Neuropsychology
2004, Vol. 18, No. 3, 477–484

0894-4105/04/$12.00 DOI: 10.1037/0894-4105.18.3.477

Factors Influencing Stroop Performance in Schizophrenia

Deanna M. Barch
Washington University

Cameron S. Carter
University of Pittsburgh Medical School

Jonathan D. Cohen
University of Pittsburgh Medical School and Princeton University

Recent studies suggest that individuals with schizophrenia show enhanced facilitation but similar interference in reaction times (RTs), compared with control participants, combined with increased error interference. This study examined the relationship between errors and RTs on the Stroop task among individuals with schizophrenia. The authors examined performance on a speeded Stroop task, designed to increase errors, in 29 individuals with schizophrenia and 29 nonpatient control participants. The authors also analyzed color-naming and word-reading estimates from process dissociation analyses. The findings suggest that a lack of increased RT interference among patients (compared with control participants) is not solely due to the increased number of errors they produce in the incongruent condition but is also influenced by a greater impact of the word even in the neutral condition.

Disturbances of selective attention have long been considered a prominent component of cognitive deficits in schizophrenia. In recent years, a growing number of researchers have used single-trial versions of the classic selective-attention paradigm, the Stroop task, to examine cognitive function in schizophrenia. In this task, participants are presented with words printed in colors and are typically told to name the print color and ignore the word. In most studies, the single-trial Stroop task contains three conditions: (a) congruent (color and word are the same, such as the word RED written in red ink), (b) neutral (a noncolor word printed in some ink color, such as the word DOG written in red ink), and (c) incongruent (color and word conflict, such as the word BLUE written in red ink; MacLeod, 1991). Participants are usually faster to name the color of a word in the congruent condition than in the neutral condition, an effect referred to as *Stroop facilitation.* In contrast, participants are typically slower to name the ink color in the incongruent condition than in the neutral condition, an effect referred to as *Stroop interference.* This latter effect is thought to result from the prepotency of word reading disrupting color-naming performance (Cohen, Servan-Schreiber, & McClelland, 1992; MacLeod, 1991).

This single-trial version of the Stroop task produces an interesting pattern of results in patients with schizophrenia. Specifically, patients with schizophrenia often do not exhibit increased reaction time (RT) interference (incongruent–neutral RT) compared with control participants (though they do show RT interference) but can instead exhibit increased errors in the incongruent condition compared with control participants, often combined with increased RT facilitation (neutral–congruent RT; Barch, Carter, Hachten, & Cohen, 1999; Barch, Carter, Perlstein, et al., 1999; Carter, Robertson, & Nordahl, 1992; Chen, Wong, Chen, & Au, 2001; Cohen, Barch, Carter, & Servan-Schreiber, 1999; Elvevåg, Duncan, & McKenna, 2000; Henik et al., 2002; Taylor, Kornblum, & Tandon, 1996). Such results surprised some researchers, because many had predicted that selective-attention deficits among schizophrenia patients would lead to increased RT interference and not increased RT facilitation on the Stroop task. Our goal in the current work was to shed further light on the mechanisms leading to this pattern of single-trial Stroop performance among patients with schizophrenia by testing the following two hypotheses: (a) Increased errors in the incongruent condition among patients with schizophrenia contribute to a lack of increased RT interference (compared with control participants) on the Stroop task, and (b) patients with schizophrenia show performance deficits on the Stroop because of a disturbance in context processing rather than a disturbance in a mechanism specifically dedicated to inhibition. Understanding the precise nature of the mechanisms giving rise to cognitive deficits in schizophrenia on tasks such as the Stroop is important in that it may help researchers better understand the pathophysiology of this disorder.

In prior work, we have argued that a lack of increased RT interference among patients with schizophrenia might reflect at least two factors (Barch, Carter, Hachten, & Cohen, 1999; Barch, Carter, Perlstein, et al., 1999). One potential factor is that deficits in the ability to ignore the word influence the performance of patients with schizophrenia in the neutral condition as well as in the incongruent condition. RT interference is measured as a difference between neutral and incongruent trials. Thus, if the RTs of patients are increased in both the neutral and the incongruent conditions, the overall magnitude of their RT interference effect might not appear enhanced compared with that of control participants. Consistent with this hypothesis is our finding in previous

---

Deanna M. Barch, Department of Psychology, Washington University; Cameron S. Carter, Department of Psychiatry, University of Pittsburgh Medical School; Jonathan D. Cohen, Department of Psychiatry, University of Pittsburgh Medical School, and Department of Psychology, Princeton University.

This work was supported by National Alliance for Research on Schizophrenia and Depression Young Investigators awards to Deanna M. Barch and Cameron S. Carter. We thank the staff and patients of Western Psychiatric Institute and Clinic in Pittsburgh, PA, and Mayview State Hospital in Bridgeville, PA, particularly the Special Studies Research Unit, for their kind cooperation and support. We also thank Dave Balota and Larry Jacoby for their thoughtful comments and helpful suggestions.

Correspondence concerning this article should be addressed to Deanna M. Barch, Department of Psychology, Washington University, Campus Box 1125, One Brookings Drive, St. Louis, MO 63130-4899. E-mail: dbarch@artsci.wustl.edu

work that patients with schizophrenia show a disproportionate slowing of RT in Stroop tasks with neutral words compared with nonwords (Barch, Carter, Hachten, & Cohen, 1999). A second potential factor may be the increase in errors that patients demonstrate in the incongruent condition (Barch, Carter, Hachten, & Cohen, 1999; Barch, Carter, Perlstein, et al., 1999). In healthy individuals, it is typically assumed that responses are slowed in the incongruent condition because the influence of the word interferes with the processing of the color. However, among patients with schizophrenia, selective-attention deficits appear severe enough to lead to more than just a slowing in the incongruent condition, with patients actually responding to the word and not to the color (i.e., increased errors). Because calculations of RT interference contain only correct RTs, the increase in errors may serve to eliminate those trials on which the patients had the most difficulty. Patients may still demonstrate some slowing on the remaining correct trials in the incongruent condition. However, with the trials potentially most sensitive to the interference effect eliminated (i.e., errors), it may be difficult to detect significantly increased slowing in the incongruent condition when examining the remaining correct trials. If the increase in errors contributes to findings of no increase in RT interference among patients with schizophrenia compared with control participants, we should be able to produce enhanced RT interference among patients if we could eliminate those trials in which control participants also had the most difficulty ignoring the influence of the word. Thus, one way to test this hypothesis would be to equate patients and control participants on errors, an approach that would potentially allow us to detect increased interference RT among patients with schizophrenia even on correct trials.

In one sense, this lack of increased RT interference may reflect a type of speed–accuracy trade-off that patients are forced to make in the incongruent condition (relative to their performance in other conditions) because of a deficit in the ability to inhibit the influence of the word. However, we do not mean that patients display a speed–accuracy trade-off in the way this term is usually used. The concept of a speed–accuracy trade-off is often invoked when one group has faster absolute RTs than another group but also makes more errors. When this occurs, it is often argued that the two groups are simply falling at a different point on the speed–accuracy curve and do not differ in the cognitive process of interest. The interpretation of no group differences in the cognitive process of interest clearly does not apply to performance on the Stroop task in schizophrenia patients. Patients' RTs are slower than are control participants' RTs in the incongruent condition even though they do not show greater RT interference effects (e.g., incongruent–neutral RT). As such, patients are both slower and less accurate than are control participants in the incongruent condition. Such a pattern cannot be a simple speed–accuracy trade-off, given that the patients do not show significantly less RT interference than do control participants.

A second issue in understanding Stroop performance in schizophrenia is the nature of the specific mechanism leading to selective-attention deficits on this task in schizophrenia. In prior work we have suggested that Stroop deficits in schizophrenia reflect a deficit in the ability to represent and maintain context representations. This hypothesis is based on a computational model of the mechanisms involved in the performance of the Stroop task (Cohen, Dunbar, & McClelland, 1990). In this model, it is assumed that the links between orthographic inputs and word reading are stronger than the links between color inputs and color naming (because of greater experience with word reading and the consistency of the mapping), leading to a prepotency of word reading over color naming. However, color naming can be successfully performed via control over processing from task (context) representations. In the model, the task to be performed on a particular trial (color naming or word reading) is specified by the appropriate pattern of activation over a set of units (context layer) that represents each of the two dimensions over which the stimuli can vary (i.e., color and word). Activation of the appropriate units modulates the flow of activity along the pathway from input to response, favoring processing in the task-relevant pathway over the competing one. In other words, if the task to be performed on a particular trial is color naming, then activating the color-dimension units in the context layer enhances processing in the color-naming pathway, allowing it to more effectively compete against word reading. If the ability to represent or maintain such context representations is impaired, then processing in the color-naming pathway will be degraded, and processing in the word-reading pathway will be enhanced, leading either to errors or to slowed RTs. This account suggests that in schizophrenia, deficits in the ability to inhibit the word dimension are secondary to a disturbance in context representation, and that such a deficit should lead to both reduced color processing and relatively enhanced word processing. In fact, simulations using this model have been able to account for the pattern of RTs and errors shown by patients with schizophrenia in the Stroop task (Cohen & Huston, 1994; Cohen & Usher, 1996). However, an alternative hypothesis is that context or task representations are intact in schizophrenia but that some separate mechanism dedicated to inhibition is deficient, leading to an increased influence of the word dimension on performance (Titone, Holzman, & Levy, 2002). This alternative hypothesis would predict that color processing should be intact but that word processing should be enhanced because of a deficit in inhibiting the word dimension of the stimulus.

It is difficult to distinguish between the two hypotheses described above (context vs. inhibitory deficit) by examining raw RT and error rates, as both accounts might predict the pattern of behavioral performance seen in patients with schizophrenia. In other words, findings of enhanced Stroop interference in schizophrenia patients (reflected in either RTs or errors) could be caused by either a deficit in context processing or a deficit in a mechanism dedicated to inhibition. However, the process dissociation technique developed by Jacoby (1991) provides a means of teasing apart these two hypotheses. Specifically, this technique can be used to disentangle the contributions of color and word processing to Stroop performance. The reasoning behind this approach is that on incongruent trials, correct responses can be made only through the use of color information (Jacoby, 1991). However, on congruent trials, correct responses can reflect either color or word information or both color and word information. Thus, one can derive process estimates for both color naming and word reading using the following equations (Jacoby, 1991; Lindsay & Jacoby, 1994):

$$\text{Word} = \text{Prob(Correct}|\text{Congruent)} - \text{Prob(Correct}|\text{Incongruent)}$$

$$\text{Color} = [\text{Prob(Correct}|\text{Incongruent)}] / (1 - \text{Word})$$

In prior work, Lindsay and Jacoby (1994) used this technique to examine the time course of color and word processing in healthy participants on the Stroop tasks. They found that word processing dominates early on in processing, but that with more time, color processing dominates. Further, Jacoby and colleagues have demonstrated that color and word processing can be selectively and independently manipulated (Jacoby, McElree, & Trainham, 1999; Lindsay & Jacoby, 1994). Thus, one should be able to use the processing dissociation technique with patients with schizophrenia to determine whether both color- and word-processing estimates are altered, as would be predicted by our model, or whether only word-processing estimates are enhanced, as might be predicted by an inhibitory deficit model.

The present study had two goals. First, we wished to determine whether equating patients with schizophrenia and nonpatient control participants on error rates in a single-trial Stroop task would reveal increased RT interference among the patients with schizophrenia. To examine this hypothesis, we collected new data on a speeded version of the single-trial Stroop task that was designed to increase error rates among nonpatient control participants in particular. Second, we also wished to determine whether patients with schizophrenia would demonstrate both decreased color-process estimates and increased word-process estimates. To examine this hypothesis, we combined (to increase power) data from our new sample of participants with Stroop data acquired for a previously published study (Barch, Carter, Hachten, & Cohen, 1999) and used the process dissociation methods of Jacoby (Jacoby et al., 1999; Lindsay & Jacoby, 1994) to calculate both color- and word-process estimates for patients and control participants.

Method

Participants

New sample. Participants were 30 patients with schizophrenia or schizoaffective disorder, diagnosed according to the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*; American Psychiatric Association, 1994), and 31 nonpatient controls. However, 1 control participant and 1 patient had to be excluded because they did not follow the task instructions correctly. In addition, data from 1 control were lost because of technical difficulties, resulting in a sample of 29 patients with schizophrenia and 29 nonpatient control participants. The schizophrenic/schizoaffective participants were outpatients at the Schizophrenia Treatment and Research Center at Western Psychiatric Institute and Clinic in Pittsburgh, PA. All patients were medicated and had been receiving the same medications and dosages for at least 2 weeks. Patient diagnoses were based on the Structured Interview for *DSM–IV* (SCID; R. L. Spitzer, Williams, Gibbon, & First, 1990), an interview with a primary caretaker, and a review of the participant's medical records. Healthy control participants were recruited through local advertisements and were evaluated using the SCID. Diagnostic interviews were completed by Deanna M. Barch or by a trained research assistant. Nonpatient control candidates were excluded if they had any lifetime history of Axis I psychiatric disorder or any first-order family history of psychotic disorders. Potential participants were excluded for (a) substance abuse within the previous 6 months, (b) neurological illness or history of head trauma with loss of consciousness, (c) mental retardation, (d) nonnative English speaking, or (e) color blindness.

As in our previous studies, we used the Positive and Negative Symptom Scale (PANSS; Kay, 1991) to evaluate clinical state. We examined total PANSS scores and the three symptom factors suggested by Liddle (1987). To be consistent with our prior work (Barch, Carter, Hachten, & Cohen, 1999; Barch, Carter, Perlstein, et al., 1999), we used the following items for each scale: (a) delusions, hallucinations, and unusual thought content for *reality distortion* ($\alpha = .90$); (b) blunted affect, emotional withdrawal, passive social avoidance, motor retardation, and lack of spontaneity for *poverty* ($\alpha = .75$); and (c) conceptual disorganization, mannerisms and posturing, difficulty in abstract thinking, and poor attention for *disorganization* ($\alpha = .86$). Ratings were completed either by a doctoral-level psychologist (Deanna M. Barch) or by a trained research assistant who regularly participated in reliability sessions. Both raters rated 29 patients (individuals who participated in both this study and other studies being conducted in the lab) during these reliability sessions. Interrater reliability, measured using intraclass correlations (Shrout & Fleiss, 1979) with raters treated as random effects and the individual rater as the unit of reliability, was .97 for reality distortion, .93 for poverty symptoms, .95 for disorganization, and .97 for total PANSS score. The demographic and clinical characteristics of both participant groups for this new sample are shown in Table 1. The control participants were matched with patients for age, gender, and years of parent education (to match approximately for socioeconomic status) and did not differ significantly on any of these variables. All participants signed informed-consent forms in accordance with the

Table 1
Demographic and Clinical Characteristics

	Healthy control participants				Schizophrenia patients			
	New sample		Combined sample		New sample		Combined sample	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	35.4	7.6	35.7	7.5	36.2	7.7	38.0	8.4
Gender (%)								
Male	55.0		51.0		62.0		55.0	
Female	45.0		49.0		38.0		45.0	
Parents' education (years)	14.2	3.7	14.4	3.3	13.9	3.3	13.7	3.1
Education (years)	15.4	2.5	15.8	2.3	12.8	2.3	12.7	2.1
PANSS—total score					63.5	11.9	71.0	17.1
Reality distortion					9.4	3.9	10.3	3.8
Poverty symptoms					10.8	4.2	12.2	5.5
Disorganization					9.0	4.2	10.4	4.1

Note. PANSS = Positive and Negative Symptom Scale.

policies of the University of Pittsburgh Medical School's institutional review board. All participants were paid for their participation.

Combined sample. For the processes dissociation analyses, we combined the data from our new sample of participants and participants who completed a previously reported study of Stroop performance in schizophrenia (Barch, Carter, Hachten, & Cohen, 1999). Participants from the prior study were 40 *DSM–IV* schizophrenic or schizoaffective patients and 20 nonpatient control participants. The schizophrenic/schizoaffective patients were either inpatients ($n = 20$) at Mayview State Hospital in Bridgeville, PA, or outpatients ($n = 20$) at the Schizophrenia Treatment and Research Center at Western Psychiatric Institute and Clinic in Pittsburgh, PA. All inclusion–exclusion criteria, diagnostic procedures, and symptom-rating procedures (i.e., PANSS ratings) were identical to those described above for the new sample of participants. The demographic and clinical characteristics of the combined sample of participants are shown in Table 1. In the combined sample, patients and control participants did not differ significantly on age, gender, or parental education.

Tasks

Speeded single-trial Stroop task. Each participant was administered 20 blocks of a speeded version of a single-trial Stroop task. Each block consisted of 30 trials, with 10 congruent trials, 10 incongruent trials, and 10 neutral trials, presented in random order. Each trial consisted of a stimulus printed in one of four colors: red, blue, green, or yellow. Congruent stimuli consisted of one of the four color names presented in its own color. Incongruent stimuli consisted of each of the four color names presented in one of the three remaining colors. Neutral stimuli were one of four unrelated words (*dog, bear, tiger,* or *monkey*) printed in one of the four colors (referred to as the *animal neutral*). These neutral words matched the color words in number of letters and frequency (Francis & Kučera, 1982) and were from a single semantic category to eliminate semantic confounds (MacLeod, 1991). Participants were told that they would be presented with a series of stimuli, one at a time. Their job was to name the color in which the stimulus was printed as quickly as possible. The instructions strongly emphasized speed, and participants were told that we expected them to make a number of errors because of the emphasis on speed. The experimenter coded the accuracy of the participant's response to each stimulus by pushing a button on the keyboard, allowing the computer to record the participant's accuracy as the task was being administered. At the end of each block, the computer screen displayed the participant's accuracy for each block. Our target accuracy for each block was 80%. Thus, if the participants' accuracy for the prior block was higher than 80%, they were encouraged to respond even faster on the next block. If the participants' accuracy for the prior block was approximately 80%, they were encouraged to continue performing the task in the same manner. If the participants' accuracy was below 80%, they were encouraged to slow down their responding on the next block.

Barch, Carter, Hachten, and Cohen (1999) Stroop task. Each participant was administered three blocks of the Stroop task, with block order counterbalanced across participants. Each block consisted of 96 trials, with 24 (25%) congruent, 24 (25%) incongruent, and 48 (50%) neutral trials. Each trial consisted of a stimulus printed in one of four colors: red, blue, green, or purple. The congruent stimuli consisted of one of the four color names presented in its own color. The incongruent stimuli consisted of each of the four color names presented in one of the three remaining colors. In one block, the neutral stimuli consisted of four squares printed in one of the four colors. In a second block, the neutral stimulus was one of four unrelated words (*dog, bear, tiger,* or *monkey*) printed in one of the four colors. These neutral words matched the color words in number of letters and frequency (Francis & Kučera, 1982) and were from a single semantic category to eliminate semantic confounds (MacLeod, 1991). In the third block, the neutral stimuli were four color words (*tan, gray, white,* and *yellow*) that were different from the colors in the response set. These color words were also matched to the response set color words on length and frequency.

Procedure

All of the following procedures were the same for the sample of participants performing the speeded Stroop task and the participants from the Barch, Carter, Hachten, and Cohen (1999) study. Each subject was tested individually. Stimuli were presented on an Apple Macintosh computer, using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Each stimulus remained on the screen until the participant responded or until 2,000 ms elapsed, and it then was replaced by a fixation cross that lasted until the onset of the next stimulus. Regardless of RT, a new trial started 4 s after onset of the previous stimulus so that the pace of the task was fixed for all participants. RTs for onset of verbal response were automatically recorded by the computer using a microphone and a voice-activated relay. A short practice period preceded the actual testing for each block to ensure that participants understood the instructions, were comfortable with the apparatus, and were performing the task appropriately.

Data Analysis

Speeded Stroop task. Trials with incorrect responses were excluded from the analyses of the RT data. For the RT data, outliers were removed by excluding any trials in which the participant's RT was greater than two standard deviations above or below that participant's mean RT for the condition in which the trial occurred (Ratcliff, 1993). The number of RTs exceeding this threshold were small (approximately 1.5%) and did not differ between groups. The error data were normalized using an arcsine transformation (Neter, Wasserman, & Kutner, 1990). Data were subjected to repeated measures analyses of variance (ANOVAs), as described below. Where appropriate, Greenhouse–Geisser corrections for degrees of freedom were applied. Planned comparisons were used to follow up on main effects and interactions predicted by specific hypotheses.

Process dissociation. In their first experiment, Lindsay and Jacoby (1994) calculated color- and word-process estimates by imposing a time deadline by which participants had to respond and then calculating the percentage of correct responses produced by such a deadline in each condition. However, in their second experiment, Lindsay and Jacoby demonstrated that one could use the same procedures with deadlines specified post hoc. Thus, in the current study, we used 16 post hoc bins, ranging from 500 ms to 2,000 ms in 100-ms increments. We calculated the percentage of correct responses that occurred by each deadline for each condition. We then calculated estimates of color and word processing for each deadline, using the equations provided in the introduction.

Results

Speeded Stroop Task

Error rates. Arcsine-transformed error rates were examined using a two-way ANOVA with diagnostic group (patient or control) as the between-subjects factor and condition (congruent, neutral, or incongruent) as the within-subject factor. This ANOVA revealed a significant main effect of condition, $F(2, 112) = 216.8$, $p < .001$; a trend-level main effect of group, $F(1, 56) = 3.02$, $p = .09$; and no significant Group × Condition interaction, $F(2, 112) = 1.10$, $p > .30$. The lack of significant main effects or interactions with group suggest that our manipulation of RT was somewhat successful in equating patient and control participants on overall errors (see Table 2), primarily by

Table 2
Reaction Times and Error Data for Speeded Stroop Task

Variable	Healthy control participants		Schizophrenia patients	
	M	*SD*	*M*	*SD*
Reaction times				
Congruent	527.3	72.4	690.6	161.6
Neutral	574.9	73.4	798.2	247.1
Incongruent	655.0	103.0	894.0	244.4
Facilitation	47.6	30.5	107.7	101.7
Interference	80.1	45.7	95.8	42.9
Accuracy (proportion correct)				
Congruent	0.99	0.04	0.98	0.03
Neutral	0.97	0.05	0.95	0.05
Incongruent	0.84	0.12	0.79	0.16

increasing error rates in the control group (compared with error rates in previous studies). However, the trend-level main effect of group reflected the fact that control participants were still slightly more accurate than patients in all conditions.

RTs. RTs to correct responses were examined using a two-way ANOVA with group (patient or control) as the between-subjects factor and condition (congruent, neutral, or incongruent) as the within-subject factor. This ANOVA revealed significant main effects of condition, $F(2, 112) = 165.7$, $p < .001$, and group, $F(1, 56) = 23.9$, $p < .001$, as well as a Group × Condition interaction, $F(2, 112) = 9.7$, $p < .005$. As shown in Table 2, the group main effect reflected the fact that overall, patients were slower than control participants. Planned comparisons to follow up on the main effect of condition indicated that, as expected, participants responded faster to congruent stimuli than to neutral stimuli, $F(1, 56) = 62.03$, $p > .001$, and slower to incongruent stimuli than to neutral stimuli, $F(1, 56) = 149.6$, $p > .001$. Planned comparisons to examine the Condition × Group interaction indicated that, as expected, patients demonstrated significantly more facilitation (neutral–congruent RT) than did control participants, $F(1, 56) = 9.3$, $p < .005$. However, contrary to our expectations, patients did not display significantly more interference (incongruent–neutral RT), $F(1, 56) = 1.81$, $p > .10$. As noted above, the two groups differed on overall RT. Thus, we confirmed the results of the raw data analyses using ratio scores designed to take into account RT differences between the groups. For facilitation, this ratio score was computed as (congruent–neutral RT)/neutral RT. For interference, this ratio score was computed as (incongruent–neutral RT)/neutral RT. An independent-sample *t* test, $t(56) = 2.56$, $p < .05$, confirmed that patients ($M = -.12$, $SD = .07$) demonstrated significantly more facilitation than did control participants ($M = -.08$, $SD = .05$). Similarly, an independent-sample *t* test confirmed that patients ($M = .13$, $SD = .06$) and control participants ($M = .14$, $SD = .07$) did not differ significantly on interference, $t(56) = 0.47$, $p > .10$.

The above analyses did not demonstrate evidence for increased RT interference among patients with schizophrenia once error rates were increased in control participants. However, as noted above, our manipulation—which was designed to increase errors among control participants—was only marginally successful in equating control participants and patients on errors. Thus, to examine this hypothesis further, we analyzed RT data from a subset of control participants ($n = 20$) who were better matched to the patients on accuracy in the incongruent condition (control participants: $M = .79$, $SD = .10$; patients: $M = .79$, $SD = .16$). This analysis indicated increased RT interference, $F(1, 47) = 4.11$, $p < .05$, in patients ($M = 95.8$, $SD = 42.9$) compared with control participants ($M = 70.1$, $SD = 44.4$), as well as increased RT facilitation, $F(1, 47) = 5.77$, $p < .05$, in patients ($M = 107.7$, $SD = 101.7$) compared with control participants ($M = 51.8$, $SD = 24.9$). The analyses of ratio scores confirmed that patients ($M = -.12$, $SD = .07$) demonstrated greater facilitation, $t(47) = 1.92$, $p < .05$, than did control participants ($M = -.09$, $SD = .04$). However, the ratio scores did not confirm that patients ($M = .13$, $SD = .06$) demonstrated greater interference, $t(47) = -0.47$, $p > .10$, than did control participants ($M = .12$, $SD = .07$) when overall RT was taken into account.

Process Dissociation Analyses

We used two-factor ANOVAs to analyze the color- and word-process estimates (see Figure 1), with group (patient or control) as the between-subjects factor and deadline (500–2,000 ms) as the within-subject factor. For the analyses presented next, the same pattern of results was found if the data from each of the two studies were analyzed separately, and if outpatients and inpatients were analyzed separately. For color estimates, the ANOVA revealed significant main effects of group, $F(1, 116) = 49.02$, $p < .001$, and deadline, $F(15, 1740) = 491.64$, $p < .001$, which was modified by a two-way Group × Deadline interaction, $F(15, 1740) = 34.24$, $p < .001$. As can be seen in Figure 1, the main effect of deadline reflected the fact that for both groups, color estimates increased with longer RT deadlines. The main effect of group reflected the fact that overall, color-process estimates were decreased in patients compared with control participants (see Figure 1). In fact, simple-effects tests indicated that color estimates were lower in patients than in control participants at all post hoc deadlines (all *p*s $< .05$). The Group × Deadline interaction reflected the fact that although color estimates were lower in patients than in control participants at all deadlines, the difference between patients and control participants was larger for early (e.g., $\leq$ 1,200 ms) versus late (e.g., $\geq$ 1,300 ms) deadlines, $F(1, 116) = 57.91$, $p < .001$. This finding appears to reflect a shift to the right for the patients' color-estimates curve, with a lower asymptote.

For word estimates, the ANOVA also revealed significant main effects of group, $F(1, 116) = 32.55$, $p < .001$, and deadline, $F(15, 1740) = 92.18$, $p < .001$, which was modified by a two-way Group × Deadline interaction, $F(15, 1740) = 24.40$, $p < .001$. As can be seen in Figure 1, the main effect of deadline reflected the fact that for both groups, word-process estimates initially increased and then decreased again. The main effect of group indicated that overall, word estimates were increased in patients compared with control participants. However, the Group × Deadline interaction indicated that patients had lower word-process estimates than did control participants at the 500-ms and 600-ms deadlines (single degrees of freedom tests, *p*s $< .001$), but significantly higher word-process estimates at deadlines above 700 ms (single degrees of freedom tests, all *p*s $< .01$, except 1,900

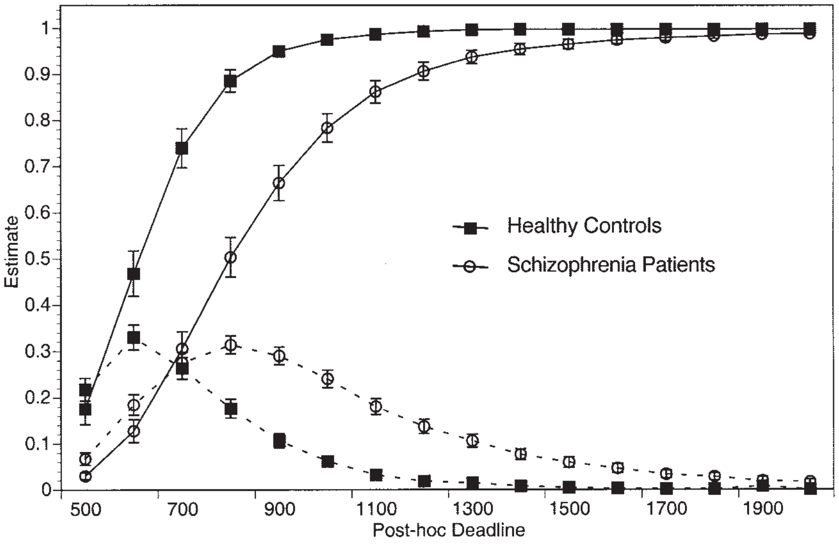

Figure 1. Time course of color (solid lines) and word (broken lines) process estimates for absolute reaction time deadlines (in milliseconds). Error bars represent standard errors.

ms). Again, this finding appears to reflect a shift to the right for the patients' word-estimates curve, with a higher asymptote.

The deadline procedures used above are consistent with the work of Lindsay and Jacoby (1994). However, using deadlines in terms of absolute RT may be problematic for groups that differ in overall response latency, such as patients with schizophrenia. Thus, we also used an alternative method suggested by Spieler and colleagues (Spieler, Balota, & Faust, 1996). Specifically, we also set deadlines in terms of standard deviation units (z scores) for each participant's mean condition RT. We used nine z-score deadlines for this analysis: -2, -1.5, -1, -0.5, 0, 0.5, 1, 1.5, and 1. For color estimates, the ANOVA revealed significant main effects of group, $F(1,\ 116) = 4.50$, $p < .001$, and deadline, $F(8,\ 928) = 6913.8$, $p < .001$, which was modified by a two-way Group × Deadline interaction, $F(8,\ 928) = 3.32$, $p < .05$. The main effect of deadline again reflected the fact that for both groups, color estimates increased with higher z-score deadlines (see Figure 2). The main effect of group reflected the fact that average color-process estimates were lower in patients than in control participants (see Figure 2). However, a contrast to follow up on the Group × Deadline interaction indicated that at z scores of 1, 1.5, and 2, patients had significantly lower color estimates than did control participants ($p < .05$) but not at earlier deadlines. Thus, early on in the time course of processing, patients and control participants do not differ in color-naming estimates. However, even with continued time, color-naming estimates among patients never rise to the same level as those of control participants.

For word estimates, the ANOVA also revealed a significant main effect of deadline, $F(8,\ 928) = 81.97$, $p < .001$; a marginal main effect of group, $F(1,\ 116) = 3.27$, $p = .07$; and a two-way Group × Deadline interaction, $F(8,\ 928) = 2.19$, $p < .05$. As can be seen in Figure 2, the main effect of deadline reflected the fact that for both groups, word-process estimates initially increased and then stayed relatively stable. Follow-up analyses for the Group × Deadline interaction indicated that patients did not have higher word-process estimates at all deadlines. Instead, patients demonstrated significantly higher word estimates than did control participants at the 1 and 1.5 z-score deadlines (see Figure 2).

Overall, the process dissociation analyses provided data consistent with the hypothesis that patients with schizophrenia have a deficit in context processing that leads to both a decrease in color naming and an increase in word reading. In addition, these process estimates might be able to shed further light on the issue of how this pattern of deficits influences performance in the neutral con-

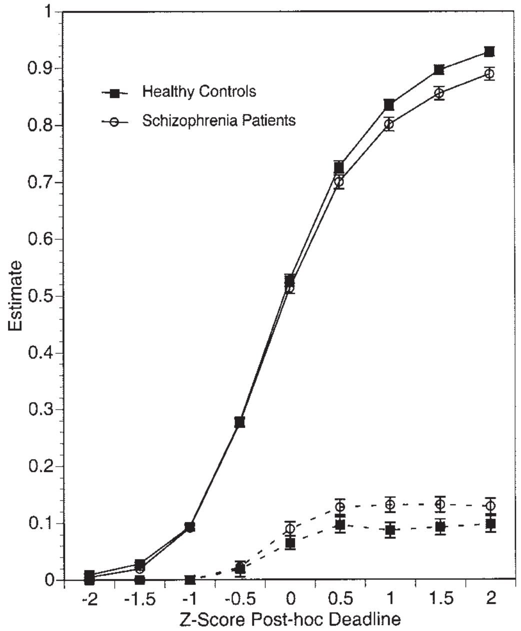

Figure 2. Time course of color (solid lines) and word (broken lines) process estimates for z-score deadlines. Error bars represent standard errors.

dition. In prior work, Jacoby and colleagues have shown that color-naming estimates, but not word-reading estimates, predict performance in the neutral condition (Lindsay & Jacoby, 1994). However, as described above, we have hypothesized that patients with schizophrenia experience an increased influence of the word dimension even in the neutral condition, which may contribute to their lack of increased RT interference. If this hypothesis is correct, then among patients with schizophrenia, performance in the neutral condition should be associated with word-reading estimates as well as color-naming estimates. To examine this hypothesis, we computed first-order correlations between each participant's average color-naming and word-reading estimates (averaged across the deadlines) and RT in the neutral condition for the Stroop task. Color-naming estimates were very strongly and significantly negatively correlated with neutral RT for both patients ($r = -.92$, $p < .001$) and control participants ($r = -.92$, $p < .001$). In contrast, word-reading estimates were significantly positively correlated with neutral RT for patients ($r = .51$, $p < .001$) but not for control participants ($r = .26$, $p = .08$). Further, there was a strong trend for word-reading estimates to be more strongly correlated with neutral RT among patients compared with control participants ($Z = 1.52$, $p = .06$).

Discussion

The results of the current study shed further light on the mechanisms contributing to the typical pattern of single-trial Stroop performance demonstrated by patients with schizophrenia—namely, equivalent RT interference but increased RT facilitation and errors in the incongruent condition. In particular, the results of this study suggest that (a) patients with schizophrenia do not show increased RT interference in comparison with control participants if the control participants and patients are matched on error rates and (b) patients with schizophrenia demonstrate both decreased color-naming estimates and increased word-reading estimates, findings that are consistent with a hypothesized deficit in context processing. Each of the findings is discussed in more detail below.

The results suggest that an increase in errors is not the only reason that patients with schizophrenia do not show an increase in RT interference compared with control participants. As described in the introduction, if increased errors was the only reason that patients with schizophrenia did not show increased interference RT, then if one could equate control participants and patients on errors, one should be able to observe increased RT interference among patients. However, the analyses with all participants who performed the speeded version of the Stroop task, designed to increase errors in control participants, did not reveal significantly increased RT interference among patients. As noted in the results, we were only marginally successful in equating control participants and patients on errors, and thus we conducted follow-up analyses with a subset of control participants exactly matched to patients on error rates in the incongruent condition. With this close matching on errors, the analysis of the raw RT data did indicate significantly greater RT interference among patients. However, the analysis of ratio scores suggests that the greater RT interference shown by patients was proportional to their overall slower RTs. Such results suggest that something in addition to the increase in errors is stopping patients from showing an increase in RT interference.

In previous work, we have argued that there is another factor preventing patients from showing an increase in RT interference as well as an increase in error interference. Their context-processing disturbances lead them to have deficits in the ability to ignore word information in the neutral as well as in the incongruent conditions. Because Stroop interference scores are calculated as a difference between RTs in the incongruent and neutral conditions, slower responding in both the neutral and the incongruent conditions can decrease the magnitude of such a difference score. As described in the introduction, our prior research provides some support for this hypothesis, in that patients, compared with control participants, showed greater "interference" from the word neutrals compared with the color patches neutrals (Barch, Carter, Hachten, & Cohen, 1999). In addition, the results of our process dissociation analyses provide some additional support for this hypothesis. Specifically, patients but not control participants demonstrated a significant positive relationship between word-reading estimates and RT in the neutral condition, and there was a strong trend for this relationship to be significantly stronger in patients than in control participants. In other words, among patients with schizophrenia, higher word-reading estimates, which are calculated using information only from the congruent and incongruent conditions, were associated with slower responses in the neutral condition. Taken together, these results provide strong support for the hypothesis that among patients with schizophrenia, selective-attention deficits lead to an increased influence of the word dimension in the neutral condition as well as in the incongruent condition. This hypothesis is consistent with recent theories regarding language processing and priming in schizophrenia. Specifically, it has been suggested that patients with schizophrenia show enhanced priming in some paradigms because the control mechanisms that normally allow a person to moderate spreading activation are deficient (M. Spitzer, 1994). In other words, patients with schizophrenia may show enhanced lexical activation in both the Stroop and priming paradigms because they cannot engage control mechanisms (e.g., context representation) that normally allow one to moderate or inhibit lexical activation.

Last, the analyses of the color-naming and word-reading estimates obtained from the process dissociation analyses provided evidence consistent with the hypothesis that Stroop-task deficits among patients with schizophrenia reflect a disturbance in context processing. As discussed in the introduction, in our model of the Stroop task, context (task) representations bias processing in the task-appropriate pathway, allowing color naming to effectively compete with or inhibit word reading (Cohen et al., 1990; Cohen & Huston, 1994; Cohen & Servan-Schreiber, 1992). Thus, context-processing deficits should lead to degradation in the color-naming pathway and a relative enhancement in the word-reading pathway. In contrast, if selective-attention deficits in schizophrenia are due to a disturbance in mechanisms specifically dedicated to inhibition, then color processing should be intact, but word processing should be enhanced due to a deficit in inhibiting the word dimension of the stimulus. In the current study, patients with schizophrenia demonstrated both decreased color-naming estimates and increased word-reading estimates, findings that are consistent with our hypothesis about context-processing deficits in this population. A concern that one might raise about this analysis is whether it is possible to see selective changes in word-reading estimates without concurrent reductions in color-reading estimates. However, Jacoby and colleagues (Jacoby et al., 1999; Lindsay & Jacoby, 1994) have demonstrated that color-naming and word-reading estimates can be independently manipulated. For example, these researchers have shown that degrading the quality of the color dimension decreases color-naming estimates but does not change word-reading estimates (Lindsay & Jacoby, 1994). In contrast, manipulating the frequency of congruent trials increases word-reading estimates but does not change color-naming estimates (Lindsay & Jacoby). In addition, prior research has also demonstrated selective increases in word-reading estimates, in the absence of color-naming estimate changes, in other populations thought to have inhibitory deficits, such as healthy aging individuals (Spieler et al., 1996). Thus, our findings of both decreased color-naming and increased word-reading estimates among patients with schizophrenia are not an artifact of the process dissociation technique, but instead provide support for the hypothesis that deficits in context processing lead to selective-attention deficits on the Stroop task.

References

American Psychiatric Association. (1994). Diagnostic and statistical manual of mental disorders (4th ed.). Washington, DC: Author.

Barch, D. M., Carter, C. S., Hachten, P. C., & Cohen. (1999). The “benefits” of distractibility: The mechanisms underlying increased Stroop effects in schizophrenia. *Schizophrenia Bulletin, 24,* 749–762.

Barch, D. M., Carter, C., Perlstein, W., Baird, J., Cohen, J., & Schooler, N. (1999). Increased Stroop facilitation effects in schizophrenia are not due to increased automatic spreading activation. *Schizophrenia Research, 39,* 51–64.

Carter, C. S., Robertson, L. C., & Nordahl, T. E. (1992). Abnormal processing of irrelevant information in schizophrenia: Selective enhancement of Stroop facilitation. *Psychiatry Research, 41,* 137–146.

Chen, E. Y. H., Wong, A. W. S., Chen, R. Y. L., & Au, J. W. Y. (2001). Stroop interference and facilitation effects in first-episode schizophrenia patients. *Schizophrenia Research, 48,* 29–44.

Cohen, J. D., Barch, D. M., Carter, C., & Servan-Schreiber, D. (1999). Context-processing deficits in schizophrenia: Converging evidence from three theoretically motivated cognitive tasks. *Journal of Abnormal Psychology, 108,* 120–133.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97,* 332–361.

Cohen, J. D., & Huston, T. A. (1994). Progress in the use of interactive models for understanding attention and performance. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV* (pp. 1–19). Cambridge, MA: MIT Press.

Cohen, J. D., MacWhinney, B., Flatt, M. R., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments, & Computers, 25,* 257–271.

Cohen, J. D., & Servan-Schreiber, D. (1992). Context, cortex, and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review, 99,* 45–77.

Cohen, J. D., Servan-Schreiber, D., & McClelland, J. L. (1992). A parallel distributed processing approach to automaticity. *American Journal of Psychology, 105,* 239–269.

Cohen, J. D., & Usher, M. (1996). A neural network model of Stroop interference and facilitation effects in schizophrenia. *Biological Psychiatry, 39,* 237.

Elvevåg, B., Duncan, J., & McKenna, P. J. (2000). The use of cognitive context in schizophrenia: An investigation. *Psychological Medicine, 30,* 885–897.

Francis, W. N., & Kučera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar.* Boston: Houghton Mifflin.

Henik, A., Carter, C. S., Salo, R., Chaderjian, M., Kraft, L., Nordahl, T. E., & Robertson, L. C. (2002). Attentional control and word inhibition in schizophrenia. *Psychiatry Research, 110,* 137–149.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30,* 513–541.

Jacoby, L. L., McElree, B., & Trainham, T. N. (1999). Automatic influences as accessibility bias in memory and Stroop tasks: Toward a formal model. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 461–486). Cambridge, MA: MIT Press.

Kay, S. (1991). *Positive and negative symptoms in schizophrenia.* New York: Brunner/Mazel.

Liddle, P. F. (1987). Syndromes of chronic schizophrenia: A re-examination of the positive–negative dichotomy. *British Journal of Psychiatry, 151,* 145–151.

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 219–234.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109,* 163–203.

Neter, J., Wasserman, W., & Kutner, M. H. (1990). *Applied linear statistical models.* Boston: Irwin Press.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114,* 510–532.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin, 86,* 420–428.

Spieler, D. H., Balota, D. A., & Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer’s type. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 461–479.

Spitzer, M. (1994). *Associative networks, self-organizing semantic maps, neuroplasticity, neuromodulation, and noise: A neurocomputational view of schizophrenic thought disorder.* Unpublished manuscript, Harvard University, Cambridge, MA.

Spitzer, R. L., Williams, J. B., Gibbon, M., & First, M. B. (1990). *Structured clinical interview for DSM–III–R—patient edition (SCID–P, version 1.0).* Washington, DC: American Psychiatric Press.

Taylor, S. F., Kornblum, S., & Tandon, R. (1996). Facilitation and interference of selective attention in schizophrenia. *Journal of Psychiatric Research, 30,* 251–259.

Titone, D., Holzman, P. S., & Levy, D. L. (2002). Idiom processing in schizophrenia: Literal implausibility saves the day for idiom priming. *Journal of Abnormal Psychology, 111,* 313–320.

Received January 27, 2003
Revision received June 10, 2003
Accepted August 7, 2003 ■