The "Benefits" of Distractibility: Mechanisms Underlying Increased Stroop Effects in Schizophrenia

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Abstract

Recent studies of selective attention in schizophrenia patients suggest a particular pattern of single-trial Stroop performance: increased facilitation but not interference in reaction times (RTs), combined with increased error interference. Our Stroop task analysis suggests that this pattern can be explained by a selective attention deficit if one accounts for (1) performance in the congruent condition; (2) the nature of the neutral stimulus; (3) the relationship between accuracy and RT; and (4) response set effects. To test these hypotheses, we examined Stroop performance in 40 *DSM-IV* schizophrenia patients and 20 healthy control subjects, using a range of neutral stimuli (color patches, noncolor words, color words not in the response set). The findings confirmed several of our predictions and the results were consistent with the hypothesis that abnormal Stroop performance in schizophrenia reflects a failure to adequately attend to the task-appropriate stimulus dimension (color). This inattention affects both the congruent and incongruent conditions and multiple points in the information processing pathway.

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Both clinicians and researchers have considered selective attention deficits a prominent aspect of cognitive dysfunction in schizophrenia since the earliest descriptions of the illness (Bleuler 1950; Kraepelin 1950). In the cognitive psychology literature, researchers often use the Stroop (Stroop 1935) color-naming task as a paradigmatic measure of selective attention (MacLeod 1991). In this task, participants are presented with words printed in colors and are told to either (1) read the word and ignore the print color, or (2) name the print color and ignore the word. When participants are asked to read the word, the print color has little influence on their reading time. However, when participants are asked to name the print color, they have difficulty suppressing the effects of the word. In particular, when the word and its color conflict (such as "Red" printed in blue), participants are slower than when there is no such conflict. This effect is called Stroop *interference* and is thought to result from the obligatory nature of word reading disrupting color-naming performance (MacLeod 1991).

Originally, the Stroop task was presented as lists of colored words on cards and contained three conditions: (1) word reading (color words written in black print); (2) color naming (color patches or XXX printed in different colors); and (3) color conflict (color words printed in conflicting colors). More recently, researchers have begun to use single-trial versions of the Stroop task (MacLeod 1991) in which stimuli are presented one at a time in a tachistoscope or on a computer screen. This task design has allowed for the addition of a "congruent" condition in which the word and the print color are the same. Participants name the color of a word more quickly when the color is congruent with its semantic meaning (e.g., "Red" printed in red print) than when the stimulus is neutral and color-unrelated (such as "Dog" printed in red print). This effect is referred to as Stroop *facilitation.*

The initial studies of Stroop performance in schizophrenia patients, which employed the card version of the Stroop task, indicated that compared with controls, schizophrenia patients were slower at naming colors on the conflict card (color and word incongruent). Researchers have interpreted such findings as evidence for increased Stroop interference among schizophrenia patients, resulting from selective attention deficits (Wapner and Krus 1960; Golden 1976; Abramczyk et al. 1983; Wysocki and Sweet 1985; Everett et al. 1989). Theorists such as Cohen and Servan-Schreiber (1992) have proposed that such deficits arise from a disturbance in a specific mechanism

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responsible for the allocation of attention to task-relevant, versus task-irrelevant, processes. More recently, a number of studies have examined single-trial Stroop performance in schizophrenia patients. Unlike the results of card Stroop studies, single-trial Stroop studies have not found evidence for increased reaction time (RT) interference among schizophrenia patients. Instead, schizophrenia patients exhibit increased RT facilitation and increased interference in errors (Carter et al. 1992; Taylor et al. 1996; Cohen et al. 1999; Schooler et al. 1997). These results have surprised researchers; most had predicted that selective attention deficits among schizophrenia patients would lead to increased RT interference and not increased RT facilitation on the Stroop task.

What are the mechanisms underlying this particular pattern of single-trial Stroop performance among schizophrenia patients? To answer this question, we conducted a task analysis of the single-trial Stroop paradigms used with schizophrenia patients, guided in part by a computational model of this task (Cohen et al. 1992; Cohen and Huston 1994).[1] This analysis suggested that the pattern of performance displayed by schizophrenia patients on single-trial Stroop tasks can be explained by a selective attention deficit, if one takes into account four factors relevant to single-trial Stroop studies: (1) the influence of the irrelevant dimension (i.e., the word) in the congruent condition; (2) the nature of the neutral stimulus; (3) response set effects; and (4) the relationship between accuracy and RT.

First, single-trial versions of the Stroop task contain a congruent condition, a condition not present in the original card version of the Stroop task. If schizophrenia patients are less able to inhibit processing of the irrelevant dimension, this disturbance should influence performance in all task conditions, not just in the incongruent condition. For congruent trials, the semantic information in the irrelevant dimension contributes to a correct response. Thus, paying more attention to the word could result in relatively faster RTs in the congruent condition among schizophrenia patients, which would contribute to increased Stroop facilitation.

Second, as the irrelevant dimension of the neutral stimulus becomes more "wordlike," RTs to name the color of these stimuli become slower. For example, healthy controls are slower to name the color of noncolor words than of nonword stimuli, such as consonant strings or patches (e.g., Klein 1964; Redding and Gerjets 1977). Since Stroop facilitation and interference scores are calculated by taking the differences in RTs from the neutral condition, performance in the neutral condition may strongly influence the magnitude of these difference scores. In the card version of the Stroop task, the neutral condition is always presented as color patches or rows of Xs. Most of the single-trial Stroop studies in schizophrenia, however, have used a different type of neutral stimulus—noncolor words such as dog or cat (e.g., Carter et al. 1992; Taylor et al. 1996). If schizophrenia patients have a deficit in selectively attending to the appropriate stimulus dimension, which leads the word to have a greater influence, patients may experience a greater degree of interference from neutral stimuli that are words than do control participants. Slower RTs for neutral words would contribute to an increased Stroop facilitation effect in schizophrenia patients but could also contribute to no change (if incongruent RTs were also longer), or even a decrease (if incongruent RTs were not longer), in the magnitude of Stroop RT interference.

Third, selective attention deficits may influence multiple points along the information processing pathway. Prior theorizing about Stroop deficits in schizophrenia has focused primarily on the means by which such deficits might influence attention to the appropriate stimulus dimension. However, selective attention may also influence response set effects (Proctor 1978; Cohen et al. 1992; Barch et al. 1999). Response set effects refer to the fact that participants are faster to respond to items not in the response set (e.g., noncolor or color words that are never correct responses) than to items in the response set (e.g., color words that are correct responses on some trials) (Klein 1964; Proctor 1978).[2] This faster response is thought to occur because participants can distinguish between stimuli that are and are not associated with a potential response. If selective attention mechanisms support both attention to the relevant stimulus dimension and the development and maintenance of a response set, then a degradation in selective attention should impair both. If schizophrenia patients fail to adequately establish a response set, then putatively neutral words may act more like response set items (i.e., conflict color words), thus competing with verbal responses to the color stimuli and interfering with color naming. This similarity between neutral and conflict items would inflate measurements of facilitation (neutral - congruent) relative to interference (conflict - neutral). In reality, this effect is likely to be a graded one, such that the more similar the neutral stimuli

[1] Here, we provide a verbal account of this analysis. A description of the model, simulations demonstrating its ability to account for patient performance in single-trial Stroop tasks, and predictions relevant to the current study are presented in Cohen and Carter (1995).

[2] The fact that individuals are faster at color naming noncolor words (e.g., animal words not in the response set) compared with color words in the response set is also likely to be influenced by response set effects. However, this difference is confounded by the fact that noncolor words have a weaker semantic association with the correct color.

are to items in the response set, the more a deficit in establishing a response set impairs performance. For example, such a deficit should be most apparent when the neutral stimuli and the response set stimuli are similar on several dimensions, such as lexicality and semantic content. Thus, one might predict that a deficit in establishing a response set will be most apparent when neutral stimuli are words (as opposed to nonwords) and are semantically related to the items in the response set (e.g., colors as opposed to noncolors), and less apparent when the neutral and response set stimuli share only one dimension (e.g., both words, but not both colors).

Finally, with the card Stroop, studies typically analyzed either RT or errors, but not both simultaneously. With the single-trial Stroop, we can examine both RT and errors. In the single-trial Stroop, schizophrenia patients do not respond disproportionately slowly to stimuli in the incongruent condition, but they do make considerably more errors. This increase in errors in the incongruent condition may be closely related to an absence of RT interference. Slowing in the incongruent condition is thought to occur when the influence of the word interferes with the processing of the print color. However, schizophrenia patients may be less able to inhibit the influence of the word and therefore more likely to respond to it instead of the print color. Such a response may occur in the incongruent condition (but not in the congruent and neutral conditions), because the incongruent condition contains the greatest amount of conflicting word information. Thus, among schizophrenia patients, increased interference may manifest in errors rather than RTs. In one sense, this may reflect a type of speed-accuracy tradeoff that patients are forced to make in the incongruent condition (relative to their performance in the other conditions) because of a deficit in their ability to inhibit the influence of the word. However, we do not mean to imply that patients display a speed-accuracy tradeoff in the classic sense of this term. The concept of a speed-accuracy tradeoff is often invoked when one group makes more errors than another but also has faster absolute RTs. In this situation, it is often argued that the two groups do not differ in the cognitive process of interest, but that one group is simply falling at a different point on the speed-accuracy curve. The latter interpretation (no group differences) clearly does not apply to performance on the Stroop task in schizophrenia patients. Although patients do not show greater RT interference effects (e.g., incongruent - neutral RT), their absolute RTs are slower than controls in the incongruent condition. Thus, patients are both slower and less accurate than controls in the incongruent condition. We are simply arguing that greater interference of the word stimulus among schizophrenia patients—measured as a difference score between the incongruent and neutral conditions—manifests in errors rather than RT.

In summary, we suggest that a deficit in selective attention can explain the particular pattern of performance displayed by schizophrenia patients on the Stroop task—increased RT facilitation, combined with error interference, but no increase in RT interference. We hypothesize that increased Stroop RT facilitation arises because the word dimension has a greater influence in both the congruent and neutral conditions. In the congruent condition, the word information could contribute to a relative speeding of responses, while in the neutral condition, the influence of the word could serve to slow color-naming RTs. Further, we suggest that a disturbance in selective attention leads to deficits in multiple points of information processing: (1) selective attention to the appropriate stimulus dimension, and (2) development and maintenance of a response set. Deficits at both these points of information processing may contribute to slower color-naming RTs in the neutral condition as well as in the incongruent condition. Finally, we hypothesize that a lack of increased RT interference results from a commensurate (1) slowing of color-naming RTs in both the neutral and incongruent conditions, and (2) disproportionate number of errors in the incongruent condition.

The goal of this study was to test these hypotheses empirically. We examined both schizophrenia patients and healthy controls in a single-trial Stroop task that systematically varied the nature of the neutral stimulus. Specifically, we used three different types of neutrals: (1) color patches, (2) noncolor words (animal names), and (3) color words not in the response set. In the context of this experimental design, the hypotheses outlined above make a number of predictions that can be empirically tested. First, if patients process the irrelevant dimension of the stimulus to a greater degree than controls even in the congruent condition (leading to a relative speeding of responses), then schizophrenia patients should display increased RT facilitation even when measured against nonword neutral stimuli (color patches). We predict this because a stimulus such as a color patch does not contain any word information that can compete with a color-naming response. Thus, increased RT facilitation in this condition cannot be explained by word information leading to slower responses in the neutral condition. Second, if patients process the irrelevant dimension of the stimulus to a greater degree than controls in the neutral condition (leading to a relative slowing of responses), then compared with controls, patients should display (1) greater slowing of RTs in the neutral condition as the stimuli change from nonwords (color patches) to words (animal and/or color neutrals)[3] and (2) a greater increase in RT

[3] This particular hypothesis was post hoc, as it arose from the comments of an anonymous reviewer.

facilitation with a word neutral (i.e., animal or color neutrals) compared with a nonword neutral (color patches). Third, if deficits in schizophrenia patients influence the development and maintenance of a response set, then patients should show reduced response set effects. In healthy controls, establishing an appropriate response set should manifest in two ways: (1) better performance with color words not in the response set compared with color words in the response set, and (2) similar performance with neutrals that are color words (not in the response set) and neutral words that are not colors. Thus, we would predict that compared with controls, schizophrenia patients should display (1) a reduced difference in performance (manifest in either RT or errors) between color words in the response set (i.e., incongruent stimuli) and color words not in the response set (i.e., color neutrals), and (2) a larger performance difference (in either RT or errors) between noncolor neutrals (i.e., animal words) and color neutrals. Finally, if a disproportionate number of errors in the incongruent condition contributes to a lack of increased RT interference among patients with schizophrenia, then patients with schizophrenia should demonstrate significantly greater error interference than controls.

Methods

Participants. Participants were 40 *DSM–IV* (American Psychiatric Association 1994) schizophrenia or schizoaffective patients and 20 normal controls. The schizophrenia/schizoaffective patients were either inpatients (n = 20) at Mayview State Hospital or outpatients (n = 20) at the Schizophrenia Treatment and Research Center at Western Psychiatric Institute and Clinic. 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; Spitzer et al. 1990), an interview with a primary caretaker, and a review of the participant's medical records. Normal controls were recruited through local advertisements and were evaluated using the SCID. Diagnostic interviews were completed by one of the authors (DMB) or a trained research assistant. Controls 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 (1) substance abuse within the previous 6 months; (2) neurological illness or history of head trauma with loss of consciousness; (3) mental retardation; (4) color blindness; and (5) being a non-native English speaker.

The demographic and clinical characteristics of both participant groups are shown in table 1. Controls 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. Two of the patients received a diagnosis of schizoaffective disorder; both were actively psychotic at the time of participation. Of the 38 patients with schizophre-

Table 1. Demographic and clinical characteristics

	Schizophrenia Patients, n = 40		Normal Controls, n = 20	
	Mean	SD	Mean	SD
Age (years)	39.38	8.7	36.05	7.6
Sex (% male)	50.0		45	
Parents' education (yr)	13.4	3.1	14.7	2.7
Education (yr)	12.6	2.0	16.4	1.8
Number of previous hospitalizations	12.1	14.0		
Age at First Hospitalization	21.1	5.5		
Length of illness (yr)	20.1	9.2		
Chlorpromazine equivalents (mg)	917.0	640.0		
% Taking antiparkinsonians	43.0			
% Taking antidepressants	23.0			
% Taking mood stabilizers	40.0			
% Taking benzodiazepines	23.0			
PANSS				
Reality Distortion	11.0	3.6		
Poverty Symptoms	13.2	6.1		
Disorganization	11.3	3.8		

Note.—SD = standard deviation; PANSS = Positive and Negative Syndrome Scale.

nia, 14 received a subtype of paranoid, 15 undifferentiated, 5 disorganized, and 4 residual. Daily oral doses of antipsychotics for patients were converted to chlorpromazine equivalents according to guidelines suggested by Davis and colleagues (1983). Depot doses were converted to average daily dosages using the guidelines suggested by Baldessarini (1985). All participants signed informed consent forms and were paid for their participation.

The Positive and Negative Syndrome Scale (PANSS; Kay 1991) was used to evaluate clinical state. Ratings were completed by either a Ph.D.-level psychologist (D.M.B.) or a trained research assistant who regularly participated in training and reliability sessions. Because we did not have the power to examine each individual symptom, symptoms were grouped into the three factors suggested by Liddle (1987): Reality Distortion, Poverty, and Disorganization. On the basis of a review of studies examining the dimensional structure of the PANSS (Cuesta and Paralita 1995), the following items were chosen for each scale: (1) delusions, hallucinations, and unusual thought content for Reality Distortion (alpha = 0.75); (2) blunted affect, emotional withdrawal, passive social avoidance, motor retardation, and lack of spontaneity for Poverty (alpha = 0.87); and (3) conceptual disorganization, mannerisms and posturing, difficulty in abstract thinking, and poor attention for Disorganization (alpha = 0.62). A subset of 9 patients was rated by both experimenters. Interrater reliability, measured using intraclass correlations (Shrout and Fleiss 1979) with raters treated as random effects and the individual rater as the unit of reliability, was 0.88 for Reality Distortion, 0.81 for Poverty, and 0.77 for Disorganization.

Materials. Each participant was administered three blocks of the Stroop task, with the order counterbalanced across participants. Each Stroop block consisted of 96 trials, with 24 (25%) congruent trials, 24 (25%) incongruent trials, 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 (referred to as the patch neutral). In a second block, the neutral stimuli were one of four color-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 and Kucera 1982) and were from a single semantic category to eliminate semantic confounds (MacLeod 1991). In the third block, the neutral stimuli consisted of four color words (tan, gray, white, and yellow) different from the colors in the response set (referred to as the color neutral). These color words were also matched to the response set color words in length and frequency.

Procedure. Each subject was tested individually. Stimuli were presented on an Apple Macintosh computer, using PsyScope software (Cohen et al. 1993). 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 and accurately as possible. Each stimulus remained on the screen until the subject responded, or until 2000 msec elapsed, and then was replaced by a fixation cross that lasted until the onset of the next stimulus. Regardless of RT, a new trial started 4 seconds after onset of the previous stimulus, so that the pace of the task was fixed for all participants. Participants' verbal responses were coded for accuracy by the experimenter. 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.

Results

Reaction Times

Basic Stroop effects. RTs (correct responses) from the three blocks (table 2) were examined using a three-way analysis of variance (ANOVA), with diagnostic group as the between-subjects factor and Condition (congruent, neutral, incongruent) and Neutral Type block (patch, animal, and color neutral) as within-subject factors. This ANOVA (table 3) revealed a main effect of Condition and a Condition X Neutral Type Block interaction. Planned comparisons to follow up on the main effect of Condition indicated that, as expected, participants responded faster to congruent stimuli than neutral stimuli ($F(1,58) = 50.79$, $p > 0.001$) and slower to incongruent stimuli than to neutral stimuli ($F(1,58) = 81.35$, $p > 0.001$). Planned comparisons to examine the Condition X Neutral Type Block interaction indicated that RTs differed across the blocks only in the neutral condition. Responses were significantly slower to animal neutrals than to patch neutrals ($F(1,58) = 27.17$, $p < 0.001$) and significantly slower to color neutrals than to animal neutrals ($F(1,58) = 5.35$, $p < 0.05$). RTs did not differ significantly across the three blocks in either the congruent or incongruent conditions ($p > 0.10$). As illustrated in figure 1, because RTs across the different blocks varied in the neutral condition

Table 2. Means and standard deviations for Stroop reaction times

Condition	Schizophrenia Patients		Normal Controls	
	Mean	SD	Mean	SD
Patch Neutral Block				
Congruent	780.1	177.3	643.5	105.5
Neutral	809.1	184.7	627.6	81.6
Incongruent	989.7	201.1	776.1	151.3
Animal Neutral Block				
Congruent	781.8	168.2	624.7	102.3
Neutral	882.7	181.7	669.9	79.7
Incongruent	1004.9	221.9	763.4	134.7
Color Neutral Block				
Congruent	805.6	171.4	637.9	109.1
Neutral	951.1	187.4	705.1	84.6
Incongruent	977.3	187.8	736.6	89.6

Note.—SD = standard deviation.

only, participants displayed significantly more facilitation (neutral RT - congruent RT) with the animal neutrals than with patch neutrals ($F(1,59) = 59.95$, $p < 0.001$). The magnitude of facilitation was also greater with color neutrals than with animal neutrals, but this difference was not significant. As also shown in figure 1, interference (incongruent RT - neutral RT) was significantly less with animal neutrals than with patch neutrals ($F(1,59) = 14.63$, $p < 0.001$), and significantly less with color compared with animal neutrals ($F(1,59) = 13.23$, $p < 0.001$). Thus, as predicted, facilitation and interference varied inversely as a function of changes in the neutral stimulus.

Schizophrenia. The RT ANOVA also revealed a main effect of Group (table 3), with schizophrenia patients displaying slower RTs than healthy controls. Further, as predicted, there was a significant two-way interaction between Group and Condition (table 3). Planned comparisons indicated that schizophrenia patients displayed significantly more facilitation than healthy controls ($F(1,58) = 13.37$, $p < 0.01$) but did not differ significantly in interference.[4] As discussed above, the hypothesis that a greater influence of the word in the congruent condition contributes to increased RT facilitation in schizophrenia patients predicts that patients should display increased RT facilitation with nonword as well as word-neutral stimuli. To examine this hypothesis, we analyzed the magnitude of facilitation effects within each block using planned contrasts. Consistent with our hypothesis, schizophrenia patients displayed significantly more facilitation than healthy controls with patch neutrals ($F(1,58) = 5.87$, $p < 0.05$), as well as with animal neutrals ($F(1,58) = 8.84$, $p < 0.01$) and color neutrals ($F(1,58) = 11.20$, $p < 0.01$).[5]

[4] The interpretation of this interaction is the same if one examines the residual effects (Rosenthal and Rosnow 1985).

[5] In the patch neutral block, controls did not display positive facilitation. This result is consistent with the Stroop literature (e.g., MacLeod 1991), in that facilitation with neutral stimuli such as patches or XXX is not reliably found among healthy controls.

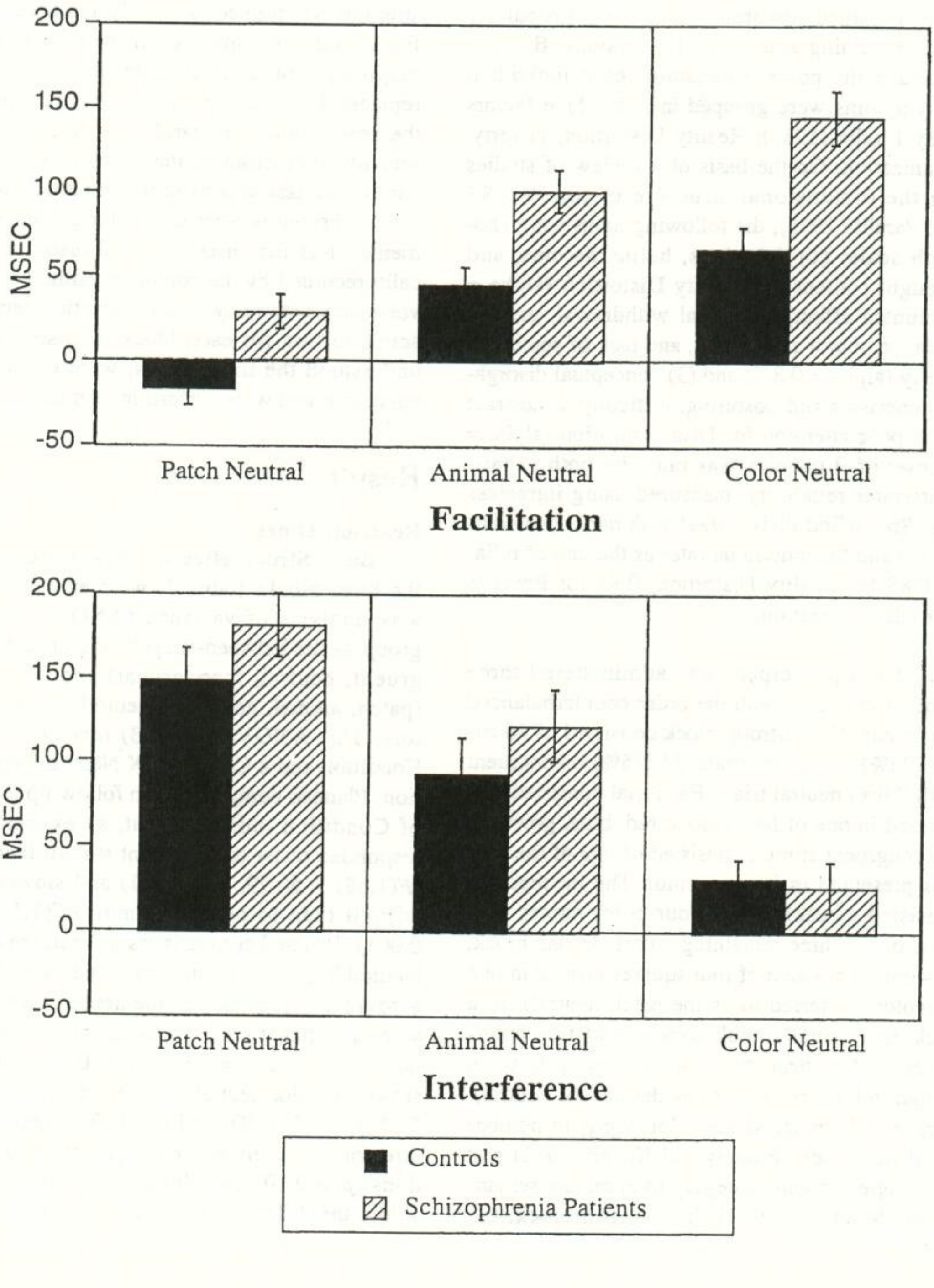
Table 3. ANOVA results for Stroop reaction times

Effect	*df*	*F* Value	*p* Value
Group	1,58	24.00	< 0.001
Condition	2,116	109.82	< 0.001
Block	2,116	2.15	> 0.10
Group × Condition	2,116	8.48	0.001
Group × Block	2,116	1.53	> 0.10
Condition × Block	4,232	20.35	< 0.001
Group × Condition × Block	4,232	0.56	> 0.10

Note.—ANOVA = analysis of variance; *df* = degrees of freedom.

The hypothesis that a greater influence of the word in the neutral condition also contributes to increased RT facilitation leads to two predictions. First, patients with schizophrenia should show a disproportionately greater slowing of RTs for neutrals that are words compared with neutrals that are not words. Consistent with this hypothesis, planned contrasts indicated a Group X Neutral Type interaction for RTs in the neutral condition ($F(1,58) = 5.70$, $p < 0.05$). As can be seen in table 2, compared with controls, schizophrenia patients demonstrated a greater increase in neutral RTs as the stimuli changed from nonwords to words. However, our hypothesis regarding the neutral condition also predicts that group differences in RT facilitation should be greater with word neutrals (i.e., animal or color neutrals) than with patch neutrals. As can be seen in figure 1, the group difference in the magnitude

Figure 1. Reaction time facilitation and interference across neutral types



of RT facilitation was greater with animal word neutrals (55.7 msec) than with patch neutrals (44.9 msec) and was even greater with color word neutrals (78.3 msec). However, the three-way interaction between Group, Condition, and Neutral Type Block was not statistically significant (table 3).

Accuracy

Basic Stroop effects. A separate three-way ANOVA examined accuracy data from each of the three blocks (table 4). The dependent measure was the arcsine transformation of percentage of correct responses (Neter et al. 1990). This ANOVA (table 5) revealed significant main effects of Condition and Neutral Type Block. Further, there was a significant Condition X Neutral Type Block interaction. Followup analyses to examine the main effect of Condition indicated that, as predicted, accuracy was significantly lower in the neutral compared with congruent condition ($F(1,58) = 10.87$, $p < 0.01$) and in the incongruent compared with neutral condition ($F(1,58) = 47.81$, $p < 0.001$). Followup analyses to examine the main effect of Neutral Type Block indicated that participants made more errors in the animal neutral block than in the patch neutral block ($F(1,58) = 6.11$, $p < 0.05$) but that accuracy did not differ between the animal and color neutral blocks.

Schizophrenia. The accuracy ANOVA also revealed a main effect of Group (table 5), with schizophrenia patients less accurate than healthy controls. Further, as predicted, there was a significant interaction between Group and Condition (table 5).[6] Planned comparisons indicated that schizophrenia patients displayed a significantly greater decrease in accuracy from the neutral to the

[6] Since one cell in this ANOVA had zero sample variance, the homogeneity of population variance assumption was plausibly violated and the arcsine transformation might not have fully compensated for this. We followed Keppel's (1991) recommendation and compensated for the violation by adopting a criterion of $p < 0.025$ rather than $p > 0.05$.

Table 4. Means and standard deviation for Stroop accuracy

Condition	Schizophrenia Patients		Normal Controls	
	Mean	SD	Mean	SD
Patch Neutral Block				
Congruent	0.988	0.019	0.996	0.013
Neutral	0.980	0.036	0.991	0.014
Incongruent	0.891	0.099	0.960	0.046
Animal Neutral Block				
Congruent	0.988	0.019	0.987	0.020
Neutral	0.988	0.043	0.980	0.030
Incongruent	0.870	0.123	0.930	0.085
Color Neutral Block				
Congruent	0.992	0.017	1.000	0.000
Neutral	0.958	0.057	0.990	0.014
Incongruent	0.891	0.103	0.962	0.049

Note.—SD = standard deviation.

Table 5. ANOVA results for Stroop accuracy

Effect	*df*	*F* Value	*p* Value
Group	1,58	9.52	< 0.01
Condition	2,116	42.59	< 0.001
Block	2,116	3.30	0.05
Group × Condition	2,116	7.87	0.001
Group × Block	2,116	0.73	> 0.10
Condition × Block	4,232	2.03	0.09
Group × Condition × Block	4,232	0.30	> 0.10

Note.—ANOVA = analysis of variance.

incongruent condition (i.e., error interference) ($F(1,58) = 8.76$, $p < 0.01$), but patients did not differ significantly from controls in the magnitude of error facilitation. The three-way interaction between Group, Condition, and Neutral Type Block was not significant ($F(4,232) = 0.30$, $p > 0.10$). Thus, schizophrenia patients displayed more error interference than controls with all neutral types.

Response Set Effects. As described above, if impaired Stroop performance in schizophrenia involves a deficit in the development or maintenance of a response set, then compared with controls, patients should display (1) a reduced difference in performance (manifest in either RT or errors) with color words in the response set (i.e., incongruent stimuli) and color words not in the response set (i.e., color neutrals) and (2) a larger performance difference (in either RT or errors) between animal neutrals and color neutrals. Contrary to our prediction, planned contrasts indicated that compared with controls, patients did not demonstrate a smaller difference in either RTs or errors between color words not in the response set (color neutrals) and color words in the response set (incongruent stimuli). However, as predicted, planned contrasts indicated that schizophrenia patients displayed significantly more errors than controls with color neutrals ($F(1,58) = 5.64$, $p < 0.05$), but not with patch neutrals ($F(1,58) = 1.72$, $p = 0.20$) or animal neutrals ($F(1,58) = 0.68$, $p = 0.41$). There was also a trend for patients to show a greater increase in errors from animal to color neutrals than controls ($F(1,58) = 2.68$, $p = 0.11$). Also as predicted, RTs for color neutrals were significantly longer than RTs for animal neutrals among schizophrenia patients ($F(1,58) = 6.57$, $p < 0.05$) but not among controls ($F(1,58) = 1.04$, $p = 0.31$). However, the group comparison was not significant.

Correlations Among Facilitation and Interference Measures. We also examined relationships between facilitation and interference. Separate facilitation and interference measures were calculated for each of the three neutral types, using only the data from the block of trials in which that neutral type was presented. If, as we have hypothesized, worse performance in the neutral condition increases facilitation and decreases interference, then these measures should be negatively correlated. Consistent with this hypothesis, among patients RT facilitation and interference were significantly negatively correlated for both the patch ($r = -0.55$, $p < 0.01$) and color neutrals ($r = -0.61$, $p < 0.01$), although not for the animal neutrals ($r = -0.14$, $p > 0.10$). RT facilitation and interference were not significantly associated among controls (average $r = 0.06$, range = −0.08–0.19). Further, if deficits in selective attention lead to both slower color-naming RTs for neutrals (and thus greater facilitation) and more errors in the incongruent condition, then RT facilitation and error interference should be positively correlated. In patients, error interference was positively correlated with RT facilitation with all three neutral types (average $r = 0.39$, range = 0.31–0.56, $p < 0.05$). In controls, error interference was significantly positively correlated with RT facilitation with the patch neutral ($r = 0.39$, $p < 0.05$) but not with the animal ($r = 0.27$, $p > 0.05$) or color neutral ($r = 0.08$, $p < 0.10$), although these correlations did not differ statistically.

Correlations Between Stroop Performance and Clinical Symptoms. A secondary goal of this study was to examine the clinical significance of increased Stroop facilitation in schizophrenia. In previous work, we have found that the Disorganization dimension of psychopathology was more strongly associated with impaired

Table 6. Correlations between Stroop performance and symptom dimensions among schizophrenia patients

	Reality Distortion	Poverty	Disorganization
RT facilitation			
Patch neutral	0.03	0.22	0.28[1]
Animal neutral	0.11	0.38[2]	0.33[2]
Color neutral	0.13	0.16	0.31[2]
Error interference			
Patch neutral	0.22	0.11	0.28[1]
Animal neutral	0.40[2]	0.05	0.52[2]
Color neutral	0.39[2]	0.12	0.31[1]

Note.—RT = reaction time.

[1] $p > 0.05$

[2] $p > 0.01$

Stroop performance among schizophrenia patients than either the Poverty or Reality Distortion dimensions. We sought to replicate and extend this finding by examining the association between these three symptom dimensions and the Stroop RT facilitation and error interference measures in the current study. As shown in table 6, the pattern of correlations again suggests that impaired performance in the Stroop task is more consistently associated with Disorganization symptoms than with Poverty symptoms or Reality Distortion.

Psychometric Issues. Studies with schizophrenia patients are often confounded by the effects of longer RTs, because difference scores can be spuriously inflated in participants who exhibit overall worse or more variable performance (Chapman et al. 1994). This issue is relevant for our study given that schizophrenia patients displayed larger facilitation scores than controls but also had longer RTs. Thus, it is possible that the larger facilitation scores simply reflect an artifact of longer RTs among schizophrenia patients. Chapman and colleagues (1994) have suggested examining this issue by computing the regression equation that predicts difference scores (e.g., neutral RT - congruent RT) from a measure of overall RT, using only the data from the controls and then determining whether the schizophrenia patients fall on this same regression line. However, the distribution of overall RT scores among our controls does not fully overlap with the RT distribution patients. Thus, such an analysis could be criticized on the basis that one cannot make predictions about values that fall outside the range used to generate the original regression equation (Chapman et al. 1994). Therefore, we used two alternative approaches to address this issue.

First, we used the normal mean-deviate (i.e., *Z*-score) of the mean RT across all conditions as the measure of RT in each condition for each participant. The logic behind this analysis is that the standard deviation (SD) across the conditions for patients should be larger than the SD for controls. *Z*-scores are calculated as a function of the magnitude of the SD. Thus, if the magnitude of facilitation scores among schizophrenia patients is simply proportional to their overall longer RTs, an analysis using normal mean-deviates should show no group differences in the magnitude of facilitation. We conducted this analysis with our data, and the results of the ANOVA using *Z*-scores again indicated a significant two-way interaction between Group and Condition ($F(2,116) = 5.48$, $p < 0.01$). Planned comparisons indicated that schizophrenia patients displayed significantly more RT facilitation than healthy controls ($F(1,58) = 6.44$, $p < 0.05$) when the normal mean-deviate was used as the dependent variable. The three-way interaction between Group, Condition, and Neutral Type Block remained nonsignificant ($F(4,232) = 1.63$, $p > 0.10$). Second, we compared the controls with a subgroup of the patients ($n = 13$) who did not differ significantly on average RT from the controls (694 msec for controls, 715 msec for patients). The ANOVA using this subset of participants for Stroop RTs continued to show a significant Group × Condition interaction ($F(2,62) = 3.56$, $p < 0.05$). Taken together, these results suggest that increased Stroop facilitation among schizophrenia patients is not simply an artifact of their slower RTs.

Discussion

Consistent with a growing body of research, we found that patients with schizophrenia displayed increased RT facilitation, but not increased RT interference, combined with an increase in error interference. More important, schizophrenia patients displayed a detailed pattern of performance that provides some insight into the mechanisms contributing to disturbed Stroop performance in schizophrenia. As predicted, we found that schizophrenia patients displayed increased Stroop facilitation with patch-neutral as well as with word-neutral stimuli. A color patch does not contain word information that can compete with a color-naming response. Thus, increased RT facilitation in this condition cannot be explained solely by word information leading to slower responses in the neutral condition. This finding is consistent with the hypothesis that selective attention deficits in schizophrenia patients lead to a greater influence of the word dimension in the congruent condition. In the congruent condition, the word information is consistent with the correct response and thus appears to contribute to a relative speeding of responses and an increase in RT facilitation (neutral RT - congruent RT).

We also found that the magnitude of Stroop facilitation and interference varied as a function of the neutral stimulus among both patients and controls. When the neutral stimulus contained more word information that could compete with a color-naming response (word vs. nonword, color-related vs. color-unrelated), participants displayed greater RT facilitation and less RT interference. This finding is not particularly surprising, given the long history of Stroop studies demonstrating that noncolor words as well as color words, and even nonword stimuli (e.g., wordlike consonant strings), can "interfere" with color-naming responses (MacLeod 1991). Also, schizophrenia patients displayed a greater slowing of RTs in the neutral condition as the stimuli changed from nonwords to words. Further, the absolute value of the group difference in RT facilitation was greater with a word (e.g., animal name) than with a patch neutral. However, the increase in the group difference in RT facilitation with a word neutral was not statistically significant, failing to demonstrate the pattern of differences implied by such a triple interaction. It is possible that our failure to find a significant three-way interaction between Group, Condition, and Neutral Type Block reflects a lack of power. Our power for this interaction was moderate at 67 percent, with a 0.5 effect size. As such, our results provide only partial support for the hypothesis that a slowing of responses in the neutral condition contributes to a larger facilitation effect and to no change, or a decrease, in the interference effect. However, the results of this study highlight the need for schizophrenia researchers to carefully examine the assumptions underlying the interpretation of "neutral" conditions in the Stroop, as well as in other experimental paradigms. As this study demonstrates, "neutral" stimuli may not be truly neutral.

We found that although patients did not display increased interference in RT, they did exhibit increased interference in errors. This finding is consistent with the hypothesis that an increase in errors in the incongruent condition contributes to an absence of RT interference. As noted in the introduction, slowing in the incongruent condition is thought to occur when the influence of the word interferes with naming of the color. Among patients, selective attention deficits appear severe enough to lead to more than slowing in the incongruent condition, with patients actually responding to the word and not the color. The production of errors may then serve to eliminate those trials on which the patients had the most difficulty. This finding highlights the importance of examining both RT and error indices in the Stroop task. In the context of the Stroop task, selective attention deficits may manifest as changes in both RT and error performance, and critical indications of deficits may be missed if only RT indices are examined.

We also found some evidence consistent with the hypothesis that selective attention deficits among schizophrenia patients influence the establishment of a response set, in addition to the ability to selectively attend to the appropriate stimulus dimension. As discussed in the introduction, the establishment of a response set allows individuals to distinguish between information associated with a correct response and information not associated with a correct response. Thus, an intact response set should lead individuals to respond to color neutrals (not in the response set) and animal neutrals similarly. If a deficit in establishing a response set exists, problems should be more severe for color than animal neutrals, since the former are more similar to the response set members than the latter. Schizophrenia patients displayed several examples of a reduction in the ability to establish or maintain a response set or both. First, patients displayed significantly more errors than controls with color neutrals but not with animal or patch neutrals. Second, patients also tended to show a significantly greater increase in errors from animal to color neutrals than controls, although this difference was not statistically significant. It should be noted, however, that the pattern of performance among controls was in the opposite direction of patients; patients displayed more errors with color neutrals than animal neutrals, whereas controls displayed fewer errors on color neutrals than animal neutrals. Third, among schizophrenia patients, but not among controls, RTs to color neutrals were significantly longer than RTs to animal neutrals.

The results described above are consistent with the hypothesis that a response set deficit influences Stroop performance in schizophrenia. However, two of our findings, at least on the surface, do not appear to support this hypothesis. First, patients did not show significantly more errors than controls with animal neutrals, even though responses to these stimuli should also be influenced by a response set deficit, although perhaps less severely. Second, patients did not display a reduction in the difference in naming RTs to color words in the response set (i.e., incongruent stimuli) and color words not in the response set (i.e., color word neutrals). Both of these findings are likely related to the relationships between accuracy and RT discussed previously. Although patients did not produce more errors to animal neutrals than controls, they did show increased RT facilitation with these stimuli. Since animal neutrals are less similar to response set items than color neutrals, a response set disturbance may have led to slower RTs but not to an actual increase in errors for animal neutrals. Conversely, patients may not have shown a reduction in the difference in RTs to color words not in the response set, versus those in the response set, because of their increased errors in the color neutral condition. Increased errors in the color neutral condition may circumvent disproportionate slowing in this condition, in the same way that increased errors in the incongruent condition may contribute to the lack of increased RT interference among schizophrenia patients.

We believe that the results of this experiment and our interpretations of the findings begin to explain how selective attention deficits could lead to the particular pattern of Stroop performance displayed by patients with schizophrenia. One important component of our explanation for the lack of increased RT interference is the hypothesis that the greater number of errors in the interference condition circumvents disproportionate RT slowing. However, further explanation is needed as to precisely how and why increased errors might have such an effect on RT. As mentioned previously, our task analysis of the Stroop was guided in part by a computational model of this task (Cohen and Carter 1995). This model implements a specific hypothesis regarding the mechanisms underlying selective attention—namely that Stroop performance depends critically on a module that represents and maintains context information and uses this information to support task-relevant information against interference. Our work with this model suggests that degrading processing in the context module can account for the specific pattern of single-trial Stroop performance in schizophrenia patients. Furthermore, the use of such a computational model provides a formalism for describing the relationship between errors and RT, and the relevant variables (e.g., task, cognitive, biological) that affect this relationship. In particular, the initial results of the model suggest that the relationship between errors and RT in the interference condition may arise as a consequence of the differential time course of excitatory and inhibitory influences during the dynamics of processing. Thus, the model may help provide an additional theoretical and conceptual basis for determining the precise mechanisms underlying Stroop task deficits in schizophrenia.

We also found that increased Stroop RT facilitation and error interference were more consistently related to Disorganization symptoms than to Poverty or Reality Distortion symptoms. This result is consistent with previous studies (Barch et al. 1999; Carter et al. 1993; Cohen et al. 1999) and prior assertions that Disorganization is related to attentional impairment in schizophrenia (Liddle and Barnes 1990). The Disorganization syndrome contains several different symptoms, and it is not yet clear whether all of these are equally related to the attentional pathology measured by the Stroop. One of the key symptoms included in Disorganization is formal thought disorder. In previous work, we have suggested that language dysfunction in schizophrenia may be particularly associated with cognitive deficits such as those tapped by the Stroop (Barch et al. 1996; Cohen et al. 1999). However, it is difficult to examine differential relationships between specific symptoms and cognitive deficits with rating scales that assess such symptoms with a single item. In future work, we plan to use more extensive assessments of language dysfunction, as well as other symptom dimensions, to more explicitly characterize the relationship between disorganization symptoms and cognitive dysfunction in schizophrenia.

In summary, the results of this study join a growing literature suggesting that the single-trial Stroop task represents a powerful and sensitive probe of selective attention deficits in schizophrenia. Further, the results of the present study are consistent with the hypothesis that abnormal Stroop performance in schizophrenia reflects a failure to adequately attend to the task-appropriate stimulus dimension (i.e., print color). The specific pattern of deficits displayed by schizophrenia patients suggests that this disturbance influences both the congruent and incongruent conditions, and multiple points along the information processing pathway. However, our results provided only partial support for the hypothesis that a slowing of responses in the neutral condition also contributes to the specific pattern of abnormal Stroop performance demonstrated by patients with schizophrenia. We also replicated the finding that selective attention deficits in schizophrenia patients appear to be most closely related to the disorganization syndrome of symptomatology. Further work is needed to clarify the nature of this relationship and the specific means by which such cognitive deficits might give rise to disorganization symptoms found in schizophrenia.

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