delays responding. On the other hand, mixing costs were assumed to reflect processes associated with the resolution of conflict (Hübner, Futterer, & Steinhauser, 2001; Rubin & Meiran, 2005; Steinhauser & Hübner, 2005). Thus, both measures are related to task conflict, although in different ways. Accordingly, it is plausible that these measures also affect the exponential RT component.

Of course, our reasoning strongly depends on the assumption that univalent and bivalent stimuli differ with respect to the amount of task conflict induced. Whereas it is plausible that bivalent stimuli are associated with multiple tasks, it is less clear whether univalent stimuli are associated with a single task only and thus can serve as a baseline for calculating bivalency costs. For instance, there is evidence that the color white is not necessarily neutral with respect to the color task, at least when oral naming of the color is required (Masson, Bub, & Ishigami, 2007). However, the fact that we used a manual classification task in which "white" was not mapped on a response suggests that the association between this color and the color task is rather weak and that these stimuli are really univalent. Nevertheless, it is possible that the bivalency cost is slightly underestimated, because stimuli for the color task are never really univalent. For the word task, our univalent stimuli were the same colored XXXXX string as in several earlier studies (e.g., Heathcote et al., 1991; Spieler et al., 2000). It is interesting that a recent study by Roberts and Besner (2005) demonstrated that this stimulus is processed similarly as a mere color path and does not activate reading processes.

Taken together, our data support the idea that task conflict affects mainly the exponential RT component, whereas response conflict affects mainly the Gaussian RT component. However, so far we did not consider an explanation for this phenomenon. As mentioned earlier, the functional significance of the two RT components is still under debate. Strictly speaking, the ex-Gaussian analysis assumes that the exponential and the Gaussian RT components reflect two additive processing stages (Luce, 1986). From this perspective, it is conceivable that, for instance, task conflicts occur on an earlier (exponentially distributed) stage of processing, whereas response conflicts occur on a later (Gaussian-distributed) stage of processing (although the ex-Gaussian distribution does not imply a specific order of stages).

However, different patterns for exponential and Gaussian components can also emerge without assuming additive processes. Spieler et al. (2000) simulated such a result successfully using a random walk model. This model type simulates response selection by increasing or decreasing a counter with a probability p on each time step. A correct response is selected when the counter exceeds a threshold, whereas a wrong response occurs when the counter falls below another threshold. Accordingly, response time on a given trial depends strongly on p, which is assumed to represent the evidence provided by the stimulus. In Spieler et al.'s model (2000), p is drawn from a distribution with a given mean and variability on each trial.

Using this model, Spieler et al. (2000) showed that the present results can be simulated when (a) the mean of p is reduced for incongruent stimuli, whereas (b) the variability of p is increased for congruent trials. Whereas the former reflects the interference for incongruent stimuli, the latter reflects a randomly varying, facilitating influence for congruent stimuli. Spieler et al. admitted that this is a post hoc explanation, which is merely tentative. Moreover, this model is not congruent with the present distinction between task conflict and response conflict and, therefore, cannot explain why task mixing affects mainly the bivalency cost. However, this model demonstrates that different effects for exponential and Gaussian RT components are possible without assuming different, additive processing stages.

Another way to interpret Gaussian and exponential RT components is to assume that, whatever affects the distribution skew is likely to affect the exponential component and that whatever affects symmetric aspects of the distribution is more likely to be captured by Gaussian parameters. Basically, the skew of an RT distribution is affected when the probability of slow responses is selectively altered or when a variable affects slow responses more strongly than it affects fast responses. As a consequence, one could interpret our results by assuming that task conflicts impair mainly slower responses, whereas response conflicts impair both fast and slow responses.

To explore the validity of this interpretation, we examined bivalency costs and congruency effects as a function of RT. For each condition and participant, trials were rank-ordered according to RT and were separated into five quantiles. For each quantile, mean bivalency costs and congruency effects were computed and were averaged across participants and across tasks. The results depicted in Figure 6 reveal that bivalency costs, as well as congruency effects, increase with an increasing RT.[1] However, in contrast to the congruency effect, the bivalency cost is tremendously increased in the slowest quantile of the mixed-task conditions of both experiments. In other words, bivalency influences selectively slow trials in those conditions in which also the exponential component shows a strong bivalency cost. This suggests that bivalency costs in the exponential component emerge because bivalency selectively impairs slow responses and, therefore, influences the skew of the distribution.

Several explanations could account for such a phenomenon. First, task conflicts could directly increase the probability of slow outliers. For instance, the detection of a task conflict could imply that an additional conflict resolution process is triggered, which delays processing. In contrast, a response conflict could imply that only "standard" processing is slowed. Second, slow responses could be more likely to go along with a large task conflict. For instance, slow responses could emerge particularly when preparation is insufficient or when preparation fails. At the same time, insufficient preparation should increase task conflict. Because of this, task conflicts occur more frequently on slow responses than on fast responses.

Finally, slow responses could be more susceptible to task conflict. For instance, dual-route models (e.g., Hommel, 1998; Kornblum, Hasbroucq, & Osman, 1990; Logan, 1988; Schneider & Shiffrin, 1977) often assume that slow responses are more likely to reflect the outcome of a slow, "controlled" process, whereas fast responses are more likely to be due to a fast, "automatic" process. If we assume that task conflicts occur mainly during the controlled process, then slow responses should involve a stronger task conflict. The idea that task conflicts play a stronger role for controlled processing can be explained by assuming that controlled processing includes a selection process in which task-relevant representations (e.g., the relevant stimulus categories) are selected before response selection. Task conflicts could delay particularly this task selection stage. In contrast, automatic processing could require only the selection of the response according to its activation value. Such a process would be more susceptible to response conflict (i.e., to the fact as to whether the irrelevant stimulus dimension activates the same or a different response).

At this point, we cannot definitely decide which model accounts best for our results. Moreover, it is very likely that slow responses are not sufficient to fully account for effects in the exponential parameter of the ex-Gaussian distribution. A model would be helpful for understanding the relationship between the ex-Gaussian parameters and the different conflict types. Unfortunately, existing models of the ex-Gaussian parameters (e.g., Schmiedek et al., 2007; Spieler et al., 2000) are probably too simplistic to account for a task as complex as the Stroop paradigm. However, even if we do not fully understand the mechanisms underlying our findings, they demonstrate that ex-Gaussian analysis might provide an important tool for examining the different influences on, and sources of, response conflicts and task conflicts in the future. Because the analysis is applicable to relatively small trial numbers, it can be used to distinguish effectively between conflict types in standard experiments. However, to reveal the mechanisms underlying the relationship between conflict types and features of RT distributions and to develop models of this relationship, it might be still necessary to apply nonparametric distribution analyses (e.g., delta plots) to larger trial numbers.

The goal of the present study was to examine the contribution of task conflict to performance in the Stroop paradigm. To achieve this, we used a modified version of the paradigm combining a manual Stroop task with a task-switching procedure. The question emerges as to whether the results obtained with this method can be generalized to the original Stroop paradigm. We think that this is possible because the phenomenon of interest (i.e., the bivalency effect in the exponential RT component) has been originally demonstrated within the standard paradigm (Heathcote et al., 1991; Spieler et al., 1996, 2000). Our modifications of the Stroop paradigm did not create this phenomenon; rather, they were necessary for testing specific hypotheses regarding this effect.

On the basis of this consideration, the present study has important conclusions for research on the Stroop paradigm. Our results demonstrate that task conflicts are an important aspect of Stroop performance, which has largely been neglected. For instance, the role of facilitation and interference has to be reconsidered, given that univalent stimuli are not only a baseline against which facilitation and interference can be computed. Rather, univalent stimuli

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[1] In some conditions, the congruency effect increased during the first quantiles and then decreased in the last quantile. Some authors assumed that a reduction of response conflict in trials with slow responses is due to an inhibitory process that selectively suppresses response activation produced by the irrelevant stimulus dimension (Bub, Masson, & Lalonde, 2006; Ridderinkhof, 2002; Ridderinkhof, van den Wildenberg, Wijnen, & Burle, 2004). Because this inhibition is slow, it becomes effective only on trials with a slow response and therefore reduces response conflict only on these trials. Unfortunately, we did not observe this pattern in each condition, which is difficult to interpret. Whereas it is obtained only on task-switching trials in Experiment 1, it is obtained on all trials in Experiment 2. However, the fact that such a reduction on slow trials is obtained only for the congruency effect but not for the bivalency effect suggests that this type of inhibition operates on the level of the response but not on the level of the task (see Steinhauser & Hübner, 2008). (Note that Bub et al., 2006, observed this effect for the incongruent-neutral contrast. This effect is equivalent to [bivalency cost + 0.5 × congruency effect] and, thus, resembles more the congruency effect under conditions in which the congruency effect is much stronger than the bivalency cost, as in the standard Stroop task. However, in our paradigm, the bivalency cost is more pronounced and, therefore, this contrast shows nearly the same pattern as the bivalency cost).

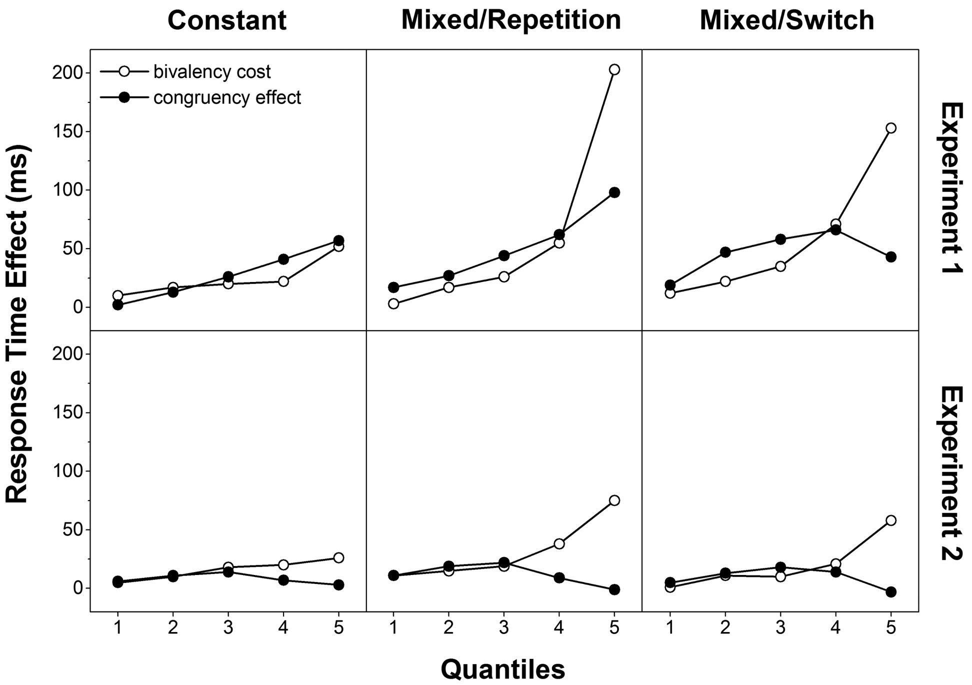

Figure 6. Congruency effects and bivalency costs as a function of task mode and response time quantile in both experiments.

differ more fundamentally from bivalent Stroop stimuli because they lack a task conflict that delays responding even on congruent stimuli.

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Appendix

Q-Q plots can be used to graphically evaluate the goodness of fit. In Figures A1 and A2, the 10 quantiles used for fitting the ex-Gaussian distribution to the data of each condition are depicted. For each quantile, the mean RT predicted by the estimated ex-Gaussian parameters is plotted against the empirically observed mean RT. The closer a point is to the diagonal line, the better is the goodness of fit. The figures show that overall goodness of fit is quite good although there is a tendency of the ex-Gaussian distribution to underestimate the mean RTs of the last quantile.

(*Appendix continues*)

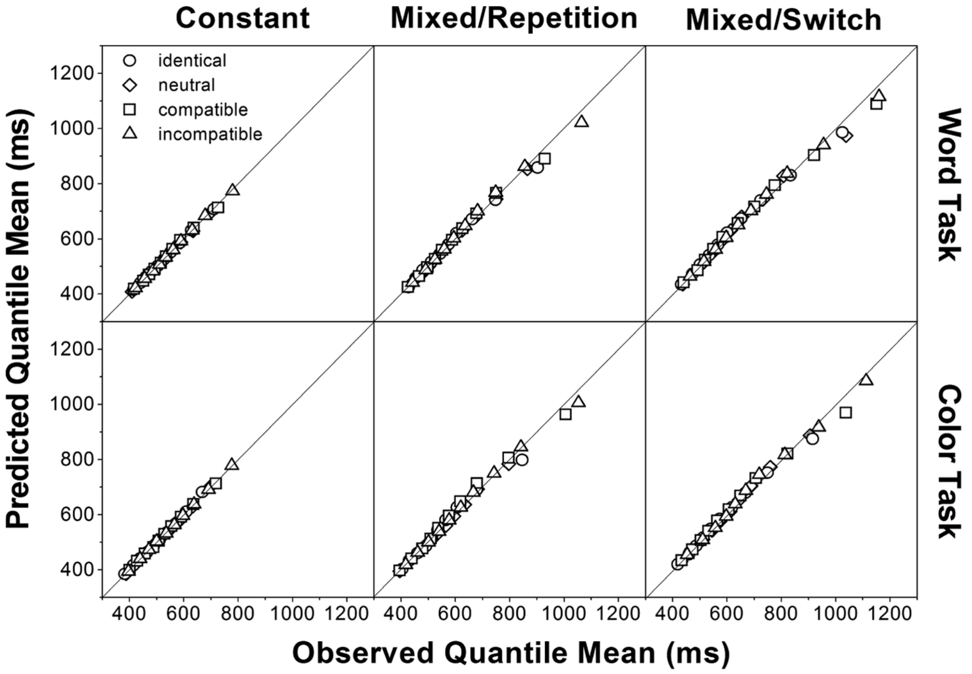

Figure A1. Q-Q plot for Experiment 1.

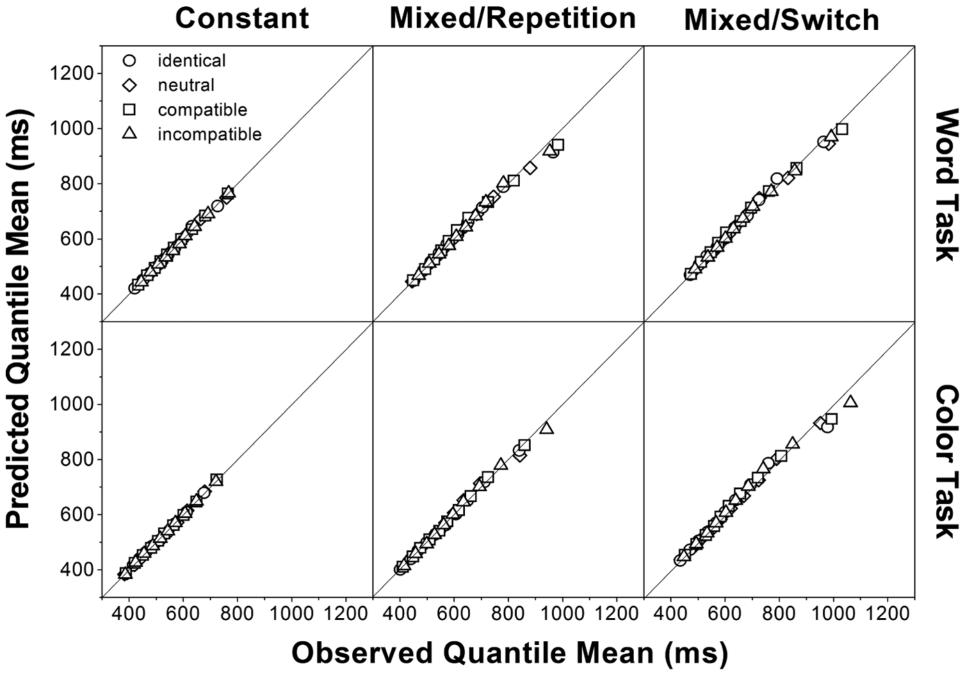

Figure A2. Q-Q plot for Experiment 2.

Received August 28, 2007
Revision received February 6, 2009
Accepted March 3, 2009 ■